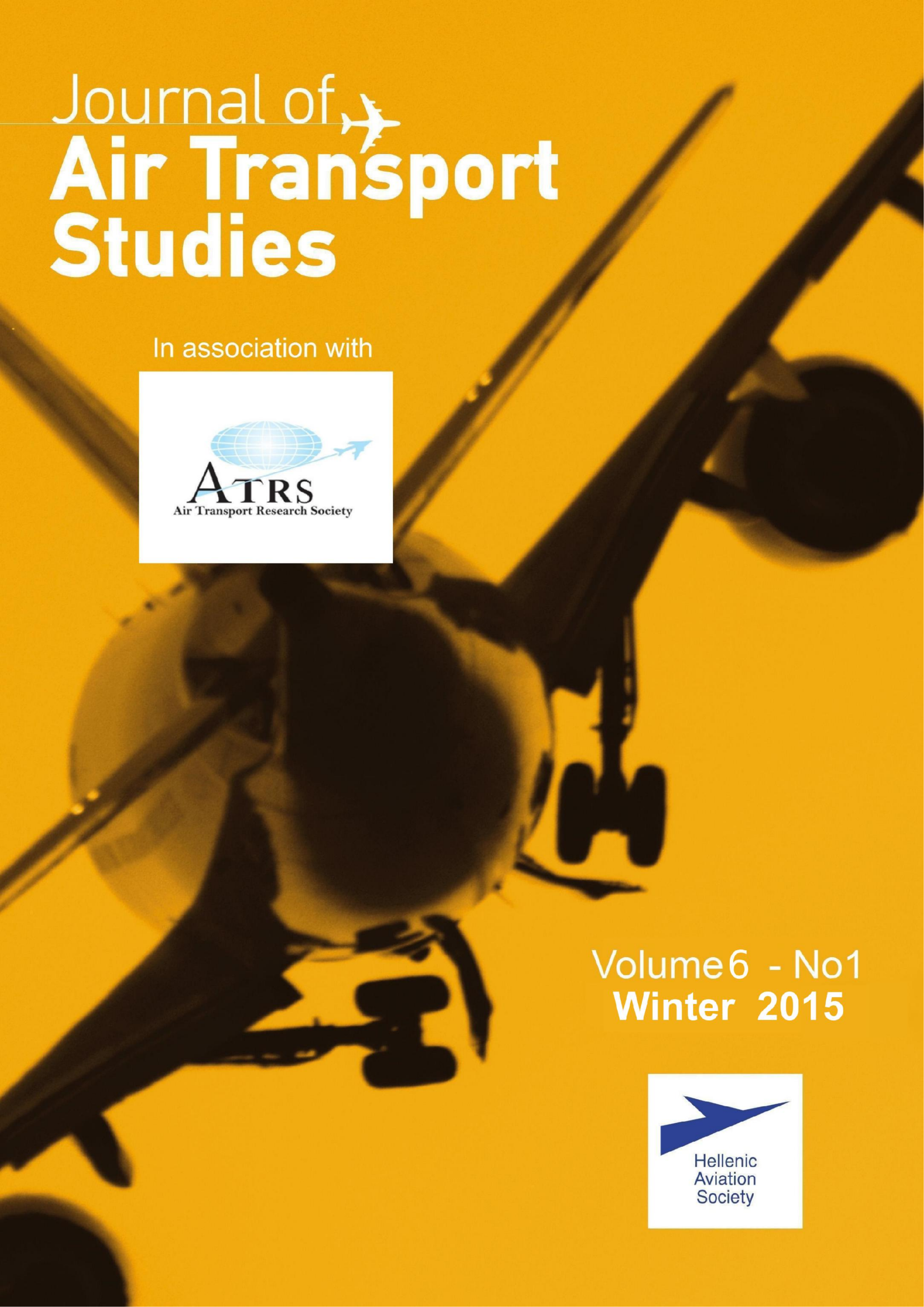

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The *Journal of Air Transport Studies* (JATS – ISSN: 1791-6771) is a peer reviewed journal aiming at publishing high quality research related to air transport. JATS is interested in publishing papers primarily focusing on economics, geography, policymaking, management, marketing, operations, technology, logistics/supply chain management and modelling.

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- Forsyth P. (2002a), 'Privatization and Regulation of Australian and New Zealand Airports', *Journal of Air Transport Management*, 8, 19-28.
- Papatheodorou, A. (2008) The Impact of Civil Aviation Regimes on Leisure Market. In Graham, A., Papatheodorou, A. and Forsyth, P. (ed) *Aviation and Tourism: Implications for Leisure Travel*, Aldershot: Ashgate, 49-57.
- Skycontrol (2007) *easyJet welcomes European Commission's decision to limit PSO abuse in Italy*. 23rd April. Available from: http://www.skycontrol.net/airlines/easyjet-welcomes-european-commissions-decision-to-limit-pso-abuse-in-italy/ (accessed on 22/08/2008).

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Industry Perspectives should be up to 1,000 words and provide a practitioner's point of view on contemporary developments in the air transport industry. Contributors should explicitly specify whether their views are espoused by their organization or not.

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Light aviation pilots are exposed to many different environmental situations due to the unpressurised and unacclimatised aircraft cabins. A literature review suggests that a significant number of the incidents and fatalities occurring within this type of aviation are related to the human factor. This could be a worrying situation because of the various psychophysiological reactions shown by different pilots under the same flight conditions. This study analyses the influence of the flight environmental conditions and the pilot's psychophysiological parameters when performing tasks, and different flight situations, taking some of their everyday habits into consideration. A portable, ergonomic monitoring system was built for the purpose. This system records cerebral oximetry and atmospheric pressure in order to correlate the influence of altitude with the pilot's physiological response in different stages of the flight. It was observed that physiological reactions such as hypoxia and stress, combined with the environmental conditions, can influence the pilot's cognitive response.

Aviation safety has been affected greatly by technological improvements. A series of Ground Proximity Warning Systems (GPWSs) were developed to prevent accidents during Controlled Flight into Terrain (CFIT). This study analyzed the role of GPWS (or Enhanced GPWS, EGPWS) in flight safety history to determine how effective GPWS/EGPWS was in terms of preventing CFIT. The result showed a substantial increase in CFIT accidents due to the rapid growth of aviation development. This situation improved after the mandatory installation of GPWSs in commercial aircraft. However, the legal requirement did not apply to all general aviation. Most CFIT accidents have involved general aviation aircraft that do not have GPWS/EGPWS installed on board. Thus, the mandatory requirement should apply to all civil aircraft. CFIT accidents have also been reduced considerably in developed countries whereas they remain a major issue in developing countries.

This paper explores contemporary issues regarding the challenges of quantifying improved decision making and situational awareness as it is applied to emerging tools in aviation weather information dissemination. The authors explore the phenomena of increased/improved pilot decision making due to additional visual representation of visual weather data. General concepts such as past and present flight planning tools and procedures are discussed. Additionally, the authors explore the Federal Aviation Administration's (FAA) Alaskan Weather Camera program as a potential case study for future exploration of these concepts. A pilot survey tool was created and administered to a small test population as a part of an

EDITORIAL

SPECIAL ISSUE: SAFETY & EFFICIENCY OF CIVIL AVIATION

SELECTED PAPERS FROM THE WORLD CONFERENCES OF THE AIR TRANSPORT RESEARCH SOCIETY AND THE WORLD CONFERENCE ON TRANSPORT SOCIETY - 2013

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The Air Transport Research Society (ATRS) is a Special Interest Group (SIG) of the World Conference on Transport Research Society (WCTRS). The ATRS annual World Conference was held at the University of Bergamo, Bergamo, Italy on 26-29 June 2013 and it attracted 266 papers from 37 countries. Also, the WCTRS triennial World Conference was held on 15-18 July at Rio de Janeiro, Brazil, during which the ATRS organised several sessions devoted to air transport topics. This special issue of the *Journal of Air Transport Studies* has drawn upon all of this material to present four papers that promote improvements in the safety and efficiency of civil aviation.

The first paper focuses attention on incidents and fatalities attributed to human factors in light aviation where unpressurised and unacclimatised aircraft cabins present pilots with a variety of environmental conditions. **Luís Patrão, Sara Zorro, André Marques, Ana Coelho and Jorge Silva** shed light on the subject with their investigation into the influence of flight environmental conditions and the pilot's psychophysiological parameters on performance. They devised a way to analyse pilot response under different flight situations while taking account of everyday habits. Specifically, they built a portable, ergonomic monitoring system which recorded cerebral oximetry and atmospheric pressure so that they could test the influence of altitude on the pilot's physiological response in different stages of the flight. This method should be of interest to other researchers studying human factors and aviation safety, particularly since the authors were able to document the link between physiological reactions such as hypoxia and stress and the pilot's cognitive response, while also accounting for environmental conditions. Safety regulators are well aware of the the importance of flight physiology in commercial and military aviation, but this paper demonstrates that the concept should also is applicable for pilots who fly in unpressurised and unacclimatised aircraft cabins as is the case with gliders, ultralights and light aircraft.

Further valuable insights into aviation safety are provided in the second paper by **Alex Y. L. Lu and Cheng-Hua Yang**. They examined the mandatory use of Ground Proximity Warning Systems (GPWSs) (or Enhanced GPWS, EGPWS) and asked whether the use of this technology delivered an improvement in preventing controlled flight into terrain (CFIT). The authors observed that, in the 1970s, aircraft cockpits began to be equipped with various electromechanical systems to provide pilots with information about fuel systems, radios, radar, engine control, and radio navigation. These were followed with artificial warning devices that tested whether systems were functioning properly such as GPWS which was designed to warn pilots when an aircraft approaches terrain in an abnormal manner. Modernisation of these systems in current generation aircraft has resulted in greater reliance on computer automated systems, but at the same time this has made it more important for pilots to learn how to interpret the computer data to avoid perception gaps during data interpretation. In this context, it is reasonable to question whether the increasing complexity of the technology results in improved safety. The authors had access to 30 years of data recording human fatalities and have shown that safety performance improved after the mandatory installation of GPWSs in commercial aircraft. But an important finding was that most CFIT accidents now involve general aviation aircraft which are not required to have GPWS/EGPWS installed on board. Another important finding is that CFIT remains a significant risk in developing countries.

The third paper by **J. Bryan Burrows-McElwain, I.K. Dabipi and Chris Hartman** focuses on emerging tools in aviation weather information dissemination. Of particular interest is the phenomena of increased/improved pilot decision-making due to additional visual representation of visual weather data. The authors point out that one of the leading causes of fatal accidents in the aviation industry over the past two decades can be traced to underlying psychological factors that result in poor decisions made by pilots in deteriorating weather. Prior research on the topic has suffered limitations because of the lack of a theoretical framework. A satisfactory understanding of the causes and consequences of the decision of a pilot to fly VFR into Instrument Meteorological Conditions (IMC) requires examination of the various stages of decision making along with factors that affect these processes. The authors review general concepts such as past and present flight planning tools and procedures and then they conducted a pilot study to evaluate whether the Federal Aviation Administration's (FAA) Alaskan Weather Camera program would be a useful case study to test these concepts. The findings arising out of this work will be of value to researchers, policy makers and regulators who are interested in quantifying improved decision-making and situational awareness in relation to aviation weather information dissemination.

In the final paper, **Kadriye Yaman, Hakan Oktal and Metin Altan** highlight the challenges that growth in air traffic is posing for air traffic controllers. Failure to increase handling capacity in line with demand results in congestion and hence delays, and these can lead to safety breaches with respect to minimum aircraft separation. They examine the case of Turkey where the growth in traffic has been particularly rapid and where there is an increasing risk of system bottlenecks, indirect routing, and lack of navigation freedom for airlines. The contribution of this paper is to show how GIS enables strategic planners to analyse structural features and capacity of airspace. Specifically, the authors digitized the map of Turkish airspace containing sector boundaries, routes and waypoints and, in doing so, made it possible to conduct efficient analyses in a GIS environment. They demonstrate the utility of the approach with traffic data of Turkish airspace for a period of two peak hours in heavy traffic during August 2007. The authors' analyses indicate that the traffic density of Turkish airspace is accumulative, especially in certain sectors, and this provided some specific solutions to capacity problems. This capability will no doubt be of interest to operational managers, but the more general conclusion is that the GIS environment greatly facilitates strategic planning of airspace.

The World Conferences held in 2013 were immensely successful and we, the editors, take this opportunity to thank the many people who organised these events and to the authors and participants whose active participation greatly promoted the cause of research. We are particularly grateful to those authors who continued to develop their material after the conference as well as to the expert reviewers who, acting anonymously, provided valuable, constructive advice. As a result we have been able to assemble a set of papers for this special issue that document current research on safety and efficiency of civil aviation. We are confident that this special issue will encourage further research on these subjects, but the papers offer valuable insights that will be of interest to practitioners in industry and government. We commend them to you.

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PILOTS PERFORMANCE AND FLIGHT SAFETY: FLIGHT PHYSIOLOGY IN UNPRESSURIZED AIRCRAFT CABINS

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ABSTRACT

Light aviation pilots are exposed to many different environmental situations due to the unpressurised and unacclimatised aircraft cabins. Literature review suggests that a significant number of incidents and fatalities occurring within this type of aviation are related to human factor. This could be a worrying situation because of various psychophysiological reactions shown by different pilots under the same flight conditions. This study analyses the influence of the flight environmental conditions and the pilot's psychophysiological parameters when performing tasks, and different flight situations, taking some of their everyday habits into consideration. A portable, ergonomic monitoring system was built for the purpose. This system records cerebral oximetry and atmospheric pressure in order to correlate the influence of altitude with the pilot's physiological response in different stages of the flight. It was observed that physiological reactions such as hypoxia and stress, combined with the environmental conditions, can influence the pilot's cognitive response.

Keywords: light aviation, psychophysiological parameters, flight conditions, monitoring system, cerebral oximetry, stress.

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1. INTRODUCTION

Gliding and ultralight aviation have been growing in popularity in Portugal in the past few years, and with it comes the responsibility to make these activities even safer for both those in the air and those on the ground. At the same time, it has been found that accidents and incidents with no apparent mechanical cause have increased. Moreover, after returning from their flights some pilots reported having noticed in themselves, while at the controls, symptoms as euphoria, decreased reaction time, and inability to perform simple tasks (Rocha, 2011). These symptoms imply a variation in the psychophysiological response compatible with the phenomenon of hypoxia which, in terms of flight safety, could represent a worrying situation.

The Flight Physiology concept is taken very seriously in commercial and military aviation, but the competent authorities in general aviation have neglected its applicability to pilots who fly in unpressurised and unacclimatised aircraft cabins, specifically pilots of gliders, ultralights and light aircrafts. This is an even more serious problem since general sport aviation is today a booming business throughout the world, and the regulatory frameworks of different countries have failed to keep up with this growth and are lagging behind in terms of current reality and needs.

The International Civil Aviation Organization (ICAO) and the European Aviation Safety Agency (EASA) do not require any type of ground training in flight physiology. However, Title 14 of the US Code of Federal Regulations (e-CFR), Part 61.31, states, for pilots, flight instructors and ground instructors, "Additional training required for operating pressurized aircraft capable of operating at high altitudes", with certain exceptions (USA Government, 2013). None of the current international regulations require altitude chamber training (ACT).

As a consequence of the Helios Airways Boeing 737-31S accident, at Grammatiko in 2005, the investigation report recommended to EASA and to the Joint Aviation Authorities (JAA) that practical hypoxia training should be required as a mandatory part of flight crew and cabin crew training (Air Accident Investigation & Aviation Safety Board, 2006). The main constraint of high altitude is that although the percentage of oxygen remains constant up to the stratosphere, with increasing altitude the atmospheric pressure and the partial pressure of oxygen in ambient air and alveolar air fall because gas exchange is reduced, which leads to hypoxia.

The appearance and intensity of the symptoms of hypoxia depend on factors like the speed of ascent, the absolute flight altitude, the duration of exposure to low atmospheric pressure and the temperature, along with individual characteristics such as disease, everyday habits, fitness, acclimatisation and stress. Symptoms such as fatigue, drowsiness, dizziness, headache, and euphoria can occur too, since exposure to this phenomenon leads to vision and hearing becoming impaired, reasoning becoming faulty, and the possibility of memory loss and slow and uncoordinated reactions (Alves et al., 2008; Thomas and Douglas, 2002).

Fatigue is a very common symptom that is frequently associated with pilot error, since it can seriously influence the susceptibility to hypoxia and the ability to make effective decisions. Factors like stress and prolonged performance of cognitive work result in mental fatigue (U.S Department of Transportation, 2009).

Time of Useful Consciousness (TUC) is defined as the time elapsing between the loss of supplemental oxygen and the failure of performance. TUC is a parameter that can be determined experimentally in a hypobaric chamber (low pressure simulation), through psychomotor tests, and with "physical activity, even moderate, the TUC reduces up to 50%" (Alves et al., 2008:252). TUC decreases as altitude increases and, depending on the activity of the individual at the time of oxygen failure, their physical condition, their daily habits and other parameters, the window of opportunity, i.e., TUC, can vary between individuals. Smoking is one factor that dramatically reduces tolerance to lack of oxygen; it can lower an individual's capacity at about 3,000 to 6,000 feet. The TUC for an average smoker at 15,000 feet would be between 10 to 20 minutes, while for a non-smoker it would be about 30 minutes or more (Yoneda and Watanabe, 1997). In situations of rapid depressurisation, TUC is reduced by half (Wolff, 2006).

The human body has different physiological reactions to different environmental scenarios. When flying in an unpressurised aircraft the changes in the cabin environment can be significant, and so the acquisition of physiological parameters is very important.

2. EXPERIMENTAL WORK

2.1. Monitoring System

This work follows a previous study (Rocha, 2011) where a monitoring system for brain oximetry was tested on ultralight pilots under real flight conditions. In this research, a flight data recorder was assembled along with the cerebral oximeter to record the atmospheric pressure inside the aircraft cabin. Both items of equipment were synchronised to the same time scale to allow the physiological and flight data to be compared.

