FINAL REPORT

EXAMINING THE PILOT AND CONTROLLER PERFORMANCE DATA WHEN IN A FREE FLIGHT WITH WEATHER PHENOMENON

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PREFACE

This document reports the results of a project conducted by The Institute for Human-Machine Studies at North Carolina A&T State University under NASA Grant # NAG2-1469. Ms. Sandra C. Lozito served as the technical monitor. The goal of the research was to investigate the effect of weather conditions on pilots in free flight modes.

During the course of the research, many people have contributed immensely to its success. My gratitude goes to the staff and students of Aviation Management program at Guilford Technical Community College (GTCC), Greensboro, Nort Carolina. In particular, Mr. Ed Frye, the Administrator of GTTC Aviation Management program, and Mr. Thomas Freeman and Joe Badick, flight instructors at GTCC who served as the experts in evaluating the experimental flight plans and performance data. The GTCC student in the Civil Aviation program and the commercial pilots from American and United Airlines serving as flight instructors at GTCC deserved special accolade for putting extra burdens on their already busy schedules to participate in the lengthy experiments. From North Carolina A&T State University in Greensboro, my deep appreciation goes to Mr. Robert Halpin who was responsible for flight software integration for the study, and Mr. Kaize Adams for developing the protocols for the experiments. Mr. Halpin is a graduate student in the Department of Computer Science, and Mr. Kaize Adams is a graduate student in the Department of Industrial & Systems Engineering. For all the students from North Carolina A&T State University who served as non-pilots, I say thank you all.

ABSTRACT

The present study investigated effects of weather related factors on the performance of pilots under free flight. A weather scenario was defined by a combination of precipitation factors (light rain, moderate rain, and heavy rain or snow), visibility (1,4,8 miles), wind conditions (light, medium, or heavy), cloud ceiling (800ft. below, 1800ft above, and 4000ft horizontal). The performance of the aircraft self-separation was evaluated in terms of detection accuracy and detection times for student- and commercial (expert) pilots. Overall, the results obtained from a behavioral analysis showed that in general, the ability to recognize intruder aircraft conflict incidents, followed by the ability to acquire the spatial location of the intruder aircraft relative to ownership aircraft were judged to be the major cognitive tasks as perceived by the participants during self-separation. Further, the participants rarely used cockpit display of traffic information (CDTI) during conflict management related to aircraft separation, but used CDTI highly during decision-making tasks. In all weather scenarios, there were remarkable differences between expert and student pilots in detection times. In summary, weather scenarios were observed to affect intruder aircraft detection performance accuracies. There was interaction effects between weather Scenario-1 and Scenario-2 for climbing task data generated by both expert- and student-pilots at high traffic density. Scenario-3 weather condition provided an opportunity for poor detection accuracy as well as detection time increase. This may be attributed to low visibility. The intruder aircraft detection times were not affected by the weather conditions during climbing and descending tasks. The decision of pilots to fly into certain weather condition was dependent in part on the warning distance to the location of the weather. When pilots were warned of the weather conditions, they were more likely to fly their aircraft into it, but mostly when the warning was not close to the weather location.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE **PAGE**

LIST OF TABLES

TABLE PAGE

NOMENCLATURE

ADS-B	Automatic Dependent Surveillance - Broadcast
AHR:	Attittude Heading And Transporter
CDTI:	Cockpit Display of Traffic Information
CFIT	Controlled Flight Into Terrain
EADI	Electronic Attitude Director Indicator
EFIS:	Electronic Flight and Information System
EHSI	Electronic Horizontal Situation Indicator
ELT:	Emergency Locator Transporter
FAA:	Federal Aviation Administration
FAR:	Federal Aviation regulation
GPS:	Global positioning System
GTCC	Guilford Technical Community College
IFR:	Instrument Flight Rules
MLAS	Minimum Lateral Separation
MLOS:	Minimum Longitudinal Separation
MHD:	Minimum Height Difference
NSTB:	National Transportation Safety Board
PCE:	Plan Continuation Event
Proximity:	The closeness distance between intruder and ownership aircraft
ROW:	Right of Way
RTCA:	Radio Technical Committee on Aerospace
SA	Situation Awareness
TCAS	Traffic Conflict Alert System
TD:	Traffic Density
VFR:	Visual Fligt Rules

1. INTRODUCTION

1.1. Background

According to the Federal Aviation Administration (FAA) "the annual air traffic rate is expected to grow by 3 to 5 percent for at least the next 15 years, and the current airspace architecture and management will not be able to efficiently handle this increase" (http://asd.orlab.faa.gov/files//ff_ov.htm, 6/11/98). This increase places a huge load on the air traffic controllers. Consequently changes need to be made to the current air system. As a result, one solution that has been designed to accommodate the overabundance of air traffic is Free Flight.

Free Flight strives to move the current air traffic system in to an age where space technology is used to its fullest potential. Free Flight can be defined as "a safe and efficient flight operating capability under instrument flight rules (IFR) in which operators have the freedom to select their path and speed in real time" (http://www.businesswire.com/emk/1201-9.tx, 6/11/98). Free Flight only limits pilots' freedom in four general cases. Those cases are "to ensure separation, to preclude exceeding airport capacity, to prohibit unauthorized flight through special use airspace, and to ensure safety" (RTCA, 1995). Because Free Flight is designed to empower pilots with new responsibilities, it may relieve the air traffic controllers from the workload that is predicted to drastically increase in the near future.

The FAA's highest priority operational outcome is to improve safety. The FAA has defined a set of safety standards for spacing between multiple aircraft, aircraft and other physical structures, and aircraft and airspace. System safety from air traffic standpoint, is measured through the ability to maintain these standards. When aircraft violate these separation standards, an operational error occurs. Specifically, an operational error can occur when (a) Less than the applicable separation minimum results between two or more aircraft, or between an aircraft and terrain or obstacles, or (b) An aircraft lands or departs on a runway closed to aircraft operating after receiving Air Traffic Controller (ATC) authorization.

1.2. Aircraft Self-Separation

Self-separation is one part of the Free Flight concept. Self-separation provides pilots the opportunity to choose their own route to reach a specified destination provided that they maintain the minimum required separation distance between airplanes. The sufficient amount of separation distance between airplanes is 5 nautical miles laterally and 1000-2000 feet vertically in domestic enroute environment. Two airspace zones are designated to monitor this separation: protected zones and alert zones. The protected zone is the smaller zone of the two and the one closest to the ownship (the ownship refers to the aircraft in questioning). Under no circumstances can this zone be violated (no two protected zones can ever touch). It is based on distance, having a radius of one half the minimal horizontal separation required (2.5 nautical miles) and ± one half the minimal vertical separation required (± 500 or 1000 feet) (RTCA, 1995). The outer or larger zone is the alert zone. Unlike the protected zone, the aircraft's speed and performance determines its size. This zone is used to decide if intervention from the air traffic controller is necessary. It is based on a defined time window. "For a given look ahead time, the Alert Zone is the locus of all possible Protected Zones of the aircraft at a given time " (RTCA, 1995). This means that the Alert Zone makes the ownship aware of how close, with respect to time, it is intruding into the Protected Zone of any surrounding aircraft. The alert zone is also said to require the inclusion of human factors' parameters, such as detection time and decision time. Aircraft are allowed to freely maneuver until its alert zone touches another aircraft's alert zone.

In the event that aircraft alert zones do touch, air traffic controllers have the option of intervening in the situation to help the pilots maintain separation. This point is known as procedural intervention (Paielli & Erzberger, 1997; Palmer, Jago, & Dubord, 1980). Some cases in which procedural intervention may occur are: (a) the workload of the crew has become too overwhelming; (b) there is vital information that is known only to the controller and not to the pilots, or (c) the controller is uncertain of the decisions that the crew is making to resolve a conflict.

Several tools are already in place that will allow the concept of Free Flight to be used as early as today (Johnson, batiste, & Bochow, 1999; Kreifeldt, 1980). The Traffic Conflict and Alert System (TCAS), in its advanced state, and related cockpit displays of traffic information (CDTI) can be used to help operators maintain self-separation. Global Positioning System (GPS) may also be used to determine more accurate locations of surrounding aircraft. When GPS is used in conjunction with ADS-B (Automatic Dependent Surveillance- Broadcast), location of aircraft can be achieved more rapidly (Zeitlin, Hammer, Cieplak, and Olmos, 1998). It is also important to know that only certain aircraft may be used for self-separation in the near term. There may be several requirements for display characteristics (e.g. display size) that may prevent the use of CDTI technology for self-separation in the near-term (Palmer, jago, Balty, & O'Connor, 1980).

1.3. Weather Phenomenon

Weather related accidents are major problems in aviation safety. For example, studies in Controlled Flight Into Terrain (CFIT) have consistently mention weather as the main factor (Bud, Hannon, Mengert, Ramsom, & Stearns, 1997; Driskill, et al., 1997). CFIT accidents occur when an aircraft, under complete control of the pilot and crew, is unintentionally flown into the ground, with the majority of the incidents occurring during low visibility (Wickens, Helleberg, & Xu, 1999). Clearly, loss of situation awareness and poor perceptual control of intended actions in the terrain is a major factor arising from weather phenomenon (Cashion & Lozito, 1999; Lozito, et al., 1997; O'Hare & Smitheram,1995).

Weather conditions can affect the capacity of a destination airport and pilot performance in several ways (Pritchett & Hansman, 1997; Wiggins, Martinussen, & Hunter, 1999). Low visibility due to clouds or fog can limit the ability of arriving pilots to see other aircraft and to see the runway environment. Thunderstorms can greatly reduce or stop arrivals to an airport, since aircraft cannot safely fly near thunderstorms. Snow or ice on the runway surface can also increase spacing that is required between arriving aircraft because of the reduced effectiveness of aircraft brakes and longer landing roll.

Previous research in free flight environment have investigated the effect of traffic density in aircraft self-separation with emphasis on convergence angles in traffic conflicts (Lozito, McGann, Mackintosh, & Cashion, 1997; Mackintosh, et al., 1998, Castano & Parasuraman, 1999). The impact of weather conditions on free flight needs to be examined. This is the major thrust of this research.

Recently, Wiegmenn, Goh, & O'Hare (2002) have investigated the role of situation awareness (SA) on pilots' decision to fly into adverse weather. Results revealed pilots who receive pre-warning on weather will continue to fly into adverse weather if the information was received far away from the location of the weather condition. Peterson & Uhlarik (1999) and Kreifdelt (1980) observed that even with CDTI supports, pilots are likely to be using distance as a cue for making decision about whether to fly into weather of change a course of action from original flight plan. A study by Sharma, Pfister, & Heath (1999) show how perception of risk by pilots influences their decision to fly aircraft into adverse weather. The study indicated the reluctant by pilots to use automation when deciding to change flight plans due to incremental weather. Those pilots who changed their flight plan do so if the perceive aircraft separation very tight.

Depending on the visibility conditions, the pilot can either use visual flying rules (VFRs) or instrument flying rules (IFRs). VFRs are rules that govern the procedures for conducting flight under visual meteorological conditions (VMC). Requirements for visual conditions are normally 3-5 miles of visibility and a 1000 foot cloud ceiling. IFRs are rules that govern the procedures for conducting flight under instrument meteorological conditions (IMC). IMC are meteorological conditions defined by visibility, distance from the clouds, and ceiling less than the minima specified for VMC. Pilots operating in IMC must comply with IFR, which require the filing of a flight plan, and ATC normally provides air traffic separation directives. Pilots may operate under IFR when flying in VMC condition. However, ATC will separate only those aircraft complying with IFR. Normally, VFR aircrafts provide their own separation, and IFR aircraft have the responsibility to see and avoid VFR aircraft (RTCA, 1995).The primary responsibility of air traffic controllers is to ensure that a safe separation distance is maintained between all IFR aircraft under their control (Krozel & Peters, 1997).

Goh & Wiegmann (2001a, 2001b) noted that VFR flight into IMC is often characterized by the pilot's decision to continue a flight into adverse weather conditions despite warnings from ATC. This behavior is termed a plan continuation event (PCE) by Orasanu, Martin, & Davison (2001). PCE related fatalities have been documented in aviation studies (Burian, Orasanu, & Hitt, 2000; Goh & Wiegmann, 2001b; McCoy & Mikumas, 2000; NTSB,1989; O'Hare & Smitheram, 1995).

1.4. Project Objective and Scope

Although aircraft self-separation may prove to be a logical solution to some of the problems in the current airways operation, there still may be instances when pilots have difficulty with this task (Cashion, et al, 1997). Pilots may find their aircraft in a threatening position. They may be intruding into the airspace of surrounding aircraft, thereby not maintaining the sufficient amount of separation distance between airplanes. One of the problems associated with this situation is the effect of weather on the pilot's flight planning and envisioning process. The major objective of this research is to investigate the pilot performance when in a free flight environment with simulated weather conditions. The problems examined and analyzed are:

1. Aircraft separation procedure: What will pilots do when they need to separate their aircraft from traffic and weather events.
2. Functionality of aircraft separation: Will free flight self-separation be practical with weather events in the airspace?
3. Separation risk: Will pilots take more risks flying into the weather under free flight decision making?
4. Usability of cockpit display aid: Will pilots use cockpit display traffic information (CDTI) features differently if they need to consider weather and traffic?
5. Automation utility: How useful are the conflict probes given that they do not consider weather events in the algorithms (decision aiding automation)?

2. METHOD

2.1. Participants

Twenty- three participants took part in the experiment. They consisted of:

- Four (4) Commercial pilots at GTCC: This group had total flying time between 456 – 1185 hours, with a mean of 719.85 hours. The expert group had three flight instructors and a former military fighter pilot with commercial license. The age ranged from 27 to 43 with an average age of the expert pilots (EXPERT) 37.55 years.
- Seven (7) student pilots at GTCC . The students have some flight training and were familiar with computer-based flight simulators. The student age ranged from 19 to 24 with an average age of the student pilots (SP) was 23.13 years.
- Twelve (12) non-pilots (NP). This group were graduate and undergraduate students from North Carolina A&T State University. The NP group had no flight experience, except, in some cases, playing games with Microsoft Flight Simulation Software. The age range was 17.5 to 26 with an average age of 21.64 years.

The participants were paid as follows: \$20.5/hour for commercial pilots, \$9.0/hour for student pilots; and \$7.5/hour for non-pilots selected from the student body at North Carolina A&T State University and Guilford Technical Community College (GTCC). The participants were paid full compensation only after completing the experiment as stipulated in the agreement.

2.1. Flight Simulator

The Professional version of Microsoft Flight Simulator 2000 was used to reconfigure Canadair 415 flight simulator located at GTCC. The Professional Edition software includes various aircraft with instrument panels, virtual cockpits, and exterior 3D models. Figure 1 shows a photographic rendering of the Canadair 415 cockpit system. The two-pilot flight deck is fitted with a Honeywell EDZ-605 EFIS electronic flight and information system and dual air data computers. The instrument panels have a three-tube Integrated Instrument Display System and an electronic attitude director indicator (EADI) and electronic horizontal situation indicator (EHSI). The cockpit is fitted with a Litef/Honeywell attitude heading reference system (AHRS) and a Honeywell radio altimeter. The communications systems include a Global multiband radio communications set covering VHF/UHF/AM/FM bands, Rockwell Collins HF radios with two transponders and an emergency locator transponder (ELT).

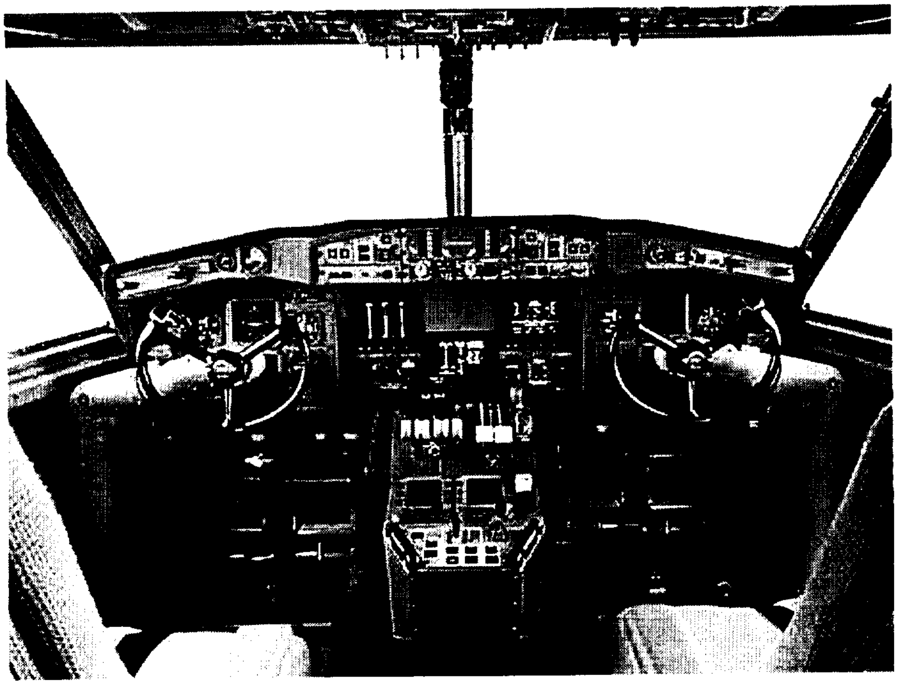

Figure 1. A photographic rendering of Canadair 415 cockpit system.

The weather system provided by the software dramatically improves the variety of weather as a user flies and the effects they see like clouds, precipitation, lightning, and more. This is very helpful in adding various complexities to the flight. Sound files were recorded and used in conjunction with the three scenarios to provide Air Traffic Control (ATC) commands and instructions. The Black Box application runs in conjunction with Flight Simulator 2000. It enables the user to record variables simultaneously, such as, airspeed, altitude, and heading in 10 second intervals. Figure 2 gives an illustration of a reconfigured cockpit with sample weather in the horizon. The basic hardware requirement consists of: (a) Two computer monitors: One monitor displays the terrain and weather while the second monitor displays the aircraft functionalities. This setup permits the experimenter to have a full control of the environment such as changing tasks, flight parameters and so on, (b) Input device: this consist of a Gameport joystick and keyboard; and (c) sound output device for communication with ATC.