The experimental tests were performed by three male individuals with different characteristics (Table 1), where the individual 1 was an inexperienced pilot, with a few hours of real flight and no hypobaric chamber training. Individual 2 was a much older pilot, with many flying hours as an instructor and pilot, and considerable hypobaric chamber training. Individual 3 was a young pilot but with many flight hours and only one hypobaric chamber training session.

Table 1: Characteristics of the Tested Individuals.

Individual	Gender	Age	Physical Exercise	Smoker	rSO2 (%) (mean value at rest)
1	Male	25	Rare	No	78
2	Male	60	Assiduous	No	62
3	Male	25	Rare	No	77

In all the figures that follow, only one lobe was monitored with cerebral oximetry since the values for each lobe were approximately the same.

2.2. Hypobaric Chamber Tests

Two different hypobaric chamber tests were performed and both took place in the *Centro de Medicina Aeronáutica* of the Portuguese Air Force, at the Lumiar military base, in Lisbon, Portugal (Table 2).

Table 2: Characteristics of the Hypobaric Chamber Tests

Tests	Participating Individuals	Maximum Altitude (feet)	Duration (minutes)
1	1 and 2	9,577.9	12
2	3	8,460.8	7

The cerebral oximetry and pressure values were measured throughout the simulation. In Figure 1 it can be seen that at the beginning of the first test, the cerebral regional oxygen saturation (rSO2) value was 77.5% for individual 1 and 62.5% for individual 2, which was the maximum absolute value recorded over the entire test. From that moment, the rSO2 mean value decreased almost continuously for Individual 1 until around 00:07:52 (hours:minutes:seconds), when it reached the absolute minimum of 71%. That was approximately two minutes before the point when the maximum altitude was reached, about 9,577.9 ft. For Individual 1, the rSO2 mean value for the entire flight was 76.2%, with a standard deviation of 1.96%. It can also be seen that the rSO2 value for Individual 2 remains practically the same for the entire test, with an absolute minimum value of 59% by the time the maximum altitude was reached, and with a mean value of 61.4% and a standard deviation of 1.33%.

Figure 1: rSO2 and Altitude Variation During the First Hypobaric Chamber Test

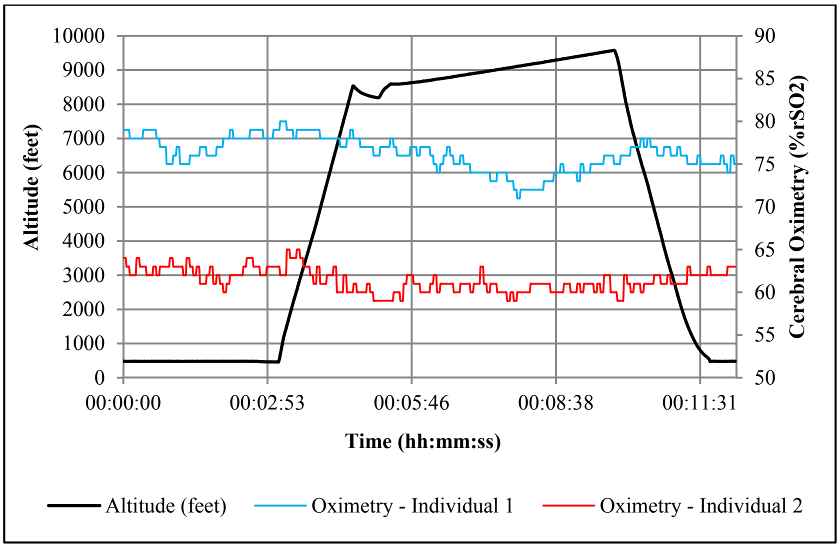


Figure 2: rSO2 and Altitude Variation During the Second Hypobaric Chamber Test

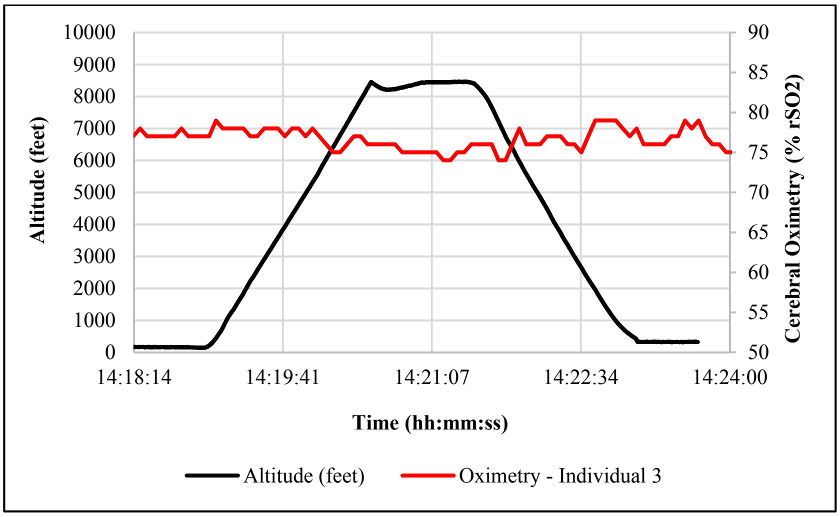


Figure 2 shows that at the beginning of the second test, the rSO2 mean value for individual 3 was 76.2%. From that moment, the rSO2 mean value decreased slightly until around 14:21:19 (hours:minutes:seconds), when it reached the absolute minimum of 74%. That is approximately the point when the maximum altitude was reached, about 8,460.8 ft. The rSO2 mean value of the flight was 75.9%, with a standard deviation of 1.9%.

2.3. Real Flight Tests

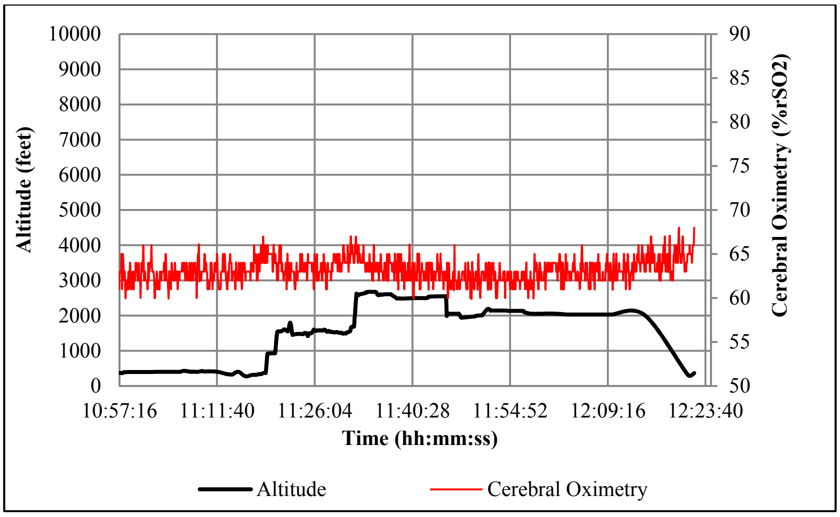
Five real flight tests were carried out (Table 3). The three flights performed by Individual 2 took place at Tires airfield, in Cascais, Portugal, while the other two took place at Viseu airfield, also in Portugal.

Table 3: Characteristics of the Flights

Real Flight Tests	Individual	Maximum Altitude (feet)	Duration (hh:mm:ss)	Observations
1	2	2,677	02:25:44	Calm Wind; Smooth Flight
2	2	3,313	00:54:32	Strong Wind; Turbulent Flight.
3	2	6,433	02:56:04	Calm Wind; Smooth Flight.
4	1	8,394	00:51:32	Calm Wind; Flight with some intense manoeuvres.
5	3	8,478	01:05:26	Calm Wind; Smooth Flight.

Figure 3 shows that at the beginning of the first test (1), the rSO2 mean value was 63.5%, and after the first ascent, at 11:19:04, it reached the 67%, which corresponded to the maximum absolute value recorded over the entire test. From that moment, the rSO2 mean value was approximately the same throughout the test, with a mean value of 63.3% and a standard deviation of 1.33%.

Figure 3: Altitude and rSO2 Variation During the Real Rlight, Test 1



In Figure 4 it can be seen that at the beginning of the second real flight test the rSO2 mean value was 64.5%; after the first climb (14:50:24), at 1,030 ft, the rSO2 reached a relative maximum value of 69%, and by the end of the second climb (15:09:13), at 3,256 ft, it reached its maximum absolute value recorded throughout the test, 70%. Apart from the moments specified above, the rSO2 mean value was practically the same throughout the test, with a mean value of 64.5% and a standard deviation of 1.66%.

Figure 4: Altitude and rSO2 Variation During the Real Flight, Test 2

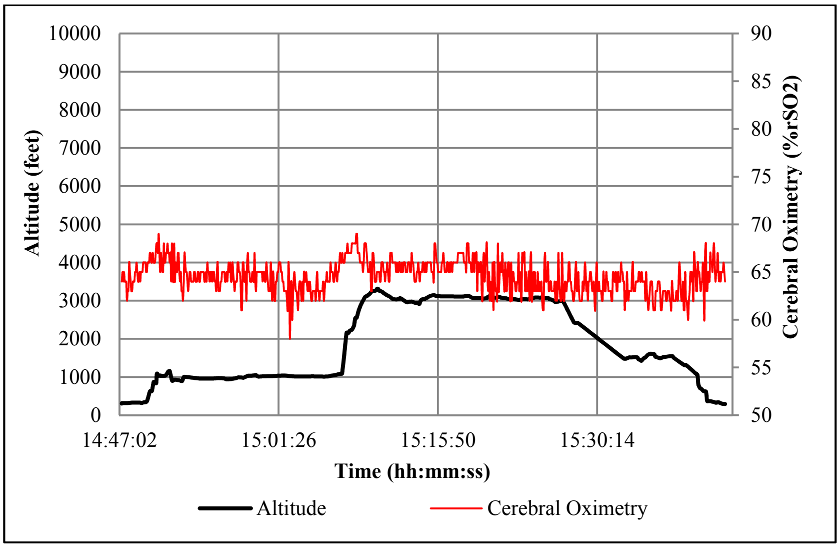
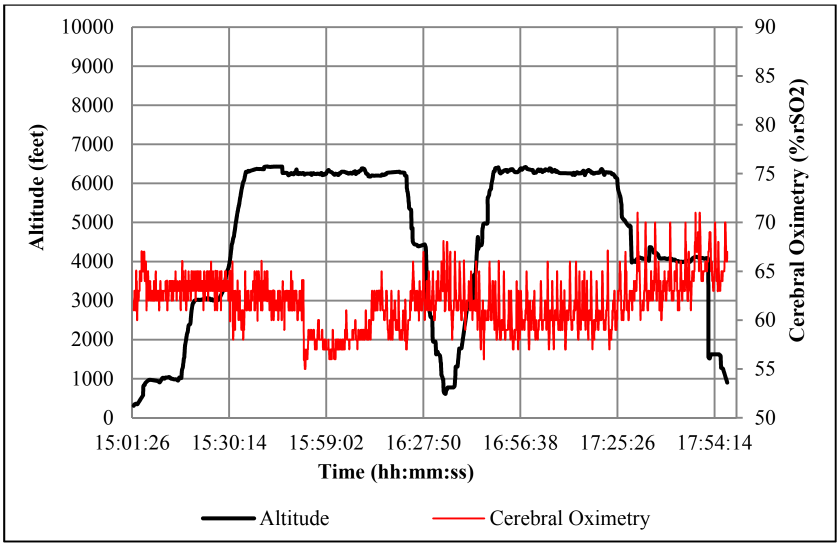


Figure 5 shows that at the beginning of the third real flight test the rSO2 mean value was 62%; at the moment before the first descent (15:52:25), at 6,264 feet, it reached a minimum value of 56%, and then started to increase until the end of the first descent (16:36:21), at 633 feet . The oscillation of the rSO2 values then becomes higher and by the start of the second descent (17:21:29), at 6,270 feet, it starts increasing until the end of the flight. The rSO2 mean value during the flight was 61.8%, with a standard deviation of 2.7%.

Figure 5: Altitude and rSO2 Variation during the Real Flight, Test 3



In Figure 6 it can be seen that at the beginning of the fourth real flight test, the rSO2 mean value was 81%, which corresponded to the maximum absolute value recorded throughout the test. The minimum rSO2 absolute value of 74% was recorded when the maximum altitude was reached (15:15:57). Apart from those moments, the rSO2 mean value was practically the same throughout the test, with a mean value of 78.8% and a standard deviation of 1.76%.

Figure 6: Altitude and rSO2 Variation During the Real Flight, Test 4

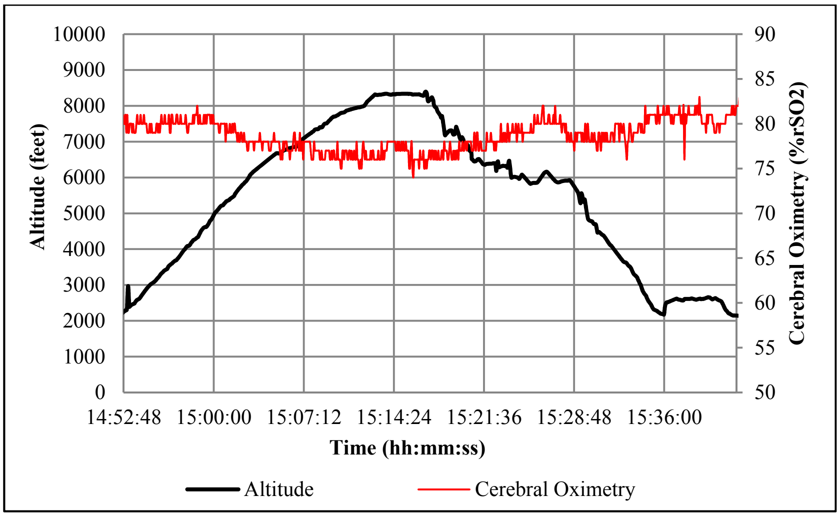
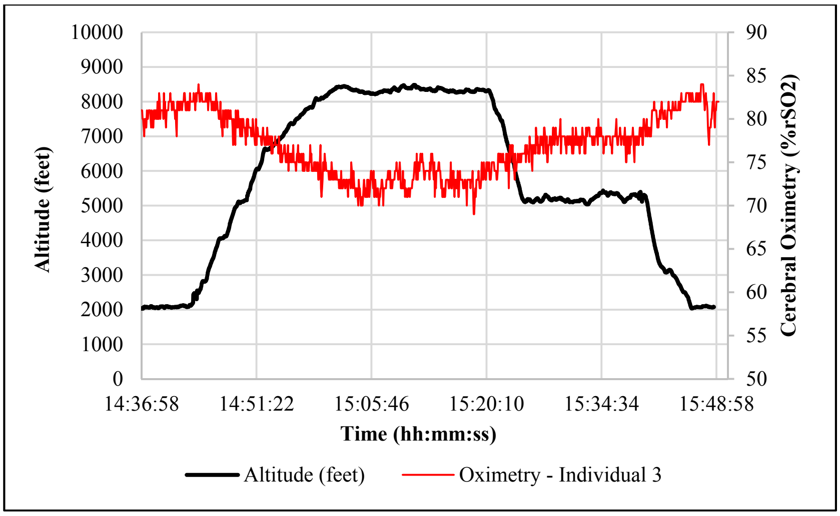


Figure 7: Altitude and rSO2 Variation During the Real Flight, Test 5



In Figure 7 can be seen that at the beginning of the fifth real flight test, the rSO2 mean value was 82%, which corresponded to the maximum absolute value recorded throughout the test. The minimum rSO2 absolute value of 69% was recorded when the maximum altitude was reached (15:18:34). The rSO2 mean value during the flight was 77.5%, with a standard deviation of 3.4%.

3. DISCUSSION – EXPERIMENTAL WORK

The comparison of cerebral oximetry with the altitude variation in the hypobaric chamber tests showed that, in the both tests, where the maximum altitude reached was 9,577.9 feet and 8,460.8 feet, respectively, the rSO2 variation between the minimum and maximum altitude was 1.5% for Individual 1, 3.5% for Individual 2 and 2.2% for Individual 3 (Table

4). Interestingly, it was Individual 2, who was a flight instructor with many hours of experience and many hypoxia training sessions in a hypobaric chamber who showed a greater variation of rSO2 than the two much younger individuals. For individuals 1 and 3, these were their first and the second experiences in the hypobaric chamber, respectively. As such, differences in age, physical characteristics and life habits could be very relevant factors for the disparity of values.

Table 4: Results of the Hypobaric Chamber Tests, Altitude VS rSO2, for Each Individual

Individual 1		Individual 2		Individual 3	
Minimum Altitude (0 ft)	77.5% (rSO2)	Minimum Altitude (0 ft)	62.5% (rSO2)	Minimum Altitude (0 ft)	76.2% (rSO2)
Maximum Altitude (9,577.9 ft)	76% (rSO2)	Maximum Altitude (9,577.9 ft)	**59%** (rSO2)	Maximum Altitude (8,460.8 ft)	**74%** (rSO2)
Altitude for minimum rSO2 value (9,200 ft)	**<u>71%</u>** (rSO2)	Altitude for minimum rSO2 value (9,577.9 ft)	**<u>59%</u>** (rSO2)	Altitude for minimum rSO2 value (8,460.8 ft)	**<u>74%</u>** (rSO2)

Table 5: Results of the Hypobaric Chamber Tests, Altitude VS rSO2, for Individual 2

Real Flight 1		Real Flight 2		Real Flight 3	
Minimum Altitude (0 ft)	63.5% (rSO2)	Minimum Altitude (0 ft)	64.5% (rSO2)	Minimum Altitude (0 ft)	62% (rSO2)
Maximum Altitude (2,677 ft)	67% (rSO2)	Maximum Altitude (3,313 ft)	69% (rSO2)	Maximum Altitude (6,433 ft)	66% (rSO2)
Altitude for minimum rSO2 value (2,500 ft)	<u>60%</u> (rSO2)	Altitude for minimum rSO2 value (1,000 ft)	<u>58%</u> (rSO2)	Altitude for minimum rSO2 value (6,264 ft)	<u>56%</u> (rSO2)

In the real flight tests, the rSO2 variation between the minimum and maximum altitude, was 3.5% for test 1, 4.5% for test 2, 4% for test 3, 7% for test 4, and 13% for test 5 (Table 5 and Table 6). However, it was found that in all the three real flights the minimum value of rSO2 for Individual 2 did not occur as expected, when the maximum altitude was reached. Such inconsistency does not have an obvious justification because there is too little information available for this type of study, so we can speculate that it might be due to psychophysiological characteristics, such as age, stress or even the reaction time that the human body takes to respond to the external environment.