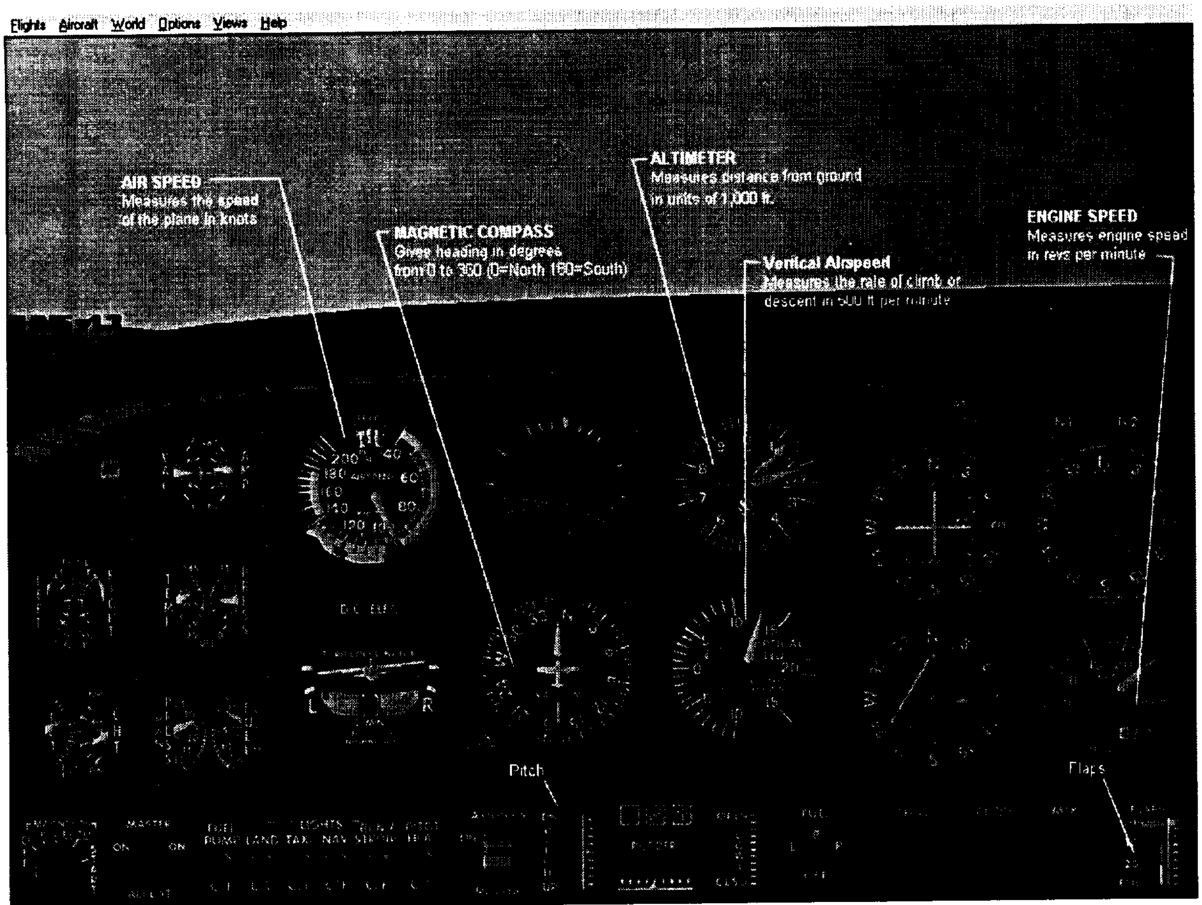

Figure 2. Candair 415 airplane cockpit display rendering with sample weather in the horizon.

2.3 Procedure

The experiment was divided into six sections:

(1) Introduction: In the introduction phase, the experimenter explained the purpose of the study and the risk involved. Prior to full participation, the participants were asked to read and sign a consent form. The participation of student pilots was required for GTCC class, other participants were voluntary.

(2) Training: In this phase, the subjects were introduced to the concept of Free Flight, aircraft separation procedures, cockpit layout, instruments, weather conditions, and displays. Only the relevance cockpit instruments needed for the flying tasks were elaborated. The subjects also learn to use the joystick for navigation. The non-pilot subjects were introduced to Instrument Flight Rules (IFR) and Visual Flight Rules (VFR), and conditions that mitigate instrument meteorological conditions (IMC). All participants were also briefed on flight plans before actual flight.

(3) Preliminary Learning of Flight Task Scenarios: In this phase, the subjects were allowed to fly in any of the scenarios while practicing aircraft separation tasks. The practice lasted 40 minutes for non-pilots, 25 minutes for student pilots, and 10 minutes for commercial (expert) pilots.

(4) Audio Comprehension Test: This test was a part of training to ascertain how the subjects understood ATC call sign commands and procedures called in by voice. All participants used in the experiment passed the audio test.
(5) Actual Flight Experiments: Each subject was supervised to perform a total of 96 tests (4 trials under two traffic densities, two proximity of intruder aircraft, two tasks (climb or descent), and three weather scenarios). Each experimental trial was set at 10 minutes each, resulting in 16 hours per participant. In each flight scenario, the participants performed either a descending (approach to land) or climbing task. Conflict aircraft were fixed at an acute angle of 45 degrees based on the previous studies which indicate higher conflict detection and separation performance (Cashion & Lozito, 1999). During the experiments, the participants (owner aircraft) had the maneuvering responsibility according VFR right-of –way (ROW) rule. This rule stipulates that the conflict aircraft is on the right according to Federal Aviation Regulation (FAR) 91.113. Each participant used 2.5 hours per day with 5 minutes rest interval between trials.
(6) At the end of each test, the subjects were asked to provide after-fact debrief by filling out scenario experience questionnaire (SEQ) (Appendix A).

2.4. Weather Scenario Configuration

The sample weather configuration with flight task representing scenarios is shown in Table 1. Three primary scenarios based on cloud ceiling, precipitation, wind conditions, and visibility were tested. These scenarios are shown in Table 2.

Table 1: Sample Weather Conditions

Cloud ceiling	Precipitation	Wind	Visibility	Traffic density	Intruder aircraft proximity	Flying task
800 ft	Light rain	Wind gust = low	8 miles	(low, high)	(near, far)	(descend, climb)
1800ft	Moderate rain	Wind gust = moderate	4miles	(low, high)	(near, far)	descend, climb)
4000ft	Rain with snow	Wind gust = high	1 mile	(low, high)	(near, far)	descend, climb)

2.5. Task

Each participant was asked to fly under free flight with the preset weather scenarios. They were told that they are responsible for monitoring the status of the aircraft display for situation awareness and that they are free to contact ATC anytime during the flight. The flight instructors at GTCC served as ATC personnel. The participants were told that within the same altitude, there would be some aircrafts (intruders) that may or may not fly closer to their (ownership) aircraft. If this should occur, they were to try to separate aircraft from that of the intruder.

Table 2: Experimental Test Scenarios

Test Scenario	Information Elements
Scenario-1	Scenario-1 Data Cloud ceiling = 800 ft Precipitation = light rain Wind gust = low Visibility = 8 miles
Scenario-2	Scenario-2 Data Cloud ceiling = 1800 ft Precipitation = moderate rain Wind gust = moderate Visibility = 4 miles
Scenario-3	Cloud ceiling = 4000 ft Precipitation = rain + snow Wind gust = high Visibility = 1 mile

They were also told that within a weather scenario, the traffic density could vary between 2-6 intruder aircraft (low TD) or between 7-12 intruder aircraft (high TD); the intruder proximity (Proximity) to the ownership aircraft can vary between 1-3 miles (near proximity) or between 4-8 miles (far proximity). As a part of flight plan, the participants were to be informed of weather conditions by ATC as follows: pre-warning of weather locations: (a) close to weather location (1-4 miles), moderate closeness to weather location (4-6 miles), and far from weather location (6-10 miles), and random weather occurrence without warning.

After getting clearance from ATC, subjects took-off and climbed to the cruise altitude of 4000 feet. The subjects were allowed to cruise for approximately 3-5 minutes. At the end of the cruise, the aircraft was programmed to generate a weather scenario, traffic density in the airspace, and the conditions requiring the participants to conduct aircraft separation tasks. The experimenter set and controlled 52 weather pre-warning and 24 random weather occurrences during the experimental cycle of a participant. Before each new trial, the air traffic was cleared and the flight plan re-initialized. The ATC used radio announcement with cockpit enunciator to broadcast separation risk and weather when necessary.

3. EXPERIMENTAL DESIGN AND RESULTS

3.1. Dependent and Independent Measures

The independent measure consisted of the weather scenarios as defined in Table 2. Each weather scenario was crossed with two levels of traffic density (the number of other aircrafts in the altitude as the ownership aircraft), two levels of intruder aircraft proximity, and two flying tasks. The effect of flight experience was also an independent variable. The dependent variables of interest were percentage detection accuracy of intruding aircraft, conflict detection time, and the frequency the participants flew into adverse weather with and without pre-warning. All participants took part in all experimental conditions resulting in within-subject experiment.

3.2. Task 1: Aircraft separation procedure: What will pilots and controllers do when they need to separate aircraft from traffic and weather events.

3.2.1 Approach

In order to answer the above question, a set of questionnaires was designed to gather information on the protocols used by the participants when faced with aircraft separation tasks. In this study, an attempt was made to delineate behaviors that can be quantified and those that cannot. Skinner (1953) observed that behavior is difficult to compute, not because it is inaccessible, but because it is extremely complex. "It is a process, rather than a thing, cannot be held still for observation (p.15)". The major premise for using a behavior model is that people exhibit certain behavior tendencies in expectation of some reward (Blanford, 1993). An example is risk avoidance behavior associated with imminent collision of two aircraft, a typical incident due to self-separation task (Edwards, 1977). It is a great advantage to suppose that the probability that a response will occur ranges continuously between all or some causes. If we know what causes pilots to behave in a certain way, by discovering and analyzing these causes, we can predict behavior and to the extent that we can manipulate such behaviors to improve design.

Pilots can exhibit one or several behavioral tendencies. For example, behavior can be intentional or goal-directed, reactive as in responding to information cues or stimuli, reflexive, as in an instant or automatic response to situations (Schneider & Schriffin, 1977); and enactive, as governed by procedures and rules such as given in FAR 91.113 or FAA-S-8081-14 (1995), available at http://afts600.faa.gov/data/practicalteststandard/faa-s-8081-14.pdf. A pilot can practice all or some of the behaviors during an aircraft self-separation task. One of the several ways to represent information about these behavior schemes is by schema. A schema is compiled of selected pieces of behaviors; typically in a ranked priority order according to some attributes, such as, the saliency of information, level of perceived risk, and the urgency or criticality of incidents (Scholl, 1987).

The following schema were identified to represent the pilot and controller task behaviors during aircraft self-separation tasks:

Recognition Schema: This schema represents the ability of agents (pilots and ATC operators) to recognize conflict incidents. Such incidents as identified by priority by the participants in the study are:

- Converging headings.
- Aircraft in the same altitude.
- Speed differences between the owner and intruder aircraft.
- Ability to predict or guess the relative position of the intruder aircraft relative to the ownership aircraft.

Spatio-temporal Schema: This schema represents the judgment of space and time with respect to ownership and intruder aircrafts. The cardinality consist of

- Positions
- Altitudes.
- Trajectories.
- Time

Aircraft position can be determined by the minimum lateral separation (MLAS), minimum height difference (MHD), and minimum longitudinal separation (MLOS). The minimum lateral separation is when the intruder aircraft is at the opposite direction traffic within the same route; MHD occurs when aircraft are at different flight levels in different directions in the same airspace; and, MLAS is the distance between consecutive aircraft at the same flight level on the same route, but the faster aircraft can overtake slower one subject to adequate MLAS and MHD.

Conflict Reconciliation Schema: This schema represents the pilot and ATC conflict management behaviors, and is a function of many task attributes, including but not limited to,

- Space available for vectoring.
- Available altitudes.
- Aircraft type and capabilities.
- Proximity of the aircraft.
- Distance of the aircraft to its destination.

Decision Schema: This represents the decision-making behavior of the pilot and ATC under risk and time constraint. Some components of this behavioral schema are:

- Determining intruder's pilot intent.
- Negotiating for airspace right of way.
- Closing angles.
- Planning and deciding on diversion of aircraft.
- Dead reckoning.
- Seeking advise from ATC or aircraft automation aid.

3.2.2. Data Collection and Results

A self-report questionnaire was administered to each of the participants at the end of the flying tasks. The first part of the questionnaire (Appendix A) was used to determine the participant' perception of cognitive tasks related to aircraft self-separation. The participants were asked to rate the knowledge content of the tasks according to its: Important (3), Relevance (2), and Concern (1). **The question asked was: During the aircraft self-separation, rate the following cognitive tasks by its importance, relevance, or concern as it pertains to task performance:**

(a). Recognition of conflict incidents.
(b). Knowledge of intruding aircraft.
(c). Conflict reconciliation between intruder aircraft and ownership aircraft.
(d). Intruder pilot intent.

The total weight for each cognitive variable was obtained by multiplying the number of respondents by the weights of the semantic attribute scores. Table 3 gives the result by the category of participants. Figure 3 shows the percent plot of the results.

Table 3: Subjective Rated Scores of Cognitive Tasks As Perceived By Participants During Aircraft Separation Tasks

Participant	Recognize	Knowledge	Reconcile	Intent
Expert (4)	4*2=8 (*)	4*3=12	4*1=4	4*1=4
Student Pilot (7)	4*3=12	4*2=8	3*1=3	1*1=1
Non-Student pilot (12)	8*3=24	10*2=20	6*1=6	5*1=5
Total Score	44	40	13	9

(*): # of Respondents * Score

As shown in Table 3, having the spatial knowledge of the intruding aircraft was more important to the expert pilot, while the ability to recognize the intruding aircraft was rated relevance. Both the intent of the intruding pilot and conflict reconciliation were viewed as only a concern to the expert pilot, but not worrisome to impact task performance. The novices (student and non-student) pilots on the other hand indicated that the ability to recognize conflict incidents was more important, while the spatial knowledge of the intruding aircraft was deemed relevance. As with the expert pilots, conflict reconciliation and the intent of the intruder pilot were deemed as only a concern. Figure 3 shows the merit scores for all participants. In general, the ability to recognize the conflict incidents, followed by the ability to acquire the spatial location of the intruder aircraft relative to ownership aircraft were judged to be the major cognitive tasks as perceived by the participants during aircraft self-separation.

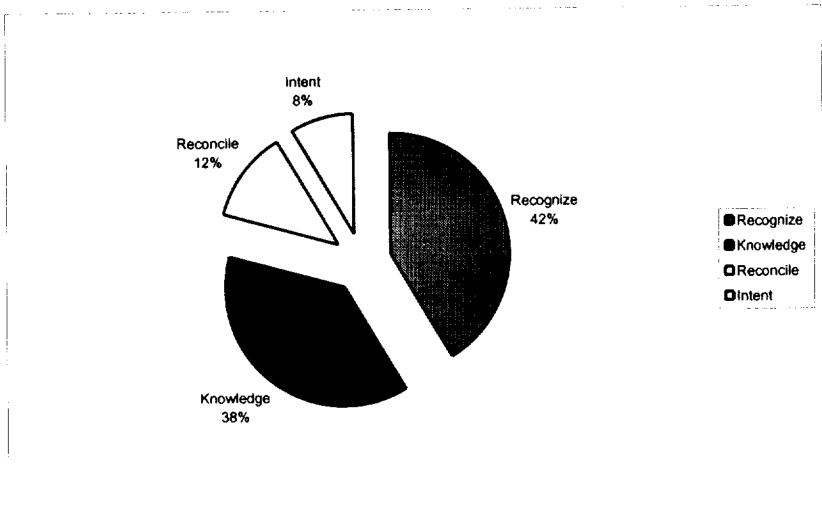

Figure 3: Percentage plot of participants' perception of cognitive tasks in aircraft self-separation.

3.2.2.1. Rating Incident Recognition And The Utility of CDTI

Table 4 shows the percentage ratings of the participants' ability to recognize conflict incidents using the available cognitive resources.

Table 4: Percentage Utilization of Resources By Participants During Conflict Incident Recognizing Task

Participants	ATC	CDTI	SELF
Expert	8.5	33.6	57.9
Student Pilot	51.3	34.3	14.4
Non-Student Pilot	66.5	26.4	7.1

Figure 4 illustrates these subjective perception scores. As shown in Figure 4, the experts tend to rely on their mental models in recognizing conflict incidents and are less likely to consult the ATC. However, they tended to use the CDTI as an assistant for situation awareness. The novice pilots were more likely to consult the ATC operators for conflict recognition tasks, used CDTI for information search and discovery, and were less likely to recognize aircraft conflicts without some support.