Table 6: Results of the Real Flight Tests, Altitude VS rSO2, for Individuals 1 and 3

Individual 1 Real Flight 4		Individual 3 Real Flight 5	
Minimum Altitude (0 ft)	81% (rSO2)	Minimum Altitude (0 ft)	82% (rSO2)
Maximum Altitude (8,394 ft)	74% (rSO2)	Maximum Altitude (8,478 ft)	69% (rSO2)
Altitude for minimum rSO2 value (8,394 ft)	74% (rSO2)	Altitude for minimum rSO2 value (8,478 ft)	69% (rSO2)

Also, from the cerebral oximetry analysis of the three individuals for both types of test, it can be seen that they have different basal values of rSO2, which may be due to having different daily habits and physical characteristics, and that sporadic peak values occur because none of the individuals were completely immobile and therefore there was the risk of poor contact with the cerebral oximetry sensors. However, these data have yet to be carefully analysed by clinicians with expertise in determining if significant changes have occurred that could constrain psychophysiological capacity and, consequently, compromise flight safety.

The results do nonetheless suggest that the human body can be trained to adapt to different situations and that, when in an unknown environment, the arousal and the stress levels can compromise the rSO2 values and the normal response to an external stimulus, by physiologically increasing its intensity, i.e. increasing the state of hypoxia.

4. FINAL REMARKS

This study involved several experimental flights, where it was only possible to extract the full data from those discussed in this paper. This factor is the main reason for the small number of experimental tests. However, despite its limitations this study provides interesting and useful information that can make a positive contribution to flight safety.

Another intrinsic part of this research is flight simulator tests (in progress), the purpose of which is to study a pilot's psychophysiological behaviour in situations of great responsibility where attention and concentration are vital.

ACKNOWLEDGEMENTS

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DID TECHNOLOGY IMPROVE SAFETY? AN EMPIRICAL STUDY OF CONTROLLED FLIGHT INTO TERRAIN ACCIDENTS

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ABSTRACT

Aviation safety has been affected greatly by technological improvements. A series of Ground Proximity Warning Systems (GPWSs) were developed to prevent accidents during Controlled Flight into Terrain (CFIT). This study analyzed the role of GPWS (or Enhanced GPWS, EGPWS) in flight safety history to determine how effective GPWS/EGPWS was in terms of preventing CFIT. The result showed a substantial increase in CFIT accidents due to the rapid growth of aviation development. This situation improved after the mandatory installation of GPWSs in commercial aircraft. However, the legal requirement did not apply to all general aviation. Most CFIT accidents have involved general aviation aircraft that do not have GPWS/EGPWS installed on board. Thus, the mandatory requirement should apply to all civil aircraft. CFIT accidents have also been reduced considerably in developed countries whereas they remain a major issue in developing countries.

Keywords: Aviation Safety, Controlled Flight into Terrain, Ground Proximity Warning System.

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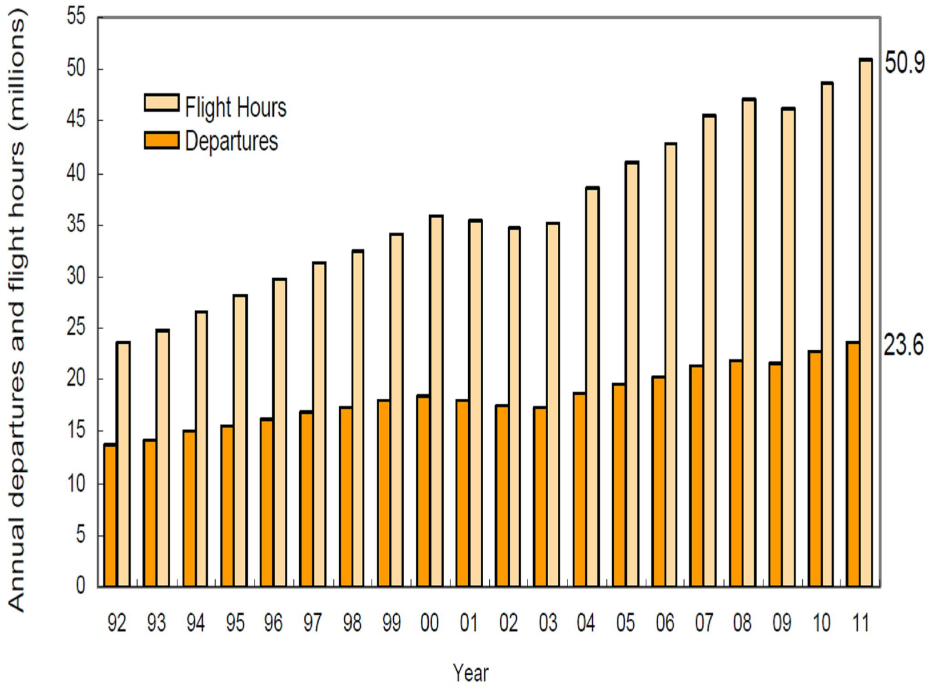
1. INTRODUCTION

According to the Boeing's statistics shown in Figure 1, flight hours and departures have risen continuously throughout the development of aviation industry (Boeing, 2012). Hours flown doubled in the 20 years between 1992 and 2011, while the departures increased by almost three quarters. The correlation between the aviation accident rate and the evolution of technological development in the past 60 years shows that the global accident rate has improved significantly, which is attributable mostly to improved technology (Mathews , 2004).

Figure 1: Annual Departures and Flight Hours (Boeing, 2012)



Given the ever-changing nature of aviation technology and automated systems, many types of aircraft accident preventive warning systems have been developed, such as ground proximity warning systems and traffic collision avoidance systems (TCAS). Since the introduction of these systems, regulations have been enacted in recent years to enforce the installation of various systems.

This study analyzed Controlled Flight into Terrain (CFIT) accident data for the past 30 years, to determine the correlation between the introduction of Ground Proximity Warning Systems (GPWSs), the number of accidents, and the death toll, by reviewing the death toll per unit flight. Thus, this study analyzed the general trend of current CFIT accidents and verified the improvement since the enactment of a regulation that mandated GPWS installation.

2. LITERATURE REVIEW

2.1 The Effects of New Systems on Pilots

Avionics systems comprise communications, navigation, and display management, and aircraft navigation systems have undergone great change in the past three decades. In early 1970s, the aircraft instruments, fuel systems, radios, radar, engine control, and radio navigation were mostly individual electromechanical systems. After the 1970s, the cockpit was equipped with various artificial warning devices, such as GPWS, to more easily determine whether the system was working properly. When an aircraft approaches terrain in an abnormal manner, the GPWS will alert the pilot with warnings based on voice, light, and the screen displays (Baxter & Ritter, 1999).

Nowadays, civil aircraft are highly reliant on computer automation, because more and more people are taking flights and air traffic is increasingly complicated, which makes flight safety an issue of concern (Orlady & Orlady, 1999). Sanfourche (2001) pointed out that in a convergence era where new aviation technology systems are replacing the old ones, pilots face challenges when adapting to the new systems, which differ tremendously from the old ones. For example, when the A320 was launched in 1988, its cockpit control system no longer followed the old-fashioned fly by cable operation and instead its systems were fly-by-wire. Computer automated systems such as the Flight Management System (FMS) have a significant role in cockpit and they have made a major contribution to flight safety.

Rudisill (1995) pointed out that the advent of navigation system aimed to relieve the pilot’s workload, but this was not the case because the workload has been transferred to other areas. A pilot’s main job is to operate the aircraft during takeoff and landing, to monitor system functioning, to manage the FMS equipment, and to make decisions.

However, pilots need to spend more time understanding and managing the operation of new systems and the meaning of the screen displays, rather than simply focusing on their missions. The advent of navigation systems requires that pilots learn how to fly and communicate during their training course, but they also need to learn how to interpret the computer data to avoid perception gaps during data interpretation.

2.2 Cognitive Gap between Computer Systems and Pilot Perception

Moray (1987) pointed out that computer automated systems may help pilots gain flight experiences, and when pilots use the systems, but they need to check the computer systems to analyze and verify that the information provided by the systems conforms to the current situation. Baxter and Ritter(1999) showed that, in critical situations, the information provided by the computer systems may not be correct because they are designed by humans who may feed all possible causes of accidents into the computer systems, but they may not be able to include unknowns so pilots should not be over-reliant on the information provided by their computer systems.

During aviation operation, a cognitive gap may occur between the pilot and the computer system when the computer system lacks clear instructions so the pilot is unable to interpret its behaviour. Sherry et al. (2002) proposed four theoretical types of cognitive inconsistency. The first two types are real errors and recognition errors. Real errors occur when the information displayed by the computer system is inconsistent with the reality of the situation. The system cannot detect dangerous conditions, which means that the computer system itself has problems. Recognition errors occur when the computer system detects a dangerous condition during flight, but the pilot checks and finds that it is a problem with the computer system and the aircraft is actually in a safe state so the pilot decides that the information provided by the computer system is incorrect. The other two error types are detecting the presence and absence of an error message, i.e., when the system detects an error message and the message is true, it can help the pilot make an amendment whereas if the system does not detect any error, but the flight is actually in a dangerous situation, the pilot may believe that the aircraft is in a safe condition.

The pilot should always pay attention to whether the computer system is consistent with the real situation. If not, the pilot should be able to decide instantly if the computer system is in error and immediately take follow-up steps to correct the problem. Computer systems are designed and developed by humans so the information is unlikely to be 100% correct, which could sometimes mislead the pilot into making an incorrect judgment.

2.3 The Features and Effects of Warning Systems

Warning systems have been developed to prevent aircraft accidents and maintain flight safety. Over the past decade, the aviation industry has developed various warning systems such as GPWS, TCAS, the predictive wind shear system, and system failure warning mechanism.

According to Amy et al. (2002), the new generation of aircraft warning systems has communication functions but constant tests and operation effect evaluations are required due to the rapid release of these new features. Billings (1997) also argued that when an aircraft experiences an emergency, this may affect the pilot's task performance and if the pilot is not fully familiar with the operation of the automation system, it may force the pilot to transfer their attention to the computer system, which increases the workload of the pilot. As a result, the avoidance of such situations should be considered in the system design.

In a strict warning system, over-rigorous standards may also result in excessive pilot distraction and possible decision errors. Hasse (1992) and Dingus et al. (1997) recognized that the pilot may often be misled by unnecessary warning messages in safe conditions, which could result in the pilot's gradual distrust of the system. Moreover, if the warning system always has intense reaction whenever a problem occurs, unnecessary warning may be regarded as a potential risk. For example, the early GPWSs had many errors and unnecessary warnings.

A warning system is expected to convey an alarm only in exceptional circumstances. Riley pointed out that if pilots do not understand the characteristics of the warning system, the pilot may mistakenly believe a critical situation occurs whenever the system signals a warning. The pilot's trust in the warning system may vary in different conditions. If the information provided by the warning system is correct, but the pilot does not comply with the instructions, or the information is incorrect and the pilot executes the instructions accordingly, this reflects whether the pilot trusts the system or not. Today, many fields such as aviation, rail, marine, medicine, and agriculture have to face the issue of whether they trust their warning system. Riley (1996) also noted that a few studies have shown that, when using a computer system, the pilot will compare their personal experiences learned during crisis handling with the information from the warning system and, in case of an emergency, the pilot will use familiar methods to deal with the crisis.

Mosier et al. (1999) suggested that the two major consequences of a pilot's excessive reliance on the warning system are reduced alertness during crises and lowered attention to the monitor screen. Elvers and Erif (1997) suggested that simplified information might be helpful for the pilot. This has been supported by several studies using different approaches, which are widely used in laboratory experiments, to depict the pilot's task execution, and they have shown that simplification does help. However, in exceptional circumstances, the pilot may not know how to operate in the moment and they may need more information to identify the situation before making decisions about the next step. Therefore, imagining the occurrence of emergency conditions and simulate how the system would react to a crisis are the most important considerations in the system design.

Parasurman and Riley (1997) noted that while the correct warning can help the pilot to complete the flight, an erroneous one can also cause a disaster. Warning systems have been designed and developed based on the findings from past accidents so all the factors related to accidents can be incorporated into the system and the pilot can be warned accordingly when similar situations occur. To some extent, simply including all of the factors related to past accidents in the system may be too conservative, because even if the alarm is legitimate because not all emergencies will have the same background.

Vandor (1999) suggested that the scope of aviation regulations is vast so when a risk occurs, the messages provided by different warning systems in various circumstances may affect the pilot's response indirectly.

2.4 Outline of CFIT

In the late 1960s, a series of Controlled Flight into Terrain (CFIT) accidents took the lives of hundreds of people. A CFIT accident occurs when a correctly functioning airplane under the control of a fully qualified and certificated crew is flown into terrain (or water or obstacles) with no apparent awareness on the part of the crew. Since the early 1970s, a number of studies looked at the occurrence of CFIT accidents. The findings from these studies indicated that many of the accidents could have been avoided if a warning device known as GPWS had been installed. As a result of these studies and recommendations from the U.S. National Transportation Safety Board (NTSB), the FAA required all large turbine and turbojet airplanes to install TSO-approved GPWS equipment from 1974. In March 2000, the U.S. FAA amended the operating rules to require that all U.S. registered turbine-powered airplanes with six or more passenger seats (excluding the pilot and copilot seating) be equipped with an FAA-approved TAWS (FAA, 2000).

A GPWS is a system designed to alert pilots if their aircraft is in immediate danger of flying into the ground or an obstacle. The U.S. FAA (2000) defines a GPWS as a type of terrain awareness warning system (TAWS). More advanced systems introduced in 1996, are known as enhanced ground proximity warning systems (EGPWS), although they are sometimes confusingly known as terrain awareness warning system (TAWS). According to the Flightglobal website, Learmount (2009) pointed that none of the accidents that occurred before 2005 involved commercial or civilian jets with jet engine or turbo propeller, installed with TAWS, which is clear evidence that TAWS can effectively reduce the occurrence of CFIT events. At present, only 5% of business jetliners are not installed with EGPWS. In the 10 years since 1997, the decline of CFIT accidents had been obvious, but the reduction is still slow. After 2004, the number of CFIT accidents involving commercial jets continued to decline.

According to the 9th edition ICAO Annex 6, a GPWS should provide an automatic timely and distinctive warning to the flight crew when the airplane is in potentially hazardous proximity to the earth's surface. A GPWS shall also provide, unless otherwise specified, warnings of the following circumstances:

(1) excessive descent rate;

(2) excessive terrain closure rate;

(3) excessive altitude loss after takeoff or turning;

(4) unsafe terrain clearance while not in a landing configuration:

- (a) gear not locked down;
- (b) flaps not in a landing position; and

(5) excessive descent below the instrument glide path.

The latest standard regarding aircrafts that are required to be equipped with GPWS, the International Civil Aviation Organization (ICAO) Annex 6, stipulates several standards, as shown as Table 1 (ICAO, 2010).

In the United States of America, the FAA (2000) requires that all its aircraft capable of carrying more than six (inclusive) passengers, under the governance of Part 121, Part 91, Part 135, Part 125, and

Part 129, should be installed with EGPWS and that all new aircraft produced after March 2002 should also be installed with EGPWS. All aircrafts already in service with the above specifications or under the same governance, should finish conversion with the EGPWS add-ons by March 2005. These measures demonstrate the necessity for EGPWS installation to avoid CFIT accidents.

Table 1: List of Aircraft that are Required to be Equipped With a GPWS

<table>
<tr><th>Class</th><th>Engine Type</th><th>MTOW</th><th>PAXs</th><th>Mandated</th><th>Remark</th></tr>
<tr><td rowspan="6">CAT[a]</td><td rowspan="5">turbine</td><td>＞15,000 kg</td><td>＞30 PAXs</td><td>EGPWS/TAWS</td><td></td></tr>
<tr><td>＞5,700 kg</td><td>＞9 PAXs</td><td>GPWS</td><td></td></tr>
<tr><td>＞5,700 kg</td><td>＞9 PAXs</td><td>EGPWS/TAWS</td><td>certificate of airworthiness first issued on or after January 1, 2004</td></tr>
<tr><td>＞5,700 kg</td><td>＞9 PAXs</td><td>EGPWS/TAWS</td><td>From January 1, 2007</td></tr>
<tr><td>≤5,700 kg</td><td>≤9 PAXs</td><td rowspan="2">GPWS that provides warnings of the descent rate and altitude loss after takeoff or turning, warnings of unsafe terrain clearance, and a forward-looking terrain avoidance function.</td><td>Recommendation</td></tr>
<tr><td>piston</td><td>＞5,700 kg</td><td>＞9 PAXs</td><td>From January 1, 2007</td></tr>
<tr><td rowspan="3">GA[b]</td><td rowspan="2">turbine</td><td>＞5,700 kg</td><td>＞9 PAXs</td><td>EGPWS/TAWS</td><td></td></tr>
<tr><td>≤ 5,700 kg</td><td>≤ 9 PAXs</td><td>EGPWS/TAWS</td><td>Recommendation</td></tr>
<tr><td>piston</td><td>＞5,700 kg</td><td>＞9 PAXs</td><td>EGPWS/TAWS</td><td>Recommendation</td></tr>
</table>

Notes:

CAT = Commercial Air Transport; GA = General Aviation; PAX = Passenger

Summarized by authors

EGPWS is an enhanced version of the original GPWS, which has a wider terrain database that gives pilots more time to react. However, the EGPWS database is constructed from multiple data sources. GPWS uses complex algorithms whereas EGPWS is simplified, and this inconsistency may make the pilot unable to understand the information provided by EGPWS during the flight, thereby requiring the pilot to spend more time interpreting the messages. The original intention of creating the new system was to help the pilot but the result may be quite the opposite because it makes the already complicated data even more intricate (Mosier & Skitka, 1999).