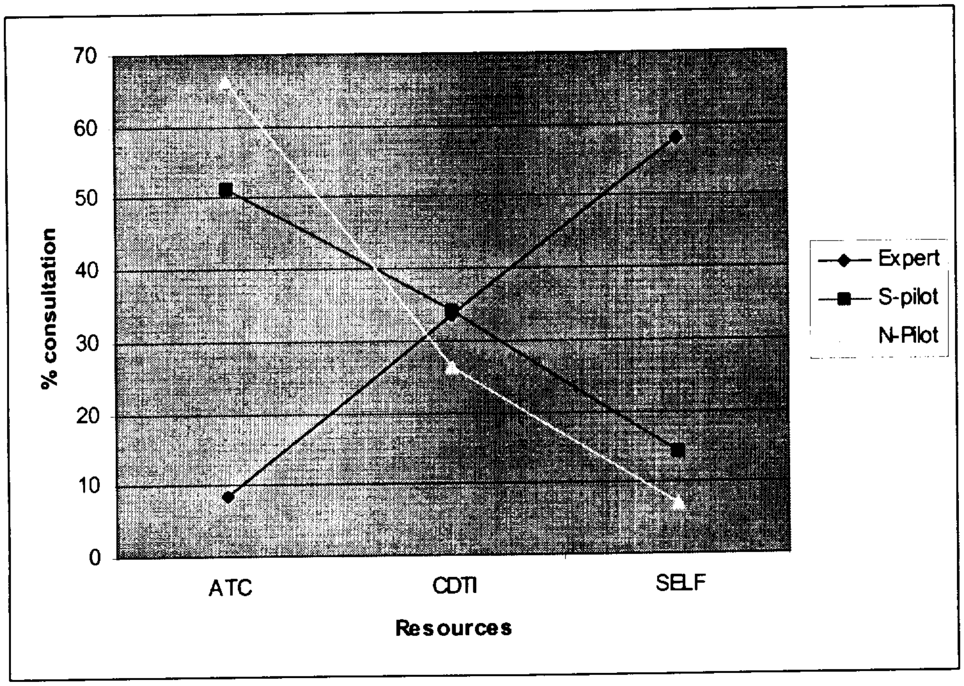

Figure 4. A graphical display showing the mean rating scores of participants' use of cognitive resources for conflict recognition tasks.

A meta-analysis was conducted on the recognition schem... to determine which tasks were most important to the participants. Figure 5 shows the response by the participants.

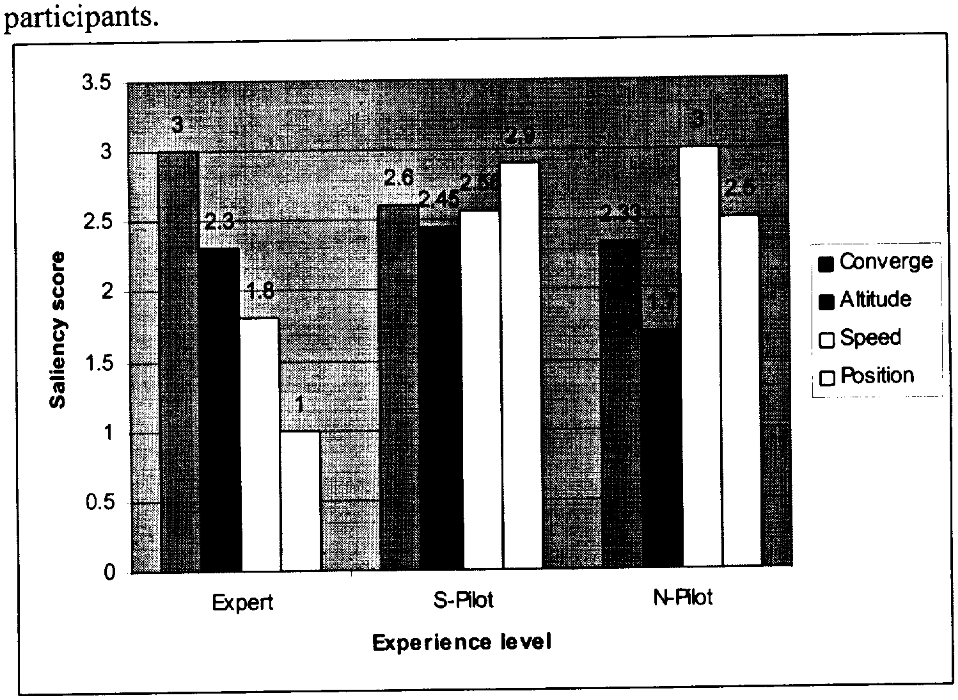

Figure 5. Mean saliency scores of recognition tasks as perceived by the participants.

As shown in Figure5, the expert pilots were more concerned with the possibility of collision (convergence) of ownership and intruder aircraft (all 4 pilots score the maximum of 3 points). The position and speed of the aircraft were not concerns to the expert pilots. The student pilots were concerned with the position of their aircraft, followed by the possibility of their convergences. Both speed and altitude were scored between concerned and importance. The non-pilot participants were worried about the speed of the intruder aircraft and less worried about the altitude. The intruder aircraft position and converging headings were also concerns.

3.2.2.2. Rating of Spatio-Temporal Tasks With Respect To Resources Used

Table 5 shows the percentage ratings of the participants' ability to judge events in space and time using the available cognitive resources.

Table 5: Percentage Utilization of Resources By Participants During Spatio-Temporal Judgment Tasks

Participants	ATC	CDTI	SELF
Expert	5.3	45.6	50.9
Student Pilot	39.3	40.2	20.5
Non-Student Pilot	80.5	14.7	4.8

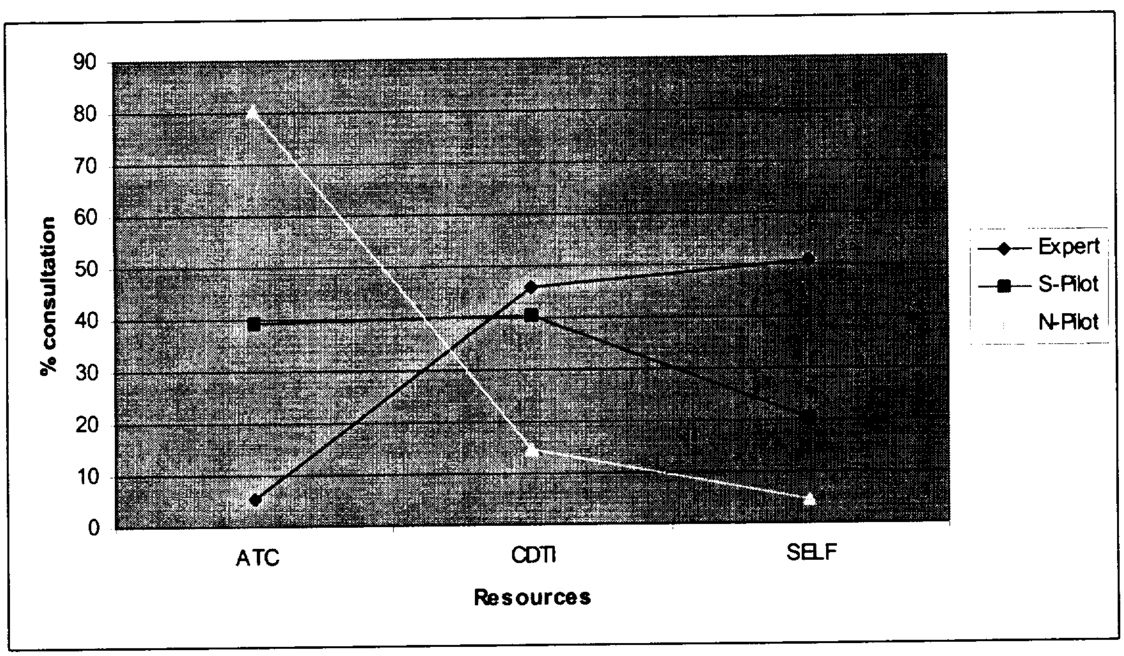

Figure 6. A graphical display of mean rating scores of the participants' use of cognitive resources during spatio-temporal judgment tasks.

Figure 6 illustrates these subjective perception scores. As shown in Figure 6, the expert pilots tended to rely on their mental models during spatial task executions and were less likely to consult the ATC. However, they tended to use the CDTI as an assistant for situation awareness support. The student pilots tended to split their dependency on both the ATC and CDTI. The non-pilots showed high dependency on the ATC for spatial and navigation task executions (about 80.5 % of the time).

A meta-analysis was conducted on the spatial memory tasks to determine which tasks were more important to the participants. Figure 7 shows the response by the participants. As shown in Figure 7, the expert pilots were more concerned with altitude and trajectory maneuvering than the position and time of the aircrafts. The student pilot showed high concern on the relative position of the intruder aircraft, and some concern on the spatial tasks. The non-pilot participants were worried about the position, speed, and trajectories of the intruder aircraft and some concern about the altitude.

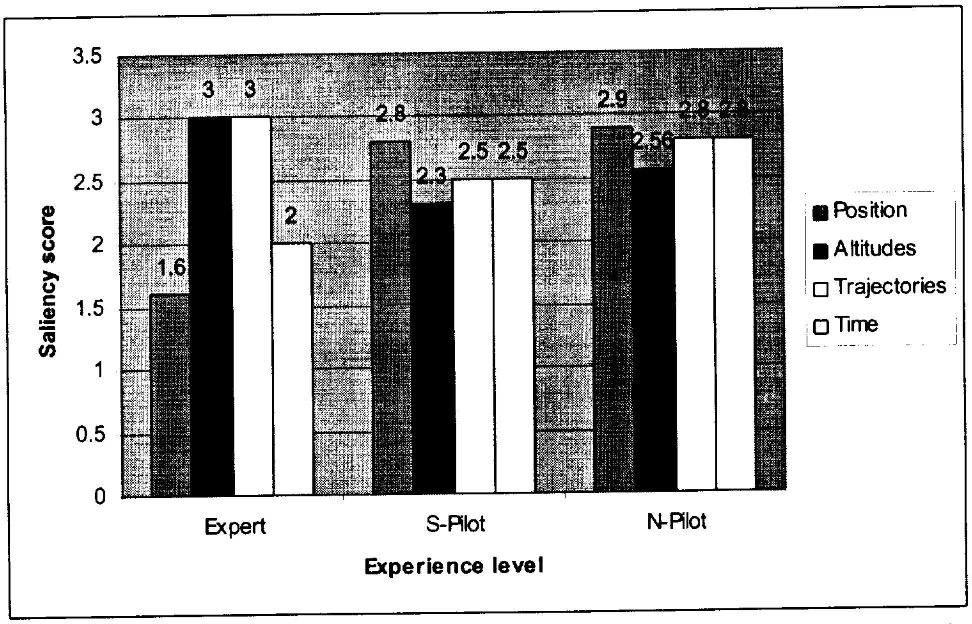

Figure 7. Mean saliency scores of spatio-temporal judgment task as perceived by the participants

3.2.2.3. Rating of Conflict Reconciliation Schema

Table 6 shows the percentage ratings of the participants' ability to resolve conflicts using the available cognitive resources.

Table 6: Percentage Utilization of Resources by Participants During Conflict Reconciliation Tasks

Participants	ATC	CDTI	SELF
Expert	20.1	10.3	69.6
Student Pilot	64.7	3.8	31.5
Non-Student Pilot	96.4	0	3.6

Figure 8 illustrates these subjective perception scores. As shown in Figure 8, the expert pilots tended to rely on their personal knowledge to conflict management with the intruder pilots (69.6%); and 20.1% of the time, the expert pilot were likely to contact ATC for help. The student pilot depended on ATC about 65% of the time, rarely used the CDTI, and 32% of the time, they depended on personal conflict management skills. The non-pilots depended almost entirely on ATC. The results showed that the participants rarely used CDTI during conflict management related to aircraft separation.

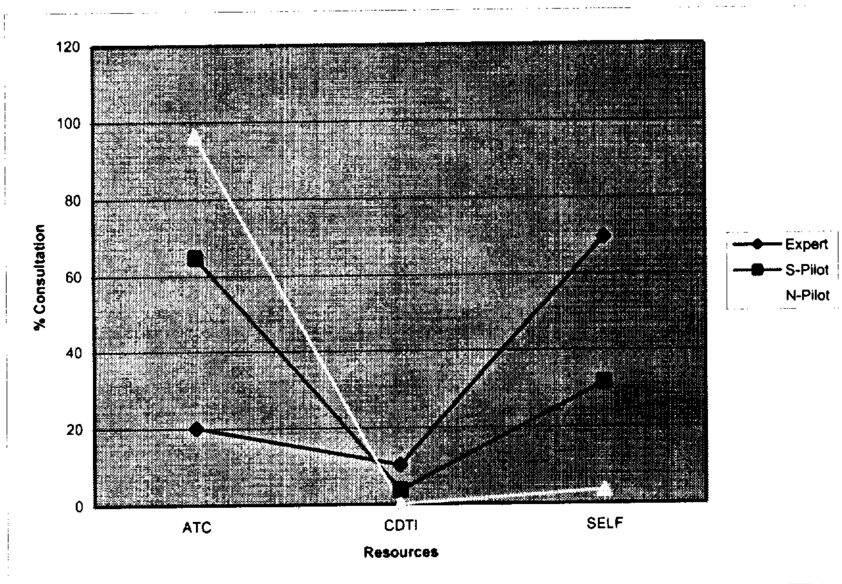

Figure 8. A graphical display of mean rating scores on participants use of cognitive resources for conflict resolution tasks.

A meta-analysis was conducted on the conflict management schema tasks to determine which tasks were more important to the participants. Figure 9 shows the response by the participants.

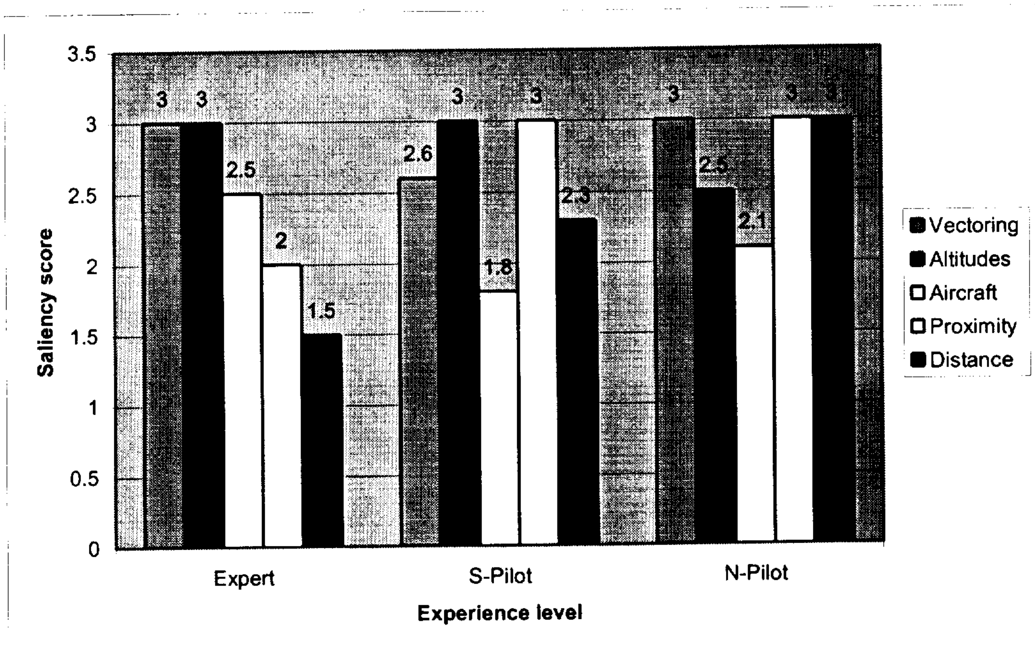

Figure 9 . Mean saliency scores of conflict management tasks as perceived by the participants.

As shown in Figure 9, the expert pilots were more concerned with altitude and vectoring; aircraft type was a high concern, and aircraft proximity was a concern. The distance between intruder and ownership aircraft was somehow worrisome to the expert pilot. The student pilots indicated absolute important to altitude availability and proximity of the aircrafts, high concerns for distance and vectoring, and little worrisome on aircraft type and capabilities. The non-student pilots showed absolute important to vectoring, proximity, and distance between the aircraft. Concern was also indicated for aircraft type and capabilities.

3.2.2.4. Rating of Decision Schema

Table 7 shows the percentage ratings of the participants' decision-making during risk as induced by adverse weather and/or aircraft convergence.

Table 7: Percentage Utilization of Resources by Participants During Decision-making Tasks.

Participants	ATC	CDTI	SELF
Expert	5.3	40.7	54.0
Student Pilot	28.5	53.1	18.4
Non-Student Pilot	45.7	48.2	6.1

Figure 10 illustrates these subjective perception scores. As shown in Figure 10, the experts tended to rely on their mental models (54%) and on CDTI (40.7%) in decision-making behaviors. The expert pilots interaction with ATC was very low (5.3%). The student pilot depended on CDTI about half the time (53.1%) and about one quarter of the time on ATC (28.5%), and depended on personal judgments about 18.4% of the time. The non-pilots depended almost equally on CDTI (48.2%) and ATC (45.7%) with 6.1% on personal judgment. The results showed that the participants use CDTI highly during decision-making tasks.

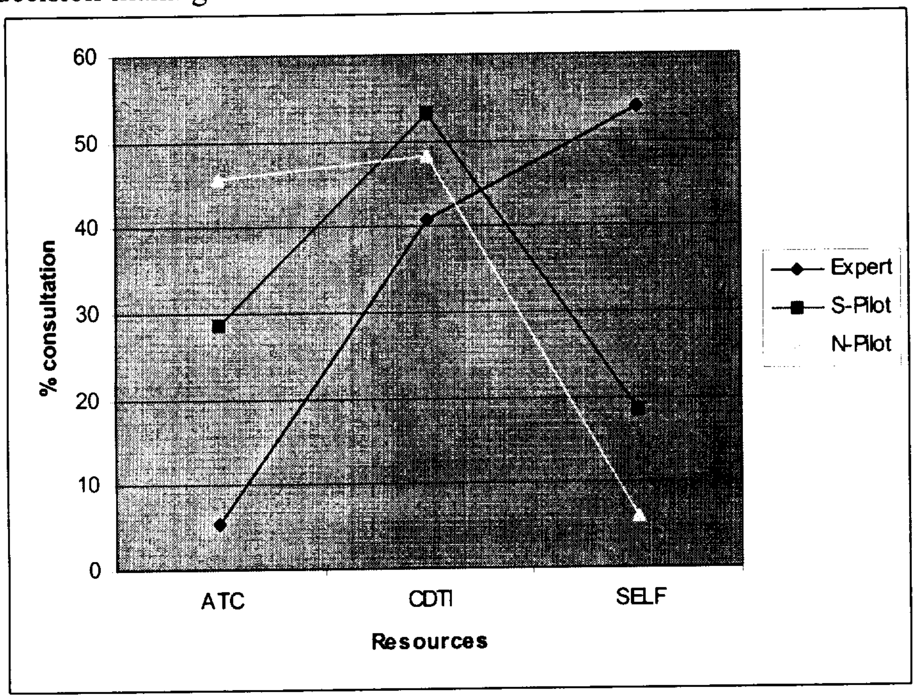

Figure 10. A graphical display of mean rating scores of participants use of cognitive resources during decision-making tasks.