3. RESEARCH TOPICS AND METHOD

This study investigated the time distribution of CFIT accidents after the enforcement of GPWS installation. The current ICAO standards and regulations for GPWS/EGPWS enforcement enacted in various countries were considered and the research focused on accidents during controlled flight that involved crashing into water, ground level, or hills/mountains.

The Aviation Safety Network (ASN) is an exclusive service of the Flight Safety Foundation (FSF), most of the information contained in the ASN site is based on information from official sources (authorities and safety boards). Based on the ASN databases, investigation reports for all accidents related to controlled flights crashing into water, level ground, and hills/mountains during the 30 years from 1979 to 2011 were collected and compiled in this study. Given that the investigations of most aviation accidents take more than one or two years, this study considered the CFIT accident statistical period from 1979 to 2011.

A GPWS is a system designed to alert pilots if their aircraft is in immediate danger of flying into the ground or water, while more advanced systems such as EGPWS/TAWS have a forward-looking terrain avoidance function that can prevent the airplane from flying into ground, water, hills, and mountains. Therefore, this study determined various detailed parameters, as follows:

(1) the accident rates for each CFIT type in each year (i.e., crashing into water, level ground, and hills/mountains);
(2) the death toll for each CFIT type in each year;
(3) the airplane type involved in each accident (i.e., turbine-engined or piston-engined airplanes);
(4) the airplane category in each accident (i.e., the maximum certificated takeoff mass and/or

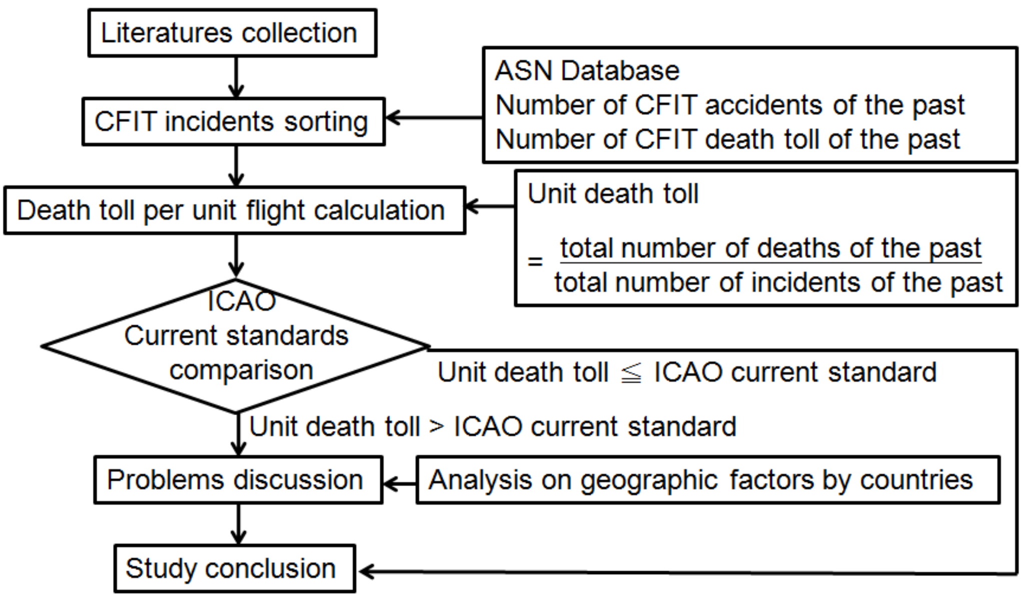
the number of authorized passengers);

(5) the location of each accident;

(6) other available considerations.

This study defined the death toll per unit flight as the test parameters to examine whether the legal requirements for GPWS installations on aircraft with a capacity over a specific number of passengers had the expected result. This study has analyzed the history of accidents to provide insights for further discussion. Geographical factors by countries were added to study CFIT-related issues and to explore the evolution of the accidents after technological advancement, and to examine whether the flight safety was improved as expected. Finally, our conclusions and recommendations are presented. The research flow is shown in Figure 2.

Figure 2: Research Flow Chart



4. DISCUSSION

4.1 Analysis of the Annual Trends of CFIT Accidents

Figure 3 shows the number of CFIT accidents yearly from 1979 to 2011 and the five-year average trend (the purple line indicates the general trend). The CFIT accidents were subdivided further into

CFIT-Hill/Mountain (green line), CFIT-Level Ground (brown line), and CFIT-Water (blue line). CFIT-Hill/Mountain and CFIT-Level Ground accidents engaged the majority of these accidents. CFIT-Hill/Mountain accidents were the most frequent, followed by CFIT-Level Ground and CFIT-Water. As to CFIT-Hill/Mountain and CFIT-Level Ground, the evolution of the trends was similar, while the overall CFIT trend also varies in tune with the distributions of these two categories. By contrast, CFIT-Water remained relatively low with around one accident each year.

The overall trend in the last 30 years indicates that the number of CFIT accidents before 1995 averaged less than 10 accidents per year while 15 accidents in 1982 and 24 accidents in 1989 reached their peaks. In general, the change in the trend before 1995 was not obvious. From 1995 to 2006, an increase in CFIT accidents was apparent, where the accident frequency was the highest and almost twice the average during 1979 to 1995. However, the mandated installation of GPWS in aircraft after 2007 reduced the overall accidents significantly. After 2001, the number of CFIT-Level Ground accidents stabilized and began to decline gradually each year, whereas the number of CFIT-Hill/Mountain accidents did not decrease until after 2007. This phenomenon manifested the function of the installation of GPWS.

In March 2002, the FAA demanded that U.S.-registered airplanes, manufactured after March 29, 2002, must be equipped with TAWS. Thus, aircraft produced before 2002 were not necessarily equipped with GPWS; therefore, the CFIT accidents in 2002 continued to increase. The decline occurred in 2006 after the regulations enforced by ICAO on January 1, 2003 and regulations enforced by FAA in March 2005, which required that all turbine-powered airplanes manufactured on or before March 29, 2002 must be equipped with TAWS, as well as the mandates of many other countries in 2005 that claimed add-on TAWS. Thus, the effect of GPWS installation was evident after 2006. The Boeing statistics on traffic growth indicate that the flight hours and the business of the aviation industry have doubled in the past 20 years, which agrees with the 10 accidents in 1990 and 18 in 2006. Accordingly, there was a close correlation between the increase in the flight hours, the overall traffic, and the annual increase in CFIT accidents.

Figure 3: Annual CFIT Accidents and the Five-Year Average

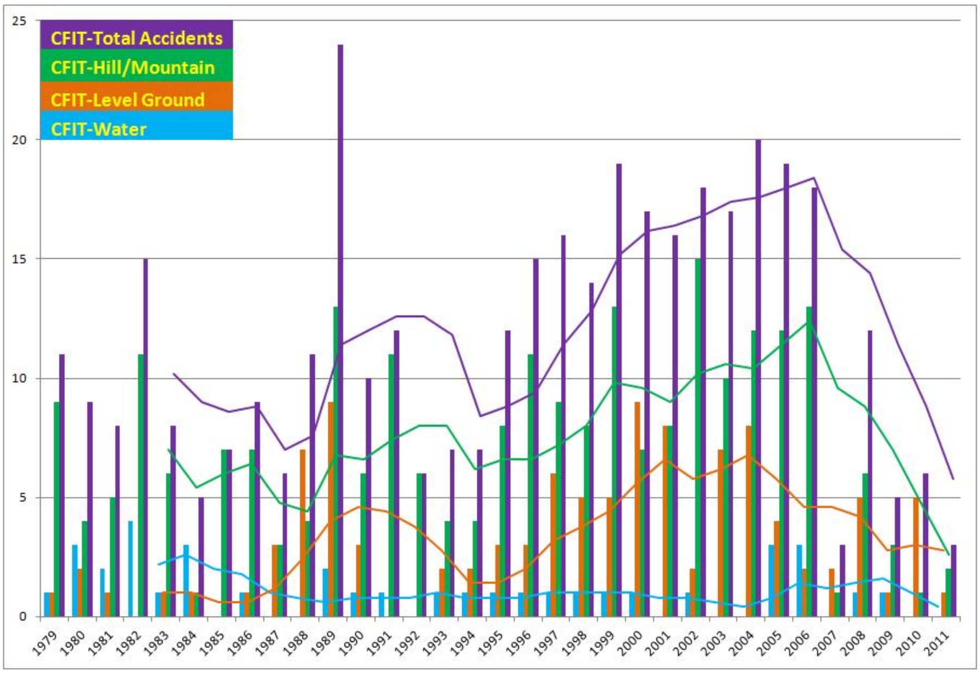


Figure 4 shows the annual CFIT accident trend for aircraft with Maximum Takeoff Weight (MTOW) more than 5,700 kg or a capacity of more than 9 passengers. This figure shows CFIT-Hill/Mountain had the largest number of accidents, followed by CFIT-Level Ground. These two have similar trends but CFIT-Water remains different from about one accident each year from 1988, which has not changed with the increased air traffic volume. Figure 4 also shows that the numbers of CFIT-Level Ground accidents in 1988 and 1989 were greater than the average number of accidents in the same years, whereas CFIT-Hill/Mountain maintained a fluctuating but generally steady trend. Since 1994, CFIT-Hill/Mountain and CFIT-Level Ground have increased, with similar growth slopes. However, CFIT-Level Ground started to decline in 2002, whereas CFIT-Hill/Mountain did not fall until 2006. The CFIT frequencies agree with the installation of GPWS functions.

Figure 5 illustrates our analysis of the situation for large aircraft with a maximum take-off weight of more than 15,000 kg or a capacity of more than 30 passengers, which determined a significantly different trend for CFIT-Level Ground accidents, compared with CFIT-Hill/Mountain accidents.

Figure 4: Annual CFIT Accidents involving Aircrafts with a Maximum Takeoff Weight of More than 5,700 Kg or 9 Passengers and the Five-Year Average

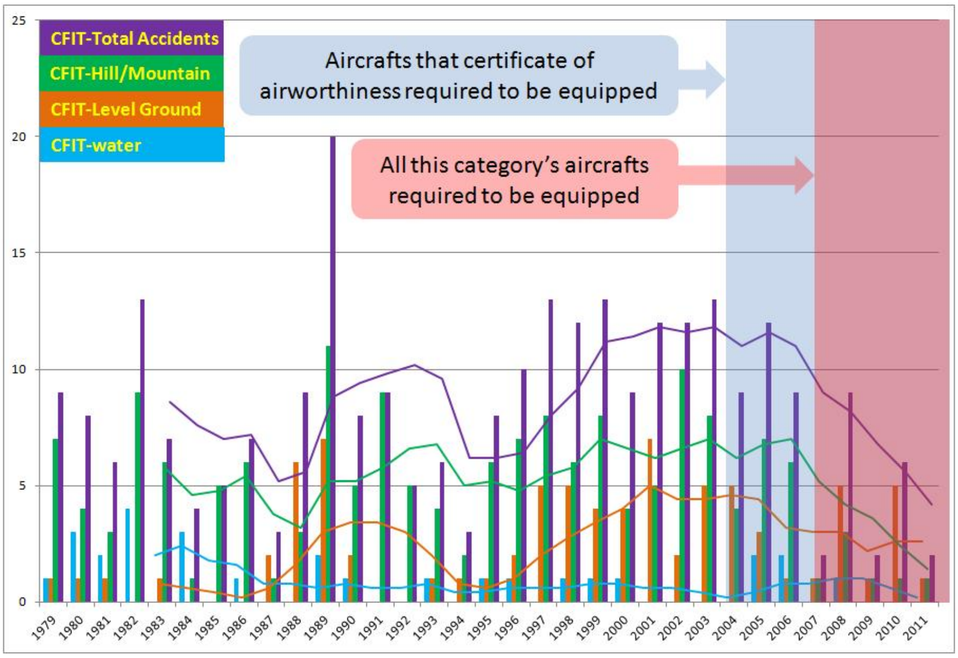
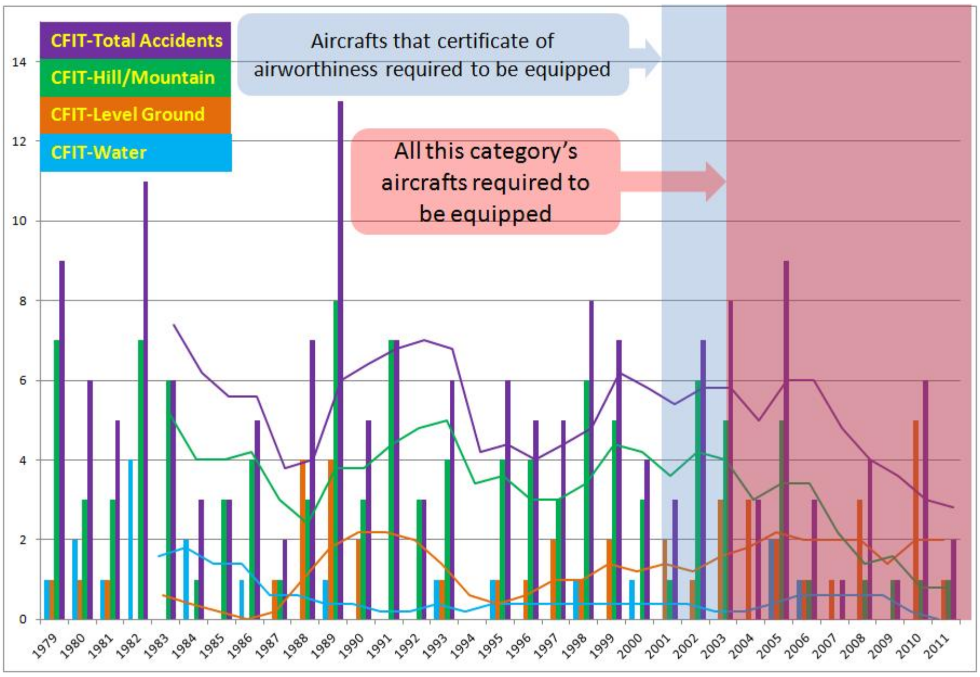


Figure 5: Annual CFIT Accidents Involving Aircrafts with a Maximum Takeoff Weight of More Than 15,000 Kg or 30 Passengers and the Five-Year Average



CFIT-Level Ground had a similar pattern with increasingly rising slope in the latter stage, whereas CFIT-Hill/CFIT-Mountain differed greatly because large aircraft trend fluctuated more than that for small aircraft, which clearly increased in the latter stage. The regulations were enforced for large aircrafts before small ones so it is easy to understand why the accidents involving large aircraft declined when the regulations were first introduced to cover them. By contrast, the regulations did not cover small aircraft, which explains why their trend continued to rise.

4.2 Analysis of the Annual Death Tolls from Cfit Accidents

Figure 6 shows the annual change in the death toll due to CFIT accidents. This figure shows the distribution of the death toll and the number of accidents is quite different. CFIT-Hill/Mountain accidents contributed the most to the death toll. The death tolls attributable to CFIT-Level Ground and CFIT-Water accidents are stable and low, apart from the accident peaks in 1988 and 1989, which makes the death tolls due to CFIT-Level Ground appear to increase rapidly. After 1994, both types returned to low death tolls. From a general view, the average annual death toll due to CFIT accidents in the past 30 years has fluctuated at around 300 persons, while there was no obvious upward trend in the number of accidents. Between 2000 and 2011, the death toll declined, especially in the most recent five years.