A meta-analysis was conducted on the conflict management schema tasks to determine which was more important to the participants. Figure 11 shows the response by the participants.

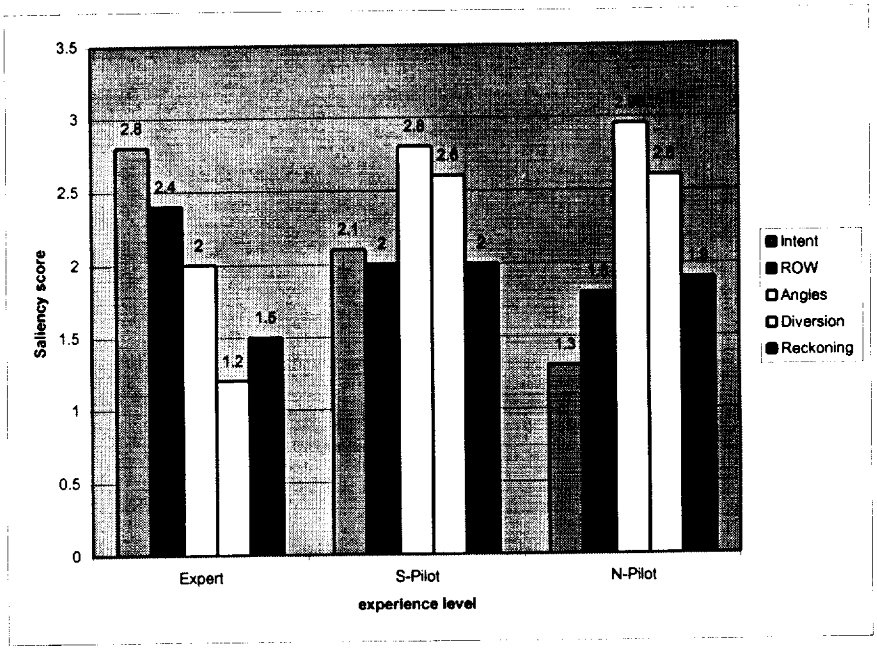

Figure 11. Mean saliency scores of decision-making tasks as perceived by the participants.

As shown in Figure11, the expert pilots were more concerned with interpreting the intruder pilot intent; as well as negotiating for airspace right of way (ROW); they also showed concerns on closing angles and above worrisome scores for dead reckoning and diversion of aircraft. The student pilots indicated high concern on closing separation angles and aircraft diversion, and concern on intruder pilot intent, right of way, and dead reckoning. The non-student pilots showed high concern on closing angles and aircraft diversion; slight concern on right of way and dead reckoning tasks, and some worry on dealing with intruder pilot intent.

3.3. Task 2: Functionality of aircraft separation: Will free flight separation be practical with weather events in the airspace?

3.3.1. Analysis of Conflict Detection Accuracy Data

The flight data for conflict detection performance on each weather scenario was summarized as shown by means and standard deviations on Tables 8-10. From now on, non-pilot data will not be used for further analysis. The intent is to only compare participants with some flight experience with commercial pilots. The data was used as a control to compare behavioral variables in Task1 only.

Table 8: Mean and Standard Deviation Summary of Percentage Accuracy for Scenario-1

	Traffic Density							
	Low				High			
	Near Proximity		Far Proximity		Near Proximity		Far Proximity	
Experience	Climb	Descend	Climb	Descend	Climb	Descend	Climb	Descend
Pilots	97.84 (1.26)	98.29 (1.46)	98.75 (1.33)	99.2 (2.0)	97.31 (1.64)	97.20 (1.29)	95.40 (1.99)	94.8 (1.61)
Student Pilots	78.42 (3.85)	80.92 (4.21)	81.26 (2.34)	84.37 (2.92)	65.21 (6.0)	63.42 (3.64)	67.3 (4.19)	66.91 (2.36)
Non Pilots	60.3 (7.51)	68.2 (6.24)	63.8 (7.93)	67.79 (8.41)	59.30 (9.45)	56.35 (6.90)	63.41 (10.15)	60.18 (7.16)

(mean, std.)

Table 9: Mean and Standard Deviation Summary of Percentage Accuracy for Scenario-2

	Traffic Density							
	Low				High			
	Near Proximity		Far Proximity		Near Proximity		Far Proximity	
Experience	Climb	Descend	Climb	Descend	Climb	Descend	Climb	Descend
Pilots	97.54 (2.61)	95.16 (1.52)	98.61 (1.84)	97.3 (2.66)	95.66 (1.97)	95.24 (2.64)	94.64 (1.99)	96.21 (2.64)
Student Pilots	71.38 (4.02)	75.2 (5.68)	73.69 (5.13)	72.11 (6.02)	63.46 (4.16)	61.24 (4.92)	68.11 (5.130)	63.89 (3.75)
Non Pilots	62.22 (5.21)	63.19 (4.67)	60.22 (5.68)	56.29 (7.14)	55.24 (3.20)	52.10 (4.29)	60.33 (5.74)	56.24 (9.34)

(mean, std.)

Table 10: Mean and Standard Deviation Summary of Percentage Accuracy for Scenario-3

	Traffic Density							
	Low				High			
	Near Proximity		Far Proximity		Near Proximity		Far Proximity	
Experience	Climb	Descend	Climb	Descend	Climb	Descend	Climb	Descend
Pilots	92.70 (1.66)	94.96 (2.41)	93.25 (1.09)	96.33 (1.24)	94.39 (2.61)	92.64 (1.68)	96.48 (2.63)	95.53 (1.97)
Student Pilots	68.71 (3.84)	72.33 (5.11)	71.40 (6.00)	70.89 (5.08)	60.32 (3.89)	56.24 (7.24)	56.82 (6.14)	59.37 (6.41)
Non Pilots	43.18 (10.42)	40.66 (12.51)	41.44 (7.41)	45.91 (10.88)	36.24 (5.62)	38.92 (11.24)	40.15 (11.96)	40.83 (8.24)

(mean, std.)

3.3.1.1. Effect of Weather Conditions on Percentage Detection Accuracy

3.3.1.1.1. Scenario-Based Performance Differences

The null hypotheses investigated for each weather scenario are as follows:

H_{01}: Both the commercial (Expert) and student pilots will perform equally in mean percentage detection accuracies.
$H_{02:}$ The levels of traffic density will not affect percentage detection accuracies.
$H_{03:}$ The proximity levels of the ownership and intruder aircraft will not affect percentage detection accuracies.
$H_{04:}$ There are no mean differences between percentage detection accuracies during climbing or descending tasks

A four-way within-subject, 2X2X2X2 ANOVA technique was used to analyze the data. The data were analyzed with the SAS software package (Dilorio, 1991).

Results for Scenario-1
The result of ANOVA is shown in Table 11. The experience levels of the pilots were ($F(1,48)=5.04$, $p<0.001$); Traffic density was significant ($F(1,48) = 11.59$, $p<0.028$); Proximity of aircraft was significant ($F(1,48) = 13.1$; $p<0.001$). There were also some interaction effects: Experience level of pilots and traffic density ($F(1,48) = 5.89$; $p<0.049$); Experience level of the pilots and proximity of the aircrafts ($F(1,48) = 4.958$; $p<0.0036$); traffic density and proximity of the aircrafts ($F(1,48) = 9.48$; $p<0.001$); Experience levels of the pilots, traffic density, and proximity ($F(1,48) = 5.37$; $p<0.0060$; Traffic density, proximity, and the flying tasks ($F(1,48) = 4.73$; $p<0.0037$).

Table 11: ANOVA Results for Scenario-1 Based on Analysis of Percentage Detection Accuracy Data ($F(1,48; \alpha = 0.05) = 4.08$)

Source	DF	SS	MS	F value	Pr>F
Experience (E)	1	9.04	9.04	5.04	0.001
TD	1	21.34	21.34	11.9	0.028
Proximity	1	23.51	23.51	13.1	0.001
Task	1	2.938	2.938	1.85	0.049
E*TD	1	10.57	10.57	5.89	0.001
E*Proximity	1	4.958	4.958	4.958	0.0036
E*Task	1	3.163	3.163	1.764	0.193
TD*Proximity	1	16.979	16.979	9.48	0.001
TD*Task	1	6.473	6.473	3.59	0.38
Proximity*Task	1	3.781	3.781	2.109	0.08
E*TD*Proximity	1	9.63	9.63	5.37	0.006
E*TD*Task	1	1.508	1.508	0.841	0.169
TD*Proximity*Task	1	8.48	8.48	4.73	0.037
E*TD*Proximity*Task	1	3.478	3.478	1.94	0.26
Error	**48**	**86.064**	**1.793**		
Total	62	211.912			

Results for Scenario-2
The result of ANOVA for scenario-2 is shown in Table 12. The experience levels of the pilots were significant ($F(1,48)=4.51$, $p<0.0001$); Traffic density was significant

(F (1,48) = 4.19; p <0.035). There were also some interaction effects: Level of experience of pilots and traffic density (F (1,48) = 5.33; p<0.001); Experience level of the pilots and proximity of the aircrafts (F (1,48) = 4.81; p<0.021); traffic density and proximity of the aircrafts (F (1,48) = 4.26; p<0.0001); Experience levels of the pilots, traffic density, and proximity (F (1,48) = 4.68; p<0. 001; Traffic density, proximity, and the flying tasks (F (1,48) = 5.18; p<0. 0219).