Figure 6: Annual Death Tolls and the Five-Year Average

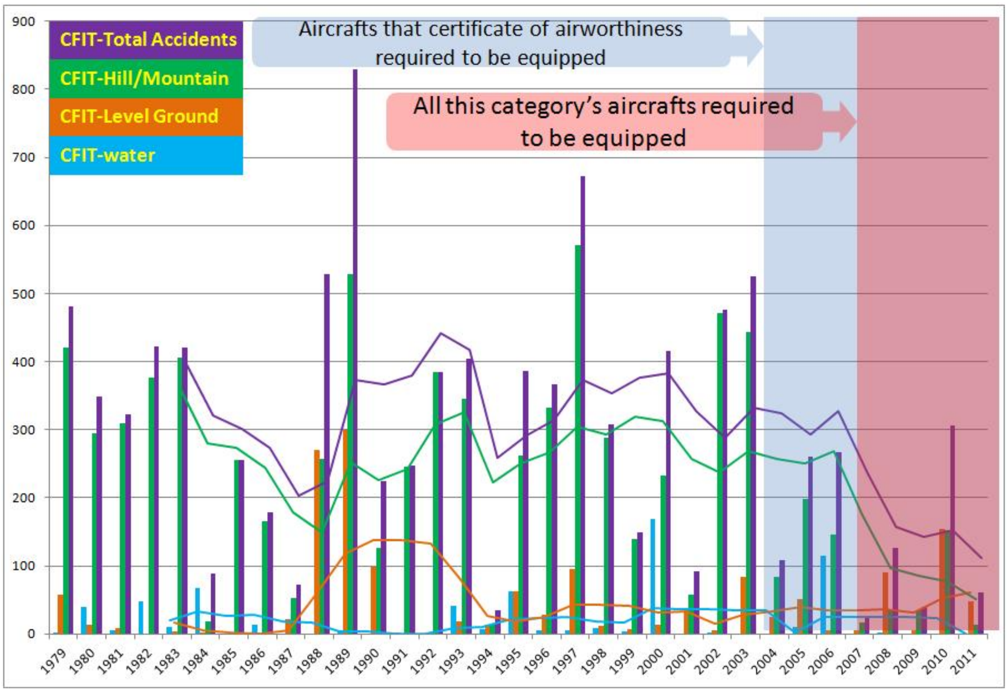
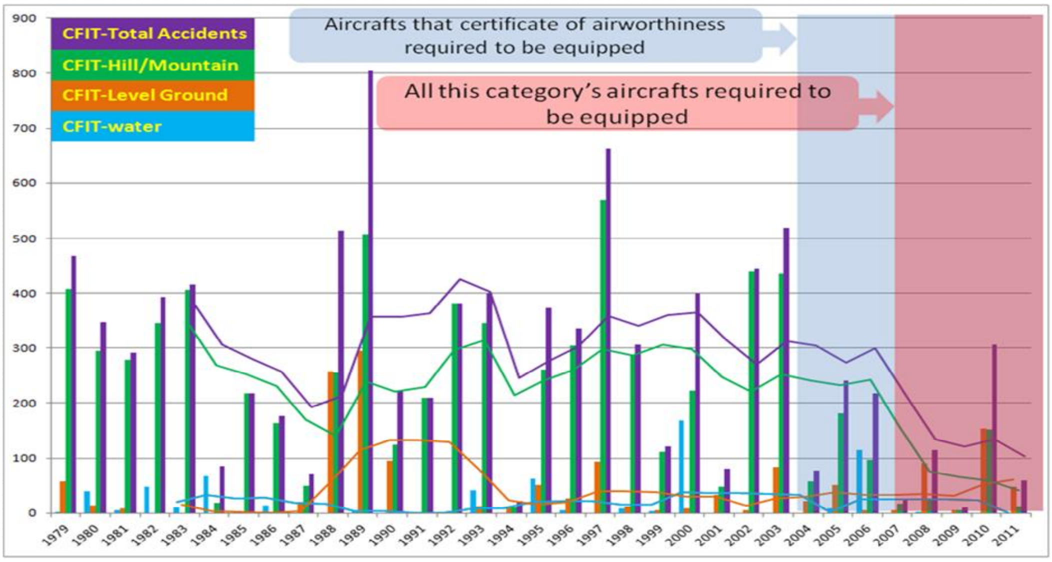


Figure 7 shows the annual death tolls for CFIT accidents involving aircraft with a maximum takeoff weight of more than 5,700 kg or a capacity of more than 9 people. This figure shows the

CFIT-Hill/Mountain was still the major cause of death. The numbers have decreased drastically in recent years, but the figures are still high. The death toll attributable to CFIT-Level Ground accidents are generally stable, after excluding the abnormal peaks in 1988 and 1989, and they are similar to the death tolls due to CFIT-Water. The figure also shows that the deaths due to CFIT-Hill/Mountain are higher than those with the other two CFIT types, which is more obvious during 1989 to 1997 and 2002 to 2003, which are attributable mostly to jetliner accidents, including the 1989 deaths of 144 people in Portugal and 127 people in the Republic of Honduras, the 1997 deaths of 288 people in Guam and 234 in Indonesia, the 2002 deaths of 119 people in Iran and 129 in South Korea, and the 2003 deaths of 275 people in Iran. The death toll did not decrease until 2004.

Figure 7: Annual Death Tolls of CFIT Accidents Involving Aircrafts with a Maximum Takeoff Weight of More Than 5,700 Kg or More Than 9 Passengers and the Five-Year Average



This also demonstrates that the highest death tolls were within less developed regions, i.e., outside the U.S.A., Canada, Europe, and Asia. The CFIT-Level Ground and CFIT-Water accident rates are generally stable, with the exceptions of for the high death tolls due to CFIT- Level Ground accidents between 1988 and 1989 in Indonesia, which claimed 124 fatalities, and in Surinam, which claimed 176 fatalities. The number of accidents remained high in other years but the death toll did not increase. The comparison of aircraft with a maximum takeoff weight of more than 15,000 kg or a capacity of more than 30 passengers showed that the death rates with large and small aircrafts had similar patterns but only the number of accidents increased. In contrast to the obvious differences in the accident trends, it is understandable that small aircraft with fewer passengers have a lower death toll, and the accident rate has risen though.

4.3 Analysis of the CFIT Death Tolls per Unit Flight

Given the standardization achieved mandatory GPWS installation and the passenger capacity, this study defined the death toll per unit flight as the test parameter to analyze the death toll during aircraft accidents. When the death toll per unit flight was greater than the regulatory requirement of the passenger carrying capacity, this represented the ineffectiveness of the regulations.

Figure 8 shows the death tolls during CFIT accidents per unit flight and the five-year average distribution. This figure shows the average for CFIT-Water accidents increased by a single event in 2000 that caused 169 deaths. Excluding that event, the average death toll per unit flight was more than 20 passengers. The death toll per unit flight for CFIT-Level Ground accidents, excluding the higher death tolls per unit flight between 1988 and 1990, was even lower than that for CFIT-Water with less than 10 fatalities per unit flight. The CFIT-Hill/Mountain death toll per unit flight was the dominant factor that shaped the overall average and it had a similar to the overall average, with an obvious decline in the most recent 15 years where death toll per unit flight fell from above 40 fatalities to under 10 fatalities. However, the average was still higher than 20 fatalities, which demonstrates that although the regulatory requirement for EGPWS has made some improvements, there is still a long way to go.

The overall average death toll per unit flight has generally remained at less than 40 fatalities and the trend has declined in the last 15 years where that in the most recent seven years was less than 20 fatalities. From a statutory point of view, the death toll per unit flight is higher than 9 fatalities, which was set by the international standard that required GPWS installation, so it is evident that some countries are still substandard and they affect the overall average.

Figure 8: Death Toll per Unit Flight and the Five-Year Average

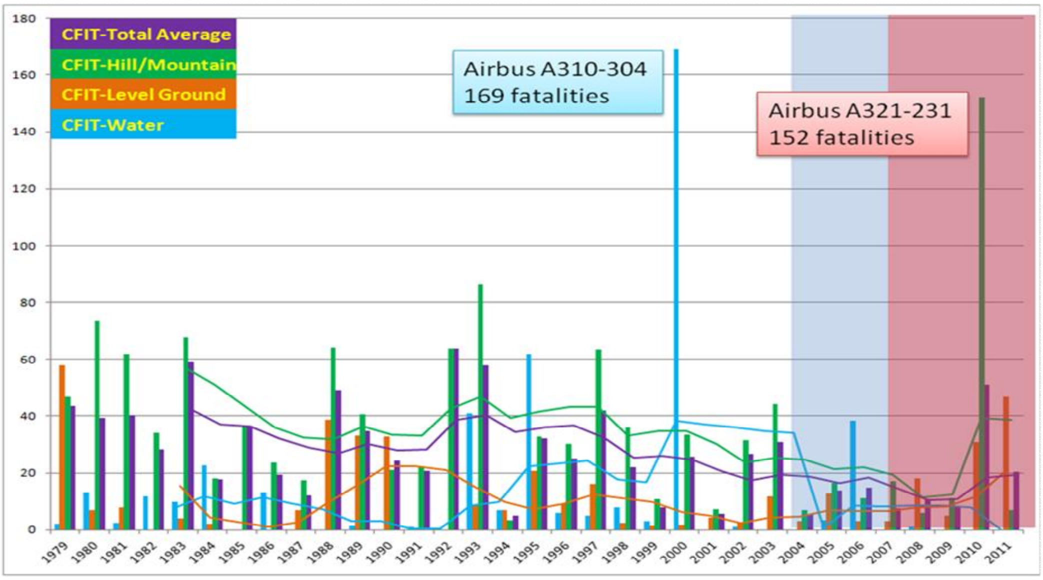
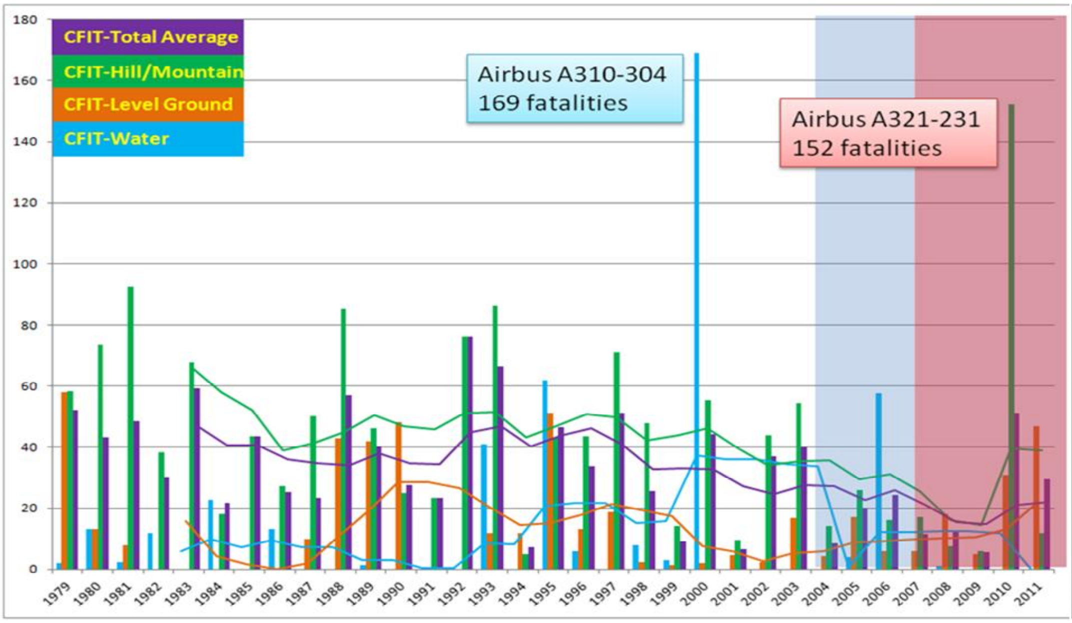


Figure 9 shows the annual death toll per unit flight for CFIT accidents involving aircraft with a maximum takeoff weight of more than 5,700 kg or a capacity of more than 9 passengers. This figure shows during the last 30 years, CFIT-Hill/Mountain accidents have declined steadily. The ICAO requirement for EGPWS installation in recent years had a major effect on the trend. CFIT-Level Ground accidents have remained low since 1995, and 2002 was the best year, although there was a slight upward trend in the following years, which contradicted expectations. CFIT-Water accidents reached their lowest average level in 1991 but there were many sudden increases, which were attributable mostly to several major CFIT-Water accidents, such as that in 2002, which claimed 169 fatalities, resulting in a soaring five-year average, and it was not until 2005 that it returned to a low level, only to soar again with new accidents.

The death tolls per unit flight in CFIT-Level Ground accidents and CFIT-Water accidents attributable to aircraft with a maximum takeoff weight of 15,000 kg or a capacity of more than 30 passengers differed little from those after the installation of GPWS in aircraft with a maximum takeoff weight of more than 7,500 kg or a capacity of more than 9 passengers, although the death toll per unit flight in CFIT-Hill/Mountain accidents declined significantly. This implies that although the number of small aircraft flights increased, the death toll did not increased proportionally because of their small size, which reduced the average death toll per unit flight. However, this also indicates the necessity of the relevant enactments to cover small aircrafts, so small aircraft should be required to install EGPWS/TAWS and the overall CFIT-Hill/Mountain accidents will be effectively prevented.

Figure 9: Annual Death Toll per Unit Flight for Aircraft with a Maximum Takeoff Weight of More than 5,700 Kg or More than 9 Passengers and the Five-Year Average



4.4 Analysis of Geographical Factors Affecting CFIT Accidents By Countries

This study sampled the U.S.A, Canada, EU, and Asian countries in the comparative analysis. The annual accident rates in these regions were low with about one or two accidents each year, while the annual death tolls were also low. Thus, the death tolls per unit flight converted were low in these regions with an average of about 5 fatalities per unit flight, which satisfies the current enactment that requires aircraft with a capacity of more than 9 passengers to be installed with GPWS/EGPWS/TAWS. However, this is not covered by the current enactment. Two inferences can be made based on an analysis of the geographical aspects. First, future regulations should continue to expand coverage to reduce the CFIT risks of small aircraft (maximum takeoff weight of less than 7,500 kg or a capacity of less than 9 passengers). Second, the analysis showed that although the overall death toll per unit flight was still greater than the regulatory standard, the U.S.A., Canada, EU, and Asian countries conformed to the regulations, which shows that the problem lies in other regions. This finding should be the focus of future improvement efforts.

5. CONCLUSIONS AND RECOMMENDATIONS

This study analyzed the annual numbers of aircraft accidents, the annual death tolls in these accidents, and the death toll per unit flight accident, as well as geographical factors, and this study reached the following conclusions.

This study defined the death toll per unit flight as the test parameter and this study examined the correlation between CFIT accidents and statutory installation of GPWS. This study compared the death toll per unit flight after this requirement, which showed that the overall frequency of CFIT accidents has been improved. The study result showed that CFIT accidents are mainly CFIT-Hill/CFIT-Mountain and CFIT-Level Ground accidents, which have similar annual trends. The overall trend is based on the distributions of these two CFIT types. Over the last 30 years, the annual average CFIT accident rate before 1995 was less than 10 with little variation. Between 1995 and 2006, however, the number of CFIT accidents increased. After 2007, the overall number of accidents declined dramatically due to the enforced installation of GPWS.

The study shows that there was a significant change in the death toll distribution in recent years and the numbers of accidents. The CFIT-Hill/Mountain accidents had the highest death toll and they dominated the overall distribution. The death toll per unit flight for CFIT-Water accidents was less than 20 people while the overall average death toll per unit flight for CFIT-Level Ground was less than 10 people. The death toll per unit flight for CFIT-Hill/Mountain, being the main factor, had a similar trend with the overall average. There has been a downward trend in the last 15 years, which demonstrates that the installation of GPWS has made improvements, although the death toll per unit flight exceeds nine persons, which shows that some countries are still substandard and such cases have affected the average.

When this study was extended from larger aircraft with a maximum takeoff weight of more than 15,000 kg or a capacity of more than 30 passengers to smaller aircraft with a maximum takeoff weight of more than 7,500 kg or a capacity of more than 9 persons, the death toll per unit flight for CFIT-Level Ground and CFIT-Water accidents did not change much, whereas the death toll per unit flight for CFIT-Hill/Mountain accidents had a significant downward trend. These results demonstrate the necessity for relevant regulations to cover small aircraft and they should be required to be installed with GPWS, so the overall CFIT accident rate can be improved.

The geographical analysis showed that the overall death toll per unit flight was still higher than the statutory standard. However, the U.S.A., Canada, EU, and Asian countries conform to the statutory standard, which indicates that the problem lies in other regions. This finding should focus future efforts in making further improvements in these areas. Finally, this study recommends that future regulations should be more extensive to diminish the CFIT risks for smaller aircraft as well as commercial airplanes.

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MAKING THE GO, NO-GO DECISION BASED ON NON-TRADITIONAL WEATHER PLANNING INFORMATION: THE CHALLENGE OF MEASURING THE IMPACTS OF NEW TECHNOLOGIES ON PILOT'S WEATHER RELATED DECISION MAKING IN GENERAL AVIATION

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ABSTRACT

This paper explores contemporary issues regarding the challenges of quantifying improved decision making and situational awareness as it is applied to emerging tools in aviation weather information dissemination. The authors explore the phenomena of increased/improved pilot decision making due to additional visual representation of visual weather data. General concepts such as past and present flight planning tools and procedures are discussed. Additionally, the authors explore the Federal Aviation Administration's (FAA) Alaskan Weather Camera program as a potential case study for future exploration of these concepts. A pilot survey tool was created and administered to a small test population as a part of an undergraduate Aviation Psychology course assignment. Preliminary findings and suggestions for future research are presented.

Keywords: human factors, aviation psychology, undergraduate pilot study, general aviation

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1. INTRODUCTION

As weather related technology becomes more and more readily available to the average general aviation (GA) pilot, users, operators and providers will need to ask the question of whether or not more data equals more information that can be interpreted and used appropriately. In short, is the pilot's situational awareness (SA) affected by the new information and are better, more informed decisions being made? Researchers will need to determine whether or not the new information has an additional cognitive value. In other words, one needs to identify the measure and articulate how pilot decision making is improved.

Approximately a decade ago in a critical review of the concept of SA, Endsley (2000) identified SA in weather forecasting as sub-domain of SA that was emerging in the literature. This paper will focus on the Task or System Factors associated with SA of weather phenomena in the flight planning stage. The addition of non-traditional sources of weather data through remote visual aids and their ability to enhance the pilot's ability to make an improved go or no-go decision will be explored and a pilot study to test its effectiveness will be proposed.

One of the leading causes of fatal accidents in the aviation industry over the past two decades has been poor decisions made by pilots in deteriorating weather (FAA, 2013). These poor decisions are caused by underlying psychological factors. Over the last 20 years, there has been introduction of safety related initiatives as general aviation accidents involves pilot's decision to navigate in inclement weather conditions which has created a need for research efforts to analyse and develop interventions aimed at mitigating the incidence of GA accidents. To satisfy this need, researchers have examined aspects of visual flight rules into instrument metrological conditions accidents and have come up with factors that might assist in reducing the degree of associated fatalities but these interventions have proved to be limited by lack of theoretical framework.

While Visual Flight Rules (VFR) flight into IMC accounts for about 4% of all GA crashes, they comprise 19% of all GA fatalities. To understand the cause and consequences of the decision of a pilot to fly VFR into Instrument Meteorological Conditions (IMC), it is important to explore the various stages of decision making along with factors that affect these processes.

Visual flight rules are a set of aviation regulations under which a pilot may operate an aircraft independently if weather conditions allow the pilot to visually control the aircraft attitude, navigate and maintain separation from obstacles like terrain and other aircraft. Although the requirements vary with airspace and altitude, generally speaking, conditions of more than 3 statute miles visibility and cloud ceilings greater than 1000 feet meet VFR minima. A pilot flying under these rules is required to remain clear of clouds and maintain a specified flight visibility based on the classification of airspace they are operating in. The pilot is also responsible for avoiding aircraft and other obstructions. In accidents in which VFR flight into IMC was a probable cause, accidents were attributed to flight crew, poor weather information, pilot error, and failure to make good decision making. In order to reduce these accidents the FAA has developed several training programs to look into cognitive and affective components of pilot decision making (FAA 2, 2013).

Successful pilot judgment and decision making is affected by motivational and cognitive components. Cognitive components are the process by which pilots establish and evaluate alternatives in a decision making situation. This involves the pilot depending on ability to sense, store, retrieve and integrate information. The motivational component involves gains and losses associated with decision outcomes, social and personal pressures.

Causes of VFR into IMC include a variety of cognitive factors like situation assessment and risk perception as well as affective factors. It also includes motivation and decision framing combined with biases and heuristics. A solution to improve decision making is found through cognitive aspects of training, displays that make it easy to detect and integrate cues, and also tools to assess and formulate courses for action (Madhavan, 2006).

2. TASK OR SYSTEM FACTORS AFFECTING SA AND DECISION MAKING IN WEATHER FORECASTING FOR GA PILOTS

Traditional sources of aviation weather products available to GA pilots are numerous. Prior to the 1960s, pilots typically planned flights with Flight Service Station (FSS) personnel face to face. Telephone information briefings (TIBS) became available in the 1970s followed an online system in place today called the Direct User Access Terminal (DUATS) which provides pilots with a cadre of printed routine weather reports (METARs), area forecasts (FA), and terminal area forecasts (TAFs). Throughout the stages of information delivery from in person to at your fingertips, the types of information that can be shared their delivery systems also improved (NTSB, 2001. Pp 10-11).

The National Weather Service (NWS) improved upon Doppler radar and provided pilots with the next generation of radar (NEXGEN) that provided users with information on precipitation and wind(s) aloft.

Today, pilots typically begin their flight planning days in advance, watching frontal movements and tracking the position of high and low pressure systems. Depending on the skill, experience or certification limitations of the pilot, early decisions to cancel or reschedule a planned flight can occur in this early stage. Pilots can obtain outlook briefings from automated or over the phone briefings provided by DUATS or Flight Service Stations (respectively). Outlook briefings provide pilots with critical flight planning weather information trips planned more than 6 hours prior to initiating the flight. Within that 6 hour window, pilots request a standard weather briefing where they will need to translate, sort through and analyse a multitude of textual and graphical weather data that is both real-time in nature as well as predictive.

Pilots attempt to gain a preliminary understanding of the *state of the environment* (Endsley, 2000. page 3). This then affects situation awareness which is broken down into to three separate levels, Perception (level 1), Comprehension (level 2), and Projection (level 3). Situational awareness, in Endsley's model, drives direction and action.

In level 1, pilots form a perception of the cues being received from the external environment. Seventy six percent (76%) of situational awareness errors committed by pilots can attribute to difficulty with perceiving information incorrectly (Jones & Endsley, 1996).

In Level 2, Comprehension, Endsley (2000. Pp. 3-4) describes how pilots integrate the incoming data with other pieces of information and determine their relevance. Endsley reported that 20% of situation awareness errors were due to comprehension of the value of the information. He stated that individuals must consider both the subjective interpretation (awareness) and the objective significance (situation).

The final level (3) in situational awareness in Endsley's Dynamic Decision Making Model (1995) is Projection. Projection is the phase of situational awareness where pilots are able to use the information gathered to make future predictions. Aviation experts use projection to anticipate future conditions based on information from current sources.

Endsley identifies two temporal aspects of situational awareness that affect pilot cognition when interpreting weather information. One, how much time and space are available to process the information? Two, at what rate does the information change? These two aspects affect one's ability to accurately form a sense of self-awareness that is timely. SA is the precursor to the decision making process. However, Endsley points out that, "Good situation awareness should increase the probability of good decisions and good performance, but does not guarantee it" (2000. Pg. 18). Pilots require analytical skills and intensive training as a guide to help them focus on very important tasks such as pre-flight weather planning (Hunter, Martinussen & Wiggins, 2003).

3. TECHNOLOGY

A great way to mitigate human error in incidents would be to design the human out the problem through the use of emerging technologies that assist in decision making. Allowing automation reduces the workload on flight crew. Some of the downfalls would be over trusting automation or not trusting the system at all. For these flaws there must be a need to adequately train pilots in the use of automation (Lincoln, 2012).

4. VARIABLES INFLUENCING DECISION MAKING IN WEATHER RELATED DECISION MAKING

Pilots have been known to trust weather information they can directly observe more than sensor-based information that is digitally displayed (Latorella, K. A., & Chamberlain, J. P., 2001). Findings of a National Transportation Safety Board (NTSB) study in weather related decision making found that the following variables contributed significantly to flight outcomes: 1) age at time of accident, 2) age at first certificate, 3) highest certification, 4) instrument rating, 5) practical test cumulative pass rate, 6) accident/incident history, 7) planned length of flight, 8) purpose of flight, and 9) aircraft ownership (NTSB, 2001).

The Safety Board recommended that the FAA add a specific requirement for all pilots who do not receive weather-related recurrent training, that the biennial flight review include recognition of critical weather situations from the ground and in flight, and the procurement and use of aeronautical weather reports and forecasts. Among other findings, the study determined that:

a. Age of initial flight training determines risk (less risk for pilots who begin their training earlier in life).
b. Weather-related knowledge and skills need continual maintenance.
c. General aviation pilots routinely consult alternative sources of aviation weather to obtain information that is not currently available from a standard weather briefing.

Two recommendations for the FAA by the NTSB (2001, p. 48) included:

a. Determine optimal information presentation methods and delivery systems for flight service station weather information briefings, including the possibility of supplementing or replacing some portions of the current standard weather briefing with graphical data. (A-05-028)

b. Revise guidance materials associated with pilot weather briefings to include guidance for pilots in the use of Internet, satellite, and other data sources for obtaining weather information suitable for meeting the intent of 14 Code of Federal Regulations Part 91.103 and subsequently inform the aviation community about this change. (A-05-029)

Goh and Wiegmann (2001. pp. 359-360) point out that, although weather related accidents between 1990 and 1997 only accounted for a small portion of GA accidents, 2.5% of accidents accounted for approximately 11% of the fatalities. Approximately 22% of accidents occur due to diagnostic error. Additionally, the study found a clear difference between novice and expert performance. Goh and Wiegmann point out that pilots that frame their decision to divert as a loss (loss of fuel, time, etc.), they may tend to choose risky behaviours and choose to fly or continue to fly in poor or deteriorating weather. Framing decisions based on the concepts of gains and losses is articulated by Kahneman & Tversky's (1982) Prospect Theory. In Goh and Weigmann's experiment, they found that pilots were more likely to proceed into hazardous weather if they perceived that weather variables were less likely to be causal factors in aviation accidents.

Wiegmann, Goh & O'Hare (2002) conducted a study assessing the impact of flight experience on pilot deviation decisions in adverse weather. Their results indicated that novice pilots were more likely to continue into poor weather conditions more often and for more time than their more experienced counterparts. This decision is attributed to poor situational assessment skills of the less experienced pilots. A previous study conducted by the FAA (Driskell, et al., 1997) found that one can measure pilot's comfort policies in terms of emphasis on variables such as ceiling and visibility, and how they prioritize weather conditions.

Human information process is classified into three sequential categories: information acquisition, situation assessment, and choice of action. In this stage the pilot seeks cues from the environment and performance is primarily driven by attention, concentration and perception. Decision making and the choice of action is influenced by information stored in working memory and long term memory. Decision at the stages is most often affected by the overconfidence bias and the availability heuristic.

Pilots often engage in VFR into IMC as a result of failing to properly assess the latent hazards or conditions. Madhavan and Lacson (2006) found that 22% of accidents were due to human error resulted primarily from diagnostic errors. These diagnostic errors were more serious than aircraft handling (Air Traffic control) errors.

5. SAFETY METRICS

Safety performance measures are used as indicators for stakeholders to monitor any change in the system against established goals and objectives providing key trend information. Common safety performance measures are accident/incident rates, response times, and public/user perceptions. The US National Highway Administration (NHWA) , in its 2009 document on safety measures for transportation highlights that safety measures can provide, "….feedback to promote ongoing improvement of business processes as they relate to supporting safety strategies" (Pg.2). Sources of safety metrics include:

1. Core – Recorded accidents, incidents or safety related events.
2. Behavioural – Observational data from survey.
3. Activity Measure – Data collected during a specified performance period (e.g. Grant activity reporting).

The National Transportation Safety Board (NTSB, 2001) found that general aviation (GA) pilots routinely consult alternative sources of aviation weather to obtain information that is not currently available from a standard weather briefing. They determined that optimal information presentation methods and delivery systems for flight service station weather information briefings, include the possibility of supplementing or replacing some portions of the current standard weather briefing with graphical data. They suggested that the FAA revise guidance materials associated with pilot weather briefings to include guidance for pilots in the use of Internet, satellite, and other data sources for obtaining weather information suitable for meeting the intent of 14 Code of Federal Regulations Part 91.103 and subsequently inform the aviation community about this change.

6. STRATEGIC DATA COLLECTION PLAN FOR METRICS

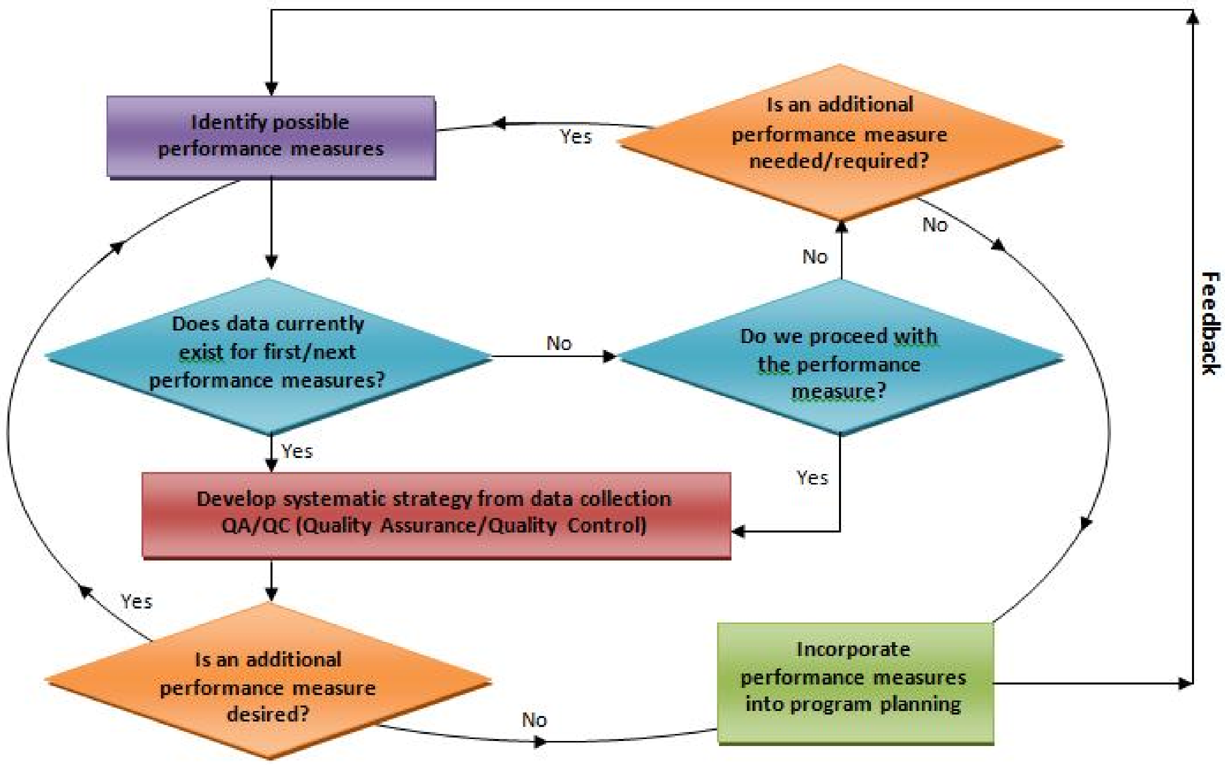
Metric identification, selection and use requires a plan. The following should be considered when choosing a metric:

* **Timeliness**- Can the data custodian produce reports and data in a timely manner to inform the performance measure process?

* **Accuracy**- How do you ensure that the data is accurate when collected initially and when received in the final desired electronic format?
* **Completeness**- What steps are you taking to ensure that all the data needed for the analysis are accurately represented? Are all factors included? Will the data account to a better understanding of physical or behavioural variables?
* **Uniformity/Consistency**- Do the databases you are utilizing have uniform codes and identifiers?
* **Integration**- Is one common database used at all levels? Ideally, this is the case.
* **Forecastability**- Is it difficult to predict future conditions using the measure given existing forecasting tools?
* **Accessibility**- How accessible is the data to those who will be conducting the analysis?

If not internal, describe the process of requesting the data and any time constraints.
Herbel et al. (2009) developed a Safety Performance Planning Process (Figure 1) for identifying and utilizing performance measures. This process is used to determine whether or not additional metrics are required to measure the desired outcome.

Figure 1: Safety Performance Planning Process



Source: Adapted from Herbel et al. (2009)

7. CASE STUDY

The Alaskan Weather Camera Program is a good example of using emergent technologies to supplement the cadre of decision making tools available to general aviation pilots in making weather related go and no-go decisions. The program's mission is to improve Safety and Efficiency by providing near real-time images to aviation users. Its goal is to reduce weather related aviation accidents and improve operator efficiencies by reducing fuel and other operations costs. Its method utilizes images are made available to the public via the FAA Aviation Weather Camera Website (http://avcams.faa.gov/). The program consists of an array of weather stations and web cameras strategically placed throughout the state of Alaska aimed at providing general aviation pilots with supplemental weather data in locales and regions critical to flight safety where weather is more difficult to forecast.

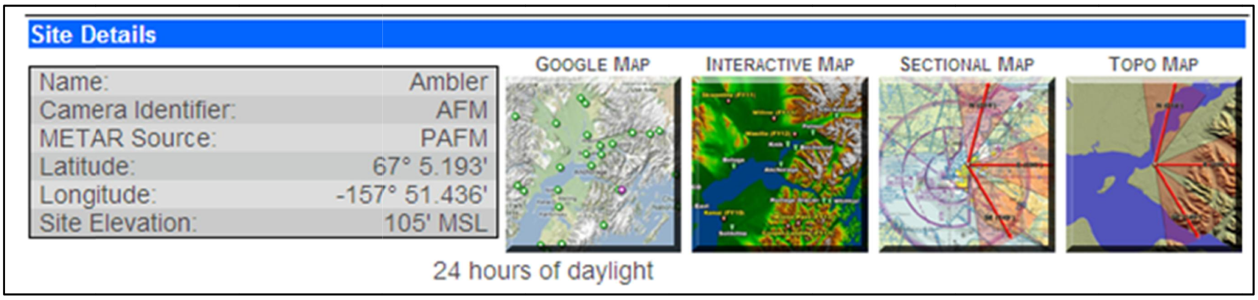
Figure 2: FAA Aviation Weather Camera Station

Source: Retrieved from www.parsons.com/projects/Pages/faa-tssc-iv.aspx

Increased safety in the form of increased pilot decision making was among one of the goals of the program, along with reduction in wasted fuel as a result of aborted flights due to un-forecasted deterioration of weather conditions.

Using the web site, pilots are able to locate the area of interest (flight path) and access real-time visual weather depictions.

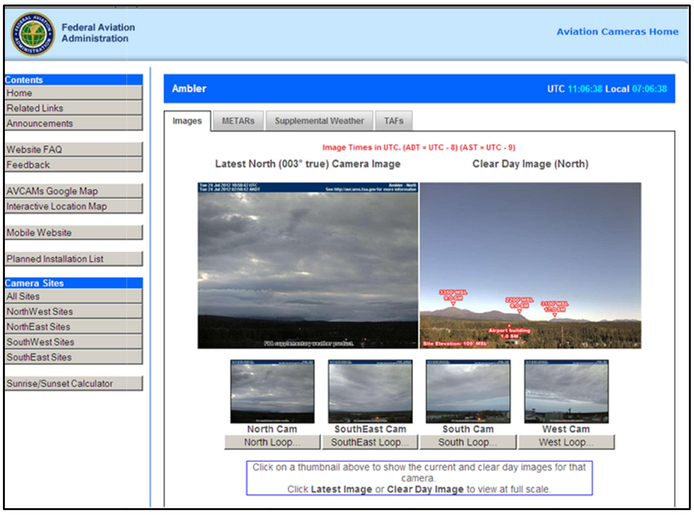
Figure 3: Weather Station Site Details



Source: Retrieved from http://avcams.faa.gov/index.php

After locating the desired site, pilots are able to compare the existing visual conditions with clear weather conditions to make an educated estimate of inflight visibility and cloud ceiling conditions.

Figure 4: Real Weather Versus Clear Day Comparison



Source: Retrieved from http://avcams.faa.gov/index.php.

8. PILOT STUDY DEVELOPMENT AND RESULTS

In an attempt to initially study the impact of additional visual data provided to pilots (via the Weather Camera System) on pilot's decision making, an undergraduate class studying Aviation Psychology developed a preliminary survey measuring pilot decision making for a fictional flight in the Alaska Region using real-world data. Students developed a preliminary pilot survey Developed a consent form Received Institutional Review Board (IRB) approval to meet exempt status and conduct the survey on campus Administered survey to freshman flight students currently enrolled in their second semester. Survey participants were first asked to make a decision to continue flight based solely on textual data provided by the FAA and National Weather Service.

Figure 5: Textual Weather Data

QUESTIONNAIRE

METAR text:	**PAFM 241056Z AUTO 19003KT 10SM OVC085 12/11 A2992 RMK AO1 PNO**
Conditions at:	PAFM (AMBLER , AK, US) observed 1056 UTC 24 July 2012
Temperature:	12.0°C (54°F)
Dewpoint:	11.0°C (52°F) [RH = 94%]
Pressure (altimeter):	29.92 inches Hg (1013.3 mb)
Winds:	from the S (190 degrees) at 3 MPH (3 knots; 1.6 m/s)
Visibility:	10 or more miles (16+ km)
Ceiling:	8500 feet AGL
Clouds:	overcast cloud deck at 8500 feet AGL
Weather:	automated observation with no human augmentation; there may or may not be significant weather present at this time

FIGURE 1. METAR 1056Z

METAR text:	**PAFM 241236Z AUTO 00000KT 10SM OVC085 11/09 A2994 RMK AO1 PNO**
Conditions at:	PAFM (AMBLER , AK, US) observed 1236 UTC 24 July 2012
Temperature:	11.0°C (52°F)
Dewpoint:	9.0°C (48°F) [RH = 87%]
Pressure (altimeter):	29.94 inches Hg (1014.0 mb)
Winds:	calm
Visibility:	10 or more miles (16+ km)
Ceiling:	8500 feet AGL
Clouds:	overcast cloud deck at 8500 feet AGL
Weather:	automated observation with no human augmentation; there may or may not be significant weather present at this time

FIGURE 2. METAR 1236Z

Source: Retrieved from http://avcams.faa.gov/index.php

After making the decision, they were given the supplemental weather data provided by the Weather Camera system.

Figure 6: Sample Progressive Weather Picture with Baseline Image

Source: Retrieved from http://avcams.faa.gov/index.php

Then, a series of questions were given to the students. A sample of the questions developed by the students appears in Figure 7 below.

Figure 7: Sample Survey Questions

1. Given the two meteorological observations from the METARS in figures 1 & 2 (from 1056Z and 1236Z), how would you define the weather at Ambler, AK?
a. Improving (getting better)
b. Slightly improving
c. Little to no change
d. Deteriorating (getting worse) slightly
e. Deteriorating

2. Based on the textual data in the Ambler METAR, if planning a Visual Flight Rules (VFR flight) cross-country flight through the Ambler, AK area which of the following would best describe your decision making process?
a. The weather is deteriorating (getting worse) and I would choose not to continue to plan this flight and stay home.
b. The weather indicates no changes in the last hour. With 10 miles visibility and a ceiling of 8500', I will continue planning for a flight through Amber.
c. The METAR weather information does not affect my decision making process when it comes to planning.

3. Based on the information available for Ambler, AK given in the METAR, a VFR flight through this area would be a:
a. Go (The weather is good for VFR, continue to plan on making the trip).
b. No-Go (The weather is marginal VFR or IFR, discontinue planning on making the trip).

Students' responses were analysed to determine whether or not the addition of the visual weather information had an impact on their *go, no-go* decision making process.

9. PRELIMINARY RESULTS

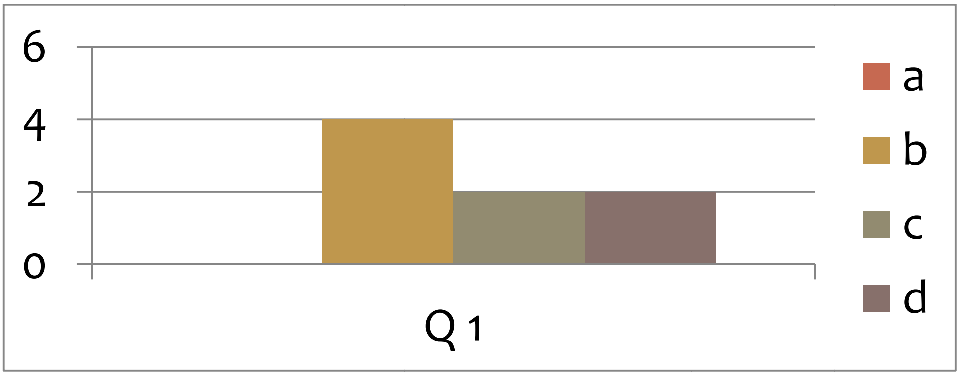
The following are results from the small pilot study conducted with undergraduate pilots in an aviation science course.

Question 1

Given the two meteorological observations from the METARS in figures 1 & 2 (from 1056Z and 1236Z), how would you define the weather at Ambler, AK?

a. Improving (getting better)
b. Slightly improving
c. Little to no change
d. Deteriorating (getting worse) slightly
e. Deteriorating

Figure 8: Question 1 Responses

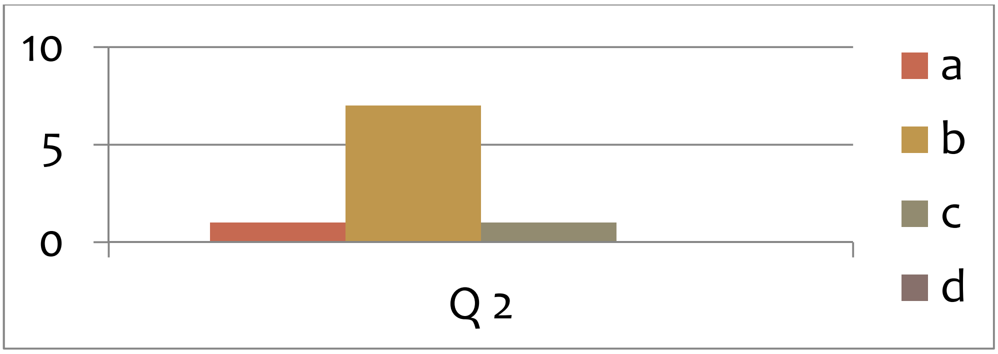


Question 2

Based on the textual data in the Ambler METAR, if planning a Visual Flight Rules (VFR flight) cross-country flight through the Ambler, AK area which of the following would best describe your decision making process?

a. The weather is deteriorating (getting worse) and I would choose not to continue to plan this flight and stay home.
b. The weather indicates no changes in the last hour. With 10 miles visibility and a ceiling of 8500', I will continue planning for a flight through Amber.
c. The METAR weather information does not affect my decision making process when it comes to planning.

Figure 9: Question 2 Responses

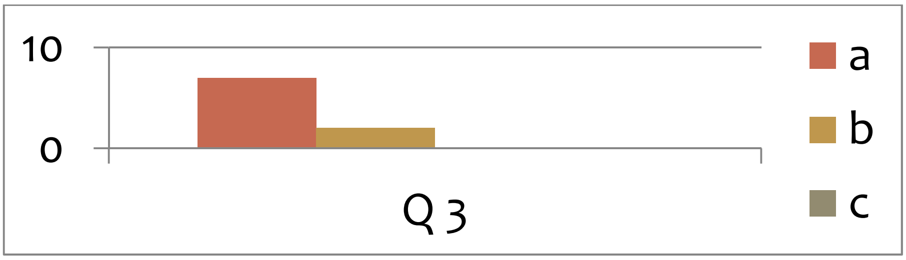


Question 3

Based on the information available for Ambler, AK given in the METAR, a VFR flight through this area would be a:

a. a. Go (The weather is good for VFR, continue to plan on making   the trip).
b. No-Go (The weather is marginal VFR or IFR, discontinue planning on making the trip).

Figure 10: Question 3 Responses

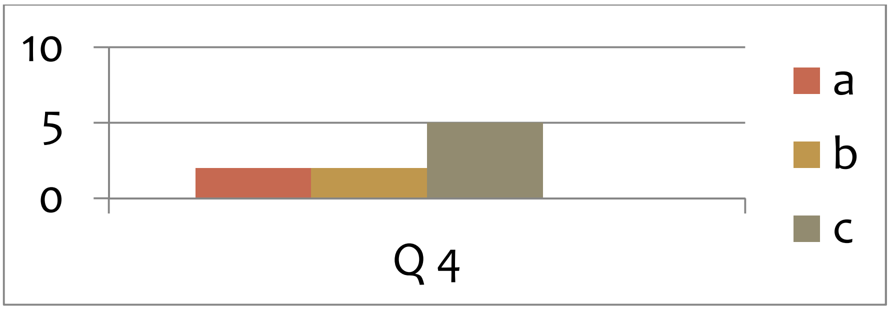


Question 4

Compared to the textual METAR data, which of the following best describes the relationship between the weather reported in the METAR data for Ambler and the visual weather image depicted by the camera at Ambler?

a. The same (No difference).
b. Slightly different (Not really significant).
c. Significantly different.

Figure 11: Question 4 Responses

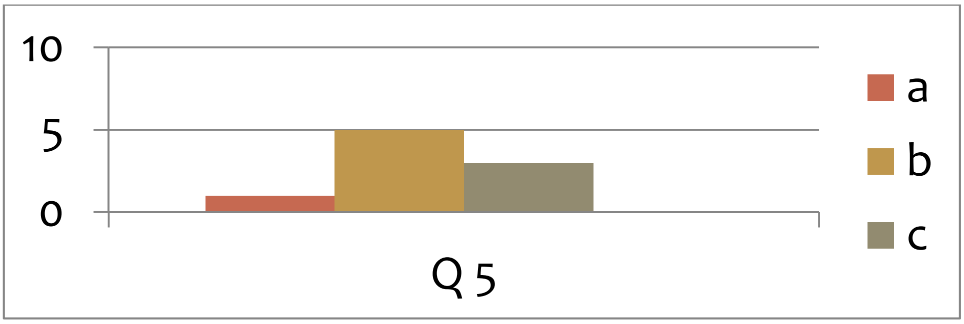


Question 5

Based on the series of visual weather images for Ambler when compared to the clear day image, which best describes your impression:

a. The cloud ceiling height and visibility based on the visual weather at Ambler was better than reported in the METAR.
b. The cloud ceiling height and visibility based on the visual weather at Ambler was the same as reported in the METAR.
c. The cloud ceiling height and visibility based on the visual weather at Ambler is worse than the reported in the METAR

Figure 12: Question 5 Responses

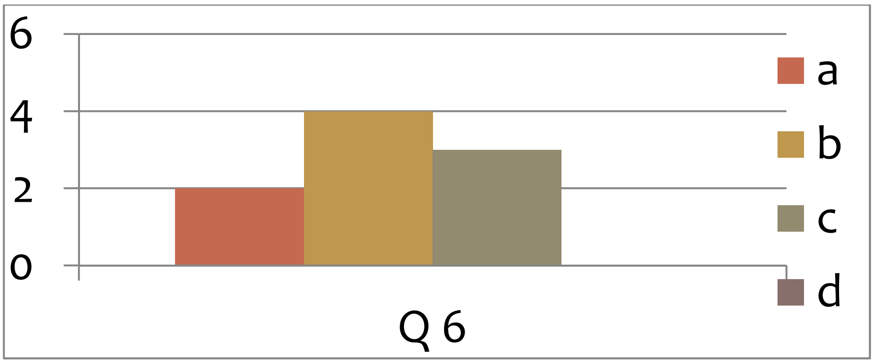


Question 6

Please choose which of the following best describes the impact of the additional visual weather information for Ambler on your flight planning decision making process to continue the flight (Go) or discontinue the flight (No-Go):

a. No impact on go, no-go decision
b. Limited impact on go, no-go decision
c. Moderate impact on go, no-go decision
d. Significant impact on go, no-go decision

Figure 13: Question 6 Responses



More than 50 % of the participants initially surveyed indicated that the weather in the textual weather report varied significantly from that in the visual weather camera data. When asked whether or not the additional information had any (scale varied from limited, moderate, significant) impact on their go or no-go decision, 77% indicated that it had some impact, and only 23% of the respondents indicated that it had no effect on their decision making. Based on the initial pilot survey activity, the students determined that additional research was warranted. Feedback from survey participants will be used to inform future focus groups to revise the survey instrument to address validity issues.

10. LIMITATIONS

These findings are only preliminary and within a classroom environment. The survey instrument is continuing to be refined and developed further into an electronic survey tool that will be deployed to a larger population to ensure greater validity and generalization to larger populations.

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STRUCTURAL ANALYSIS OF TURKISH AIRSPACE BY USING GIS

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ABSTRACT

In parallel with the rapid growth in Turkish air transportation, air traffic density and congestion of Turkish airspace have been increasing in recent years. The aim of this study is to examine the structural features and the capacity of Turkish airspace. In this context, the map of Turkish airspace containing sector boundaries, routes and waypoints is digitized and transferred to the GIS environment. The real traffic data of Turkish airspace for a period of two peak hours in heavy traffic during August 2007 was provided by the General Directorate of Turkish Airports. Analysis results indicate that the traffic density of Turkish airspace is accumulative especially in certain sectors. The results obtained from the analyses were compared with the existing sector structure of Turkish airspace and some suggestions related to capacity problems are provided. These suggestions can also be used for the strategic planning of airspace.

Keywords: Airspace Management, Air Traffic Control, Geographical Information Systems

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1. INTRODUCTION

Effective management of airspace is an important and difficult problem. In many en-route regions, air traffic is expected to exceed current capacity limits, i.e. the maximum number of aircraft allowed in a given airspace, as defined by controllers. An overestimated capacity may lead to congestion delays or safety breaches with respect to minimum aircraft separation (Salaün, 2009). Rapid growth in air traffic volume steadily increases complexity and produces drawbacks such as: system bottlenecks, indirect routing, and lack of navigation freedom for airlines (Hand et al., 2011). Galster et al. (2001) argue that controllers had difficulty both in detecting conflicts and in recognizing self-separating events in saturated airspace according to performance and workload measurements. A number of factors affect controller workload; these factors include, but are not limited to, potential conflicts, number of handoffs, heading and speed differences, aircraft proximity to each other, sector boundaries, presence of severe weather, and traffic density (Kopardekar et al., 2009).

Maximizing the efficiency of the airspace system and providing a smooth and safe flow of traffic are the main objectives of Air Traffic Management (ATM). Effective airspace organization and management enhance the ability of the ATM service provider and airspace users and also increase ATM system safety, capacity and efficiency (ICAO, 2005). Therefore strategic and tactical planning of airspace is an important function to enable flight punctuality and efficiency by optimizing the network capacity through collaborative decision making process. The strategic planning for airspace management requires a long-term focus in order to produce a coordinated plan of demand and capacity for up to 18 months ahead. It consists of analyzing the evolution of the forecast demand and the identification of potential new problems and the evaluating possible solutions. The outputs of this process are the capacity and route allocation plans for the following year. The strategic planning of airspace is aimed at forecasting the need for capacity and at adjusting the demand in order to prevent strong imbalances with the available capacity (Eurocontrol, 2004).

The main purpose of this study is to explore the potential capacity problems of Turkish airspace and to propose some solutions which can be taken into account in the strategic planning process. In this study, Geographical Information Systems (GIS) are used as a tool for the measurement of controller workload in each sector, the monitoring of traffic distribution on waypoints, attaining its characteristics and also the analyzing all kinds of data. Escobar et al. (2005) indicate that GIS is considered as an important tool in planning and decision-making. GIS can also generate recommendations and solutions for the strategic planning of airspace.

In this framework, 1:2000000 scale en-route map of Turkish airspace containing sector boundaries, routes and waypoints is digitized and converted to the appropriate format with geographic coordinate assignment and then transferred to GIS environment. The real traffic data of Turkish airspace for two peak hours period in heavy traffic covering August 2007 was provided by the General Directorate of Turkish Airports (DHMI). This data contains the call signs, types, takeoff and departure points of the aircraft, the location of the fix points, and arrival time and flight level of the aircraft on these fixes. The data table prepared in Excel format is transferred to GIS environment. Geomedia 6.1 Professional GIS software was employed for the visualization of the real traffic data.
The analyses performed in this study are given below:

- Description of the general characteristics of Turkish airspace;
- Determining the traffic density in waypoints;
- Detection of the potential conflicts between aircraft; and
- Evaluation of sector densities according to the number of aircraft.

2. ANALYSING TURKISH AIRSPACE

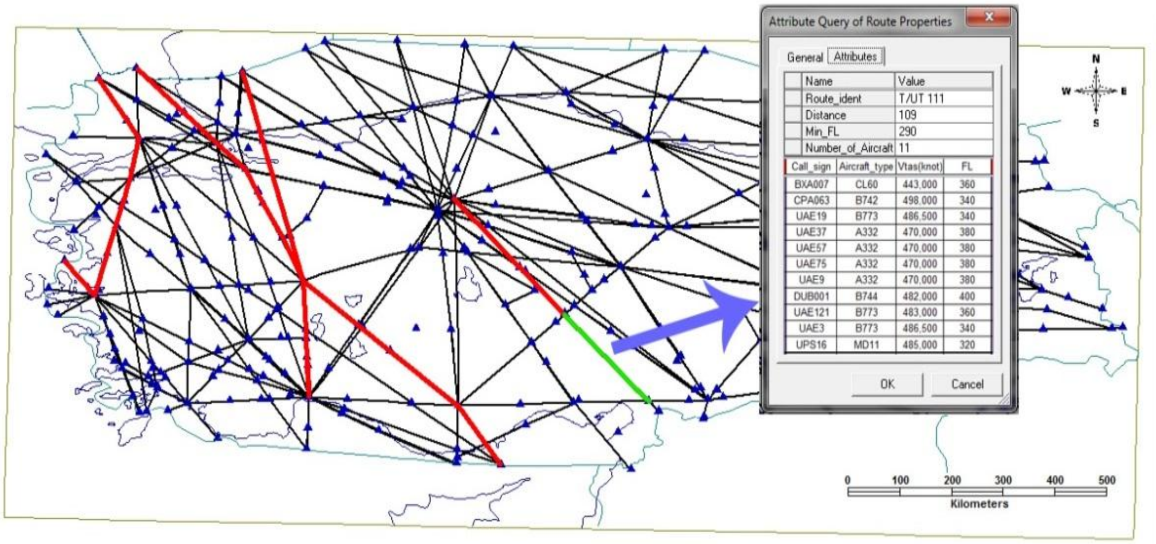
2.1. The Structure of Turkish Airspace

Turkey has a strategically important airspace with approximately 61 thousand kilometers of controlled air routes and one million square kilometers of controlled airspace over Europe and Asia continents. Due to its special geographical location, Turkish airspace includes crossroads with north-south and east-west traffic flows between Europe, Asia and the Middle East (DHMI, 2011). According to the DHMI statistics, annual aircraft traffic in Turkish Airspace increased more than twice between the years 2003 and 2013. This result shows that the growth rate of aircraft traffic in Turkey exceeds the average for other European countries.

In this study, air routes, boundaries of 6 sectors and 312 waypoints of which 64 are radio navigation aids, 100 reporting points and 148 fix are defined with their geographical coordinates into GIS environment. It is also determined that 296 aircraft fly in Turkish airspace in two peak hours. The data related to flight trajectories of 296 aircraft are prepared in Excel format. The flight data table which contains aircraft type and call sign, departure and destination points, air route and waypoint names, and flight level and time over each waypoint is loaded to the GIS for airspace analyses.

Figure 1 illustrates the waypoint locations and air routes of Turkish airspace. As depicted in this figure, it is possible to interrogate the features and the densities of any selected route (name, length, minimum flight level requested, number of aircraft flying on a route in two peak hours) and its traffic details (call sign, type, speed and flight level of aircraft). The routes witnessing relatively higher aircraft traffic (namely more than 10 aircraft in two hours) during peak periods are also designated in same figure with solid bold lines. As seen from this figure, the density of the traffic incoming from and outgoing to the north and the south directions is higher in the western part of Turkey. The speed of aircraft in accordance with the flight level was received from aircraft performance technical document – BADA (Nuic, 2004). The speeds for intermediate values of flight levels which did not feature in the document were calculated with interpolation method.

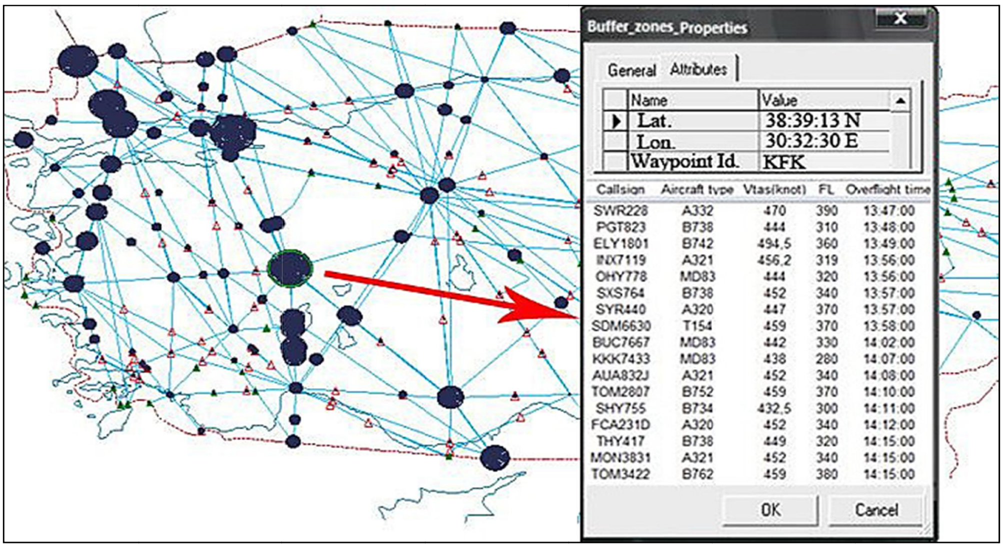
Figure 1: The location of Waypoints and Air routes in Turkish Airspace



2.2. Traffic Density in Waypoints

The controller performance and workload vary as a function of traffic density. As seen in Figure 2, the highest traffic density in Turkish airspace appears on the waypoints situated in western part of Turkey. Each flight is represented by a buffer in order to visualize the traffic density on each waypoint. The buffer diameter increases proportionally according to the number of aircraft passing through the waypoint. The name, the coordinates and the traffic statistics of a waypoint can be displayed on the screen by clicking on it. It is also possible to investigate the flight details of each aircraft flying over a waypoint. The number of aircraft, mix of aircraft, separation between aircraft, closing rates, aircraft speeds and flow restrictions influence the controller workload. In the waypoints having high traffic density, the complexity of traffic and the controller's mental operations in higher workload can increase the risk of aircraft conflict.

Figure 2: Traffic Density of Turkish Airspace in Two Peak Hours



2.3. Aircraft Conflicts

Controller workload is the main factor limiting en-route airspace capacity. As Albasman and Hu (2010) mentioned in their study, conflict prediction and avoidance is a critical and challenging task in air traffic management systems. The airspace management activities such as demand and capacity balancing and traffic synchronization obviously have a close connection to conflict management (ICAO, 2005).

Hilburn (2004) states that traffic density is not only an important driver of complexity, but also correlates well with conflict rate. In this framework, the protected zone for the conflicts in en-route airspace in Turkey is currently defined by Aeronautical Information Publication (DHMI, 2012) as a horizontally 10 NM and vertically 1,000 ft. Lindberg and Värbrand (2001), state that 8 NM separation during cruise translates into one minute. In this study, approximately one minute horizontal and 1000ft. vertical separations between aircraft are considered as potential conflict, and less than these separation values are taken into account as a conflict.

Different types of conflict identified by ICAO (2007) are as follows:

- Conflicts between aircraft on the same track and level (C1)
- Conflicts between aircraft on crossing tracks at the same level (C2)
- Conflicts between climbing or descending aircraft on the same track (C3)
- Conflicts between climbing or descending aircraft on crossing tracks (C4)
- Conflicts between climbing or descending aircraft on reciprocal track (C5)

The detected conflicts and potential conflicts in Turkish airspace during two peak hours are given in Table 1. As seen from the table, conflict between aircraft on the same track and level is the most encountered conflict type in two peak hours. The flight trajectories of different aircraft can be visualized by GIS in order to monitor potential aircraft proximities.

Table 1: The Number of Conflicts and Potential Conflicts

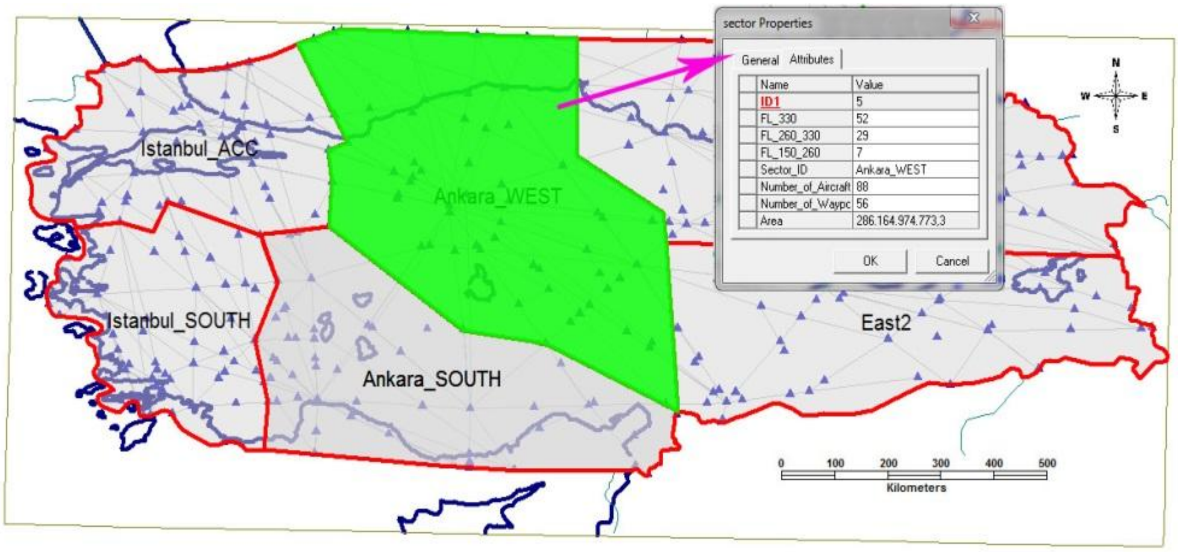
	Types of Conflict (Number of Event)					**Total**
	C_1	**C_2**	**C_3**	**C_4**	**C_5**	
Conflict	4	1	1	0	1	7
Potential Conflict	9	4	4	1	0	18

2.4. Traffic Density in Sectors

Air traffic control is currently based on sector structures. The airspace is divided into many sectors whose size depends on the average traffic volume and the geometry of air routes (Nguyen-Duc et al., 2008). Sectorization is the means of subdividing the totality of control tasks into manageable portions, at which throughput and capacity can be quantified. The classic method to overcome airspace limitations and controller workload is to provide more sectors. By either resizing or providing additional sectors, the airspace volume, the number of routes/crossing points and the number of aircraft can be reduced. This results in a reduction of workload and a corresponding increase in capacity (Eurocontrol, 2002).

As seen in Figure 3, Turkish Airspace was composed of 6 sectors horizontally and 11 sectors vertically in 2007. Sector properties such as the number of aircraft within different flight levels, sector area and the total number of waypoints can be displayed by clicking on the corresponding sector in GIS environment.

Figure 3: Sector Features of Ankara West



The number of aircraft and the number of traffic services provided according to the type of aircraft movement (such as heading change, speed change and flight level change) in each sector during one peak hour (26 August 2007, 14:00 to 15:00) are summarized in Table 2. As seen from the table, the sectors are also divided vertically to minimize controller workload by taking the sector densities into account. In this table, the following tasks are calculated in the same way as the study of Laudeman et al. (1998):

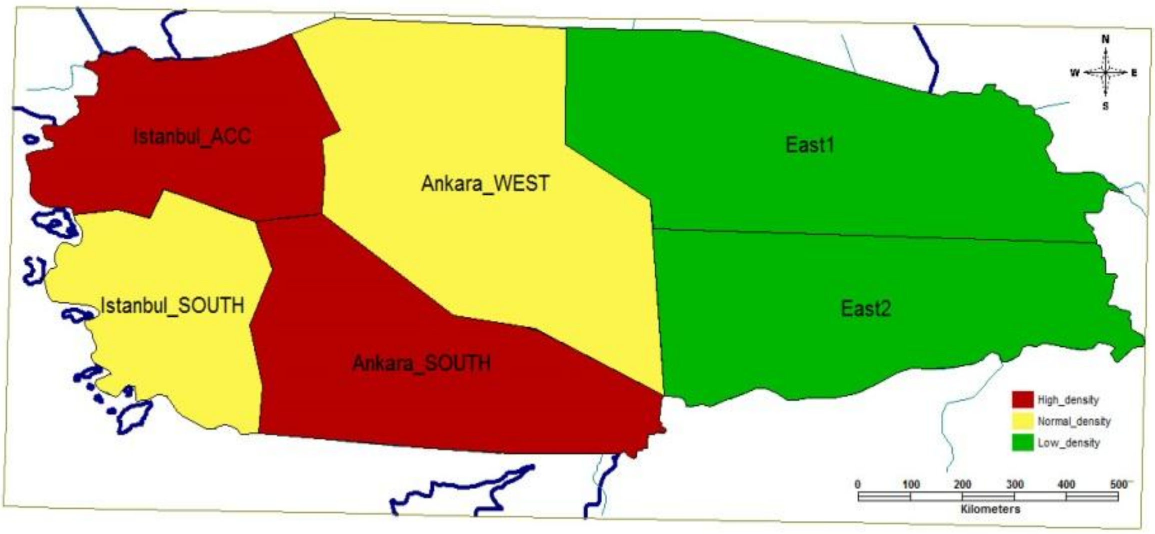
- Heading change: The number of aircraft that made a heading change greater than 15°.
- Speed change: The number of aircraft that had a computed air speed change greater than 10 knots.
- Flight level change: The number of aircraft that achieved an altitude change greater than 750 ft.

Eurocontrol (2010) argues that a controller can provide service for 40-60 aircraft per hour in heavy traffic. From this point of view, more than 40 aircraft in one hour per sector is assumed as "high traffic density". Whereas a density between 30 and 40 aircraft in one hour corresponds to "medium density" and finally less than 30 aircraft is accepted as "low density". Traffic densities of each sector are depicted in Figure 4. Ankara South and Istanbul ACC are the sectors which have high traffic densities in Turkish airspace. The results of the conflict analyses shows that 5 conflicts of 7 and 15 potential conflicts of 18 given in Table 2 are detected in these sectors. This situation confirms directly proportional relationship between the traffic density and the risk of aircraft conflict.

Table 2: Sector Densities in One Peak Hour

Sectors	Number of Aircraft	Number of Heading Change	Number of Speed Change	Number of Flight Level Change
Istanbul_ Upper	68	27	11	24
Istanbul_ Intermediate	42	27	20	31
Istanbul_ Lower	59	52	132	143
Istanbul_South_Upper	32	5	7	19
Istanbul_South_Lower	38	32	93	100
Ankara_West_Upper	39	24	1	6
Ankara_West_Lower	27	18	21	28
Ankara_South_Upper	43	34	0	5
Ankara_South_Lower	42	22	72	91
East_1	20	18	7	12
East_2	20	23	15	22

Figure 4: Traffic Densities of Sectors

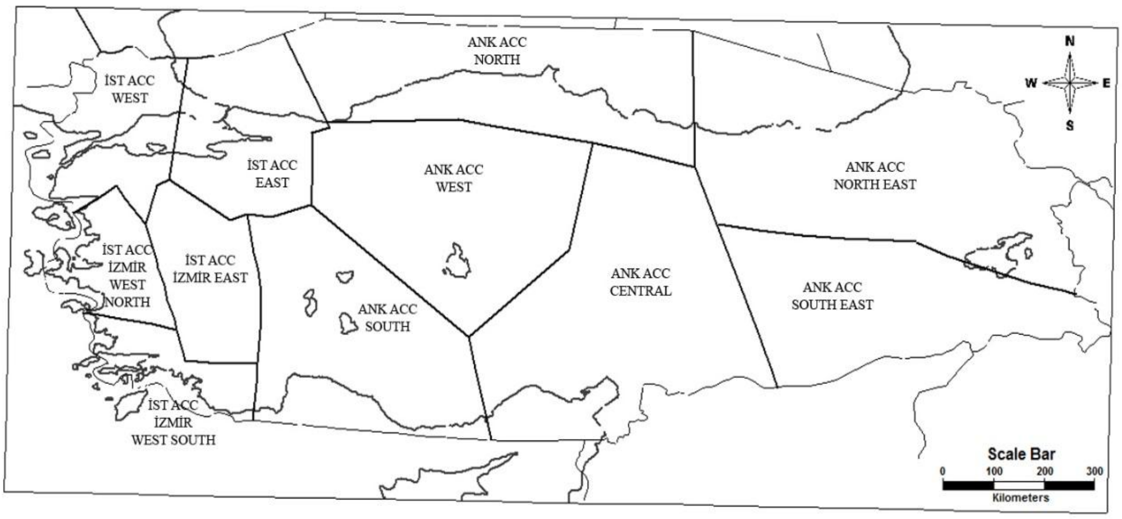


3. ANALYSIS RESULTS

From the results of the analysis, it is observed that the distribution of controller workload among sectors according to number of aircraft and types of aircraft movement is not balanced. According to the information received from the controllers working in Istanbul ACC, separations of aircraft coming from the upper or the lower sectors to intermediate level, causes the increase of the controller workload and airspace complexity in the intermediate sector. The allocation of related routes in single direction seems to be a solution of this problem. However, this solution proposed may decrease the traffic capacity of the sector. As such, this situation may require the restructuring of the horizontal and vertical sector boundaries of Turkish airspace.

According to the aircraft traffic statistics of DHMI between the years 2007 and 2013, it is found that the aircraft traffic in Turkish airspace growth approximately 60% in six years. Eurocontrol statistics released in 2012 indicate that Istanbul Ataturk-İzmir Adnan Menderes and İstanbul Ataturk-Antalya are the first and third busiest airport pairs respectively per number of daily flights in Europe. Assuming the sector structure of Turkish airspace does not change, it is seen that the sector capacities do not meet the existing and future demands. This inconvenience can be resolved by increasing the number of sectors, restructuring sector boundaries and by adding new routes to the existing airspace. Concordantly, the Turkish airspace was restructured in September 2010. The new sectors and the new routes were defined in the new airspace system. These sectors are especially opened in peak traffic periods. The new sector structure of Turkish airspace is illustrated in Figure 5.

Figure 5: The New Sector Structure of Turkish Airspace



The features of old and new airspace structures are also compared in Table 3. In the new sector structure while the number of upper and lower sectors have been augmented, the intermediate sectors are eliminated to decrease aircraft collusion risk and the controller coordination workload. Eurocontrol (2002) argues that the sub-division of sectors is a finite strategy. Furthermore, the increase of capacity is not proportional to the number of sectors available. The provision of additional sectors is the classic method of increasing capacity. Although scope still exists for this in most of many airspace, this is not always the most efficient method. Additional sectors are not always possible because of frequency shortage, increase in coordination workload among sectors, short transit times and complex network for lower airspace.

Table 3: Comparing Old and New Structures of Turkish Airspace

		Before 2010	After 2010
Number of Sectors	**Horizontal**	6	11
	Vertical	11	18
Number of Routes	**ATS**	67	82
	RNAV	44	78
Number of Waypoints		312	465

4. CONCLUSION

Since air traffic volume of airspace increased in the course of time, the problem of better utilizing airspace capacity was a growing concern. Balancing air traffic demand and airspace capacity is an actual and fundamental research problem for planning and design of airspace. The researchers focused on creating methods and algorithms that increase airspace capacity by redesigning airspace boundaries to reduce or redistribute controller workload and airspace complexity (Zelinski, 2008).

In this study, the airspace structure, the traffic density in the sectors and the potential capacity constraints of Turkish Airspace are analyzed according to 2007 results. A similar study can be performed by using 2013 statistics in order to investigate the performance of new sector structure and the distribution of controller workload in each sector of Turkish airspace. The controller task types should also be considered as well as number of aircraft while calculating of sector densities. In this framework, GIS can also be used for the determination of vertical and horizontal sector boundaries, human resource management and more effective route planning.

Recognition of deficiencies and optimization of assets will ensure maximum capacity through the balancing of operations against available assets. Earlier information of problems in critical areas will allow better co-ordination and management of the provision of en-route capacity and the use of the airspace (ICAO, 2005). In this framework, it is believed that this study will probably be a guide for strategic planning of Turkish Airspace which provides the solutions of existing and predicted problems.

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