Results for Scenario-3

The result of ANOVA for scenario-2 is shown in Table 13. The experience levels of the pilots were significant (F (1,48)=4.18, p <0.001); Traffic density was significant (F (1,48) = 4.52; p <0.008). There were also some interaction effects: Level of experience of pilots and traffic density (F (1,48) = 4.26; p<0.007); Experience level of the pilots and proximity of the aircrafts (F (1,48) = 5.69; p<0.001); traffic density and proximity of the aircrafts (F (1,48) = 4.19; p<0.06); Experience levels of the pilots, traffic density, and proximity (F (1,48) = 5.11; p<0. 001; Traffic density, proximity, and the flying tasks (F (1,48) = 4.27; p<0. 016); and interaction between all four levels of the main effect (F (1,48) = 4.18; p<0. 041).

3.3.1.1.2. Analysis of Effects of Weather Scenarios

The null hypothesis investigated is that there are no statistical significant differences in percentage detection accuracy between the weather scenarios.

Table 12: ANOVA Results for Scenario-2 Based on Analysis of Percentage Detection Accuracy Data (F (1,48; α = 0.05) =4.08)

Source	DF	SS	MS	F value	Pr>F
Experience (E)	1	9.74	9.74	4.51	0.0001
TD	1	9.05	9.05	4.19	0.035
Proximity	1	1.885	1.885	0.873	0.0292
Task	1	6.631	6.631	3.07	0.291
E*TD	1	11.51	11.51	5.33	0.001
E*Proximity	1	10.39	10.39	4.81	0.021
E*Task	1	4.26	4.26	1.97	0.073
TD*Proximity	1	9.2	9.2	4.26	0.0001
TD*Task	1	4.99	4.99	2.31	0.48
Proximity*Task	1	2.922	2.922	1.35	0.173
E*TD*Proximity	1	21.816	21.816	4.68	0.001
E*TD*Task	1	1.348	1.348	0.624	0.186
TD*Proximity*Task	1	11.59	11.59	5.18	0.0219
E*TD*Proximit y*Task	1	5.58	5.58	2.63	0.001
Error	**48**	**103.68**	**2.16**		
Total	62	214.692			

Table 13: ANOVA Results for Scenario-3 Based on Analysis of Percentage Detection Accuracy Data (F (1,48; α = 0.05) =4.08)

Source	DF	SS	MS	F value	Pr>F
Experience (E)	1	9.841	9.841	4.18	0.001
TD	1	10.622	10.622	4.52	0.008
Proximity	1	7.56	7.56	3.21	0.033
Task	1	4.311	4.311	1.83	0.26
E*TD	1	10.04	10.04	4.26	0.007
E*Proximity	1	13.41	13.41	5.69	0.001
E*Task	1	8.552	8.552	3.63	0.029
TD*Proximity	1	9.872	9.872	4.19	0.006
TD*Task	1	1.571	1.571	0.667	0.083
Proximity*Task	1	6.22	6.22	2.64	0.37
E*TD*Proximity	1	12.04	12.04	5.11	0.001
E*TD*Task	1	4.453	4.453	1.89	0.216
TD*Proximity*Task	1	10.06	10.06	4.27	0.016
E*TD*Proximity* Task	1	9.848	9.848	4.18	0.041
Error	**48**	**113.09**	**2.356**		
Total	62	231.49			

The data was analyzed with ANOVA with task data (climbing and descending) blocked since earlier analysis indicated that weather did not show any significant effect on flying tasks. The result was significant leading to the rejection of the null hypothesis (F(2,144) = 23.81; p , 0.0001) > 19.5 (F(2,144; α = 0.05). For climbing task, there were interactions between Scenario-1 and Scenarion-2 using the expert data as observed at two traffic densities (see Figure 12). There was no obvious interaction for descending task under the same conditions (Figure 13). Scenario-3 showed degrading performance in all conditions.

For the student pilots, there was significant interaction between Scenario-1 and Scenario-2 for climbing task under high traffic density (Figure 14). No obvious interactions were observed descending task (Figure 15). Again, Scenarion-3 showed the worst performance.

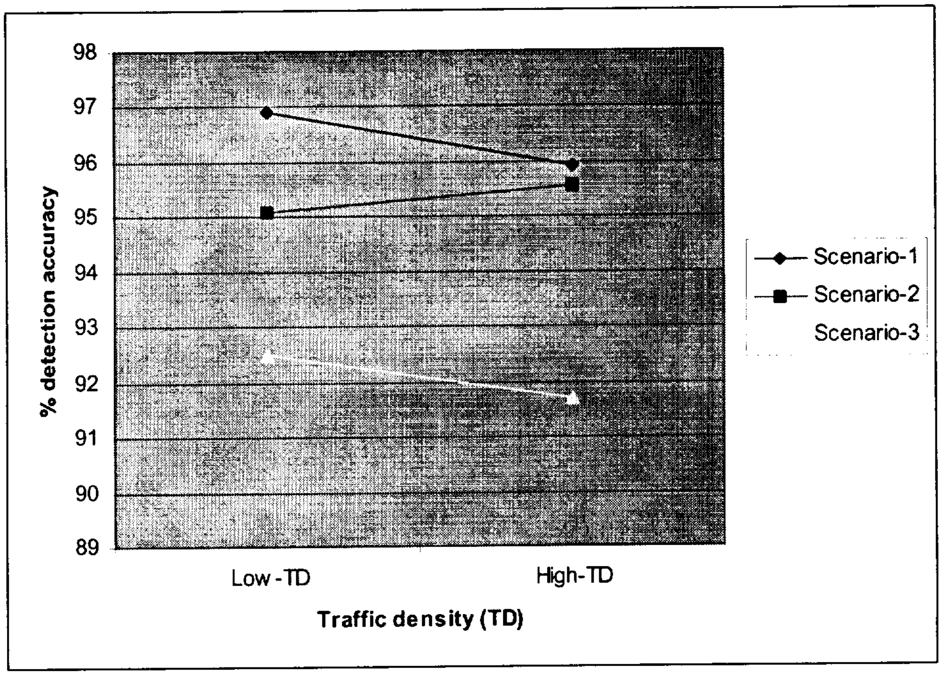

Figure 12. Mean percentage detection accuracy by expert pilots on climbing task.

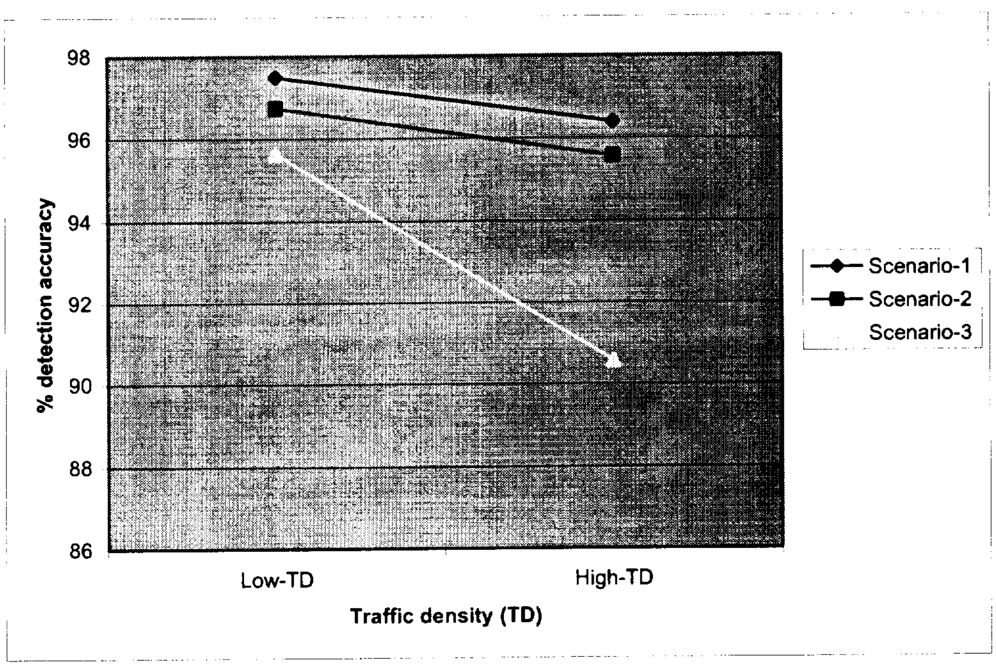

Figure 13. Mean percentage detection accuracy by expert pilots on descending task.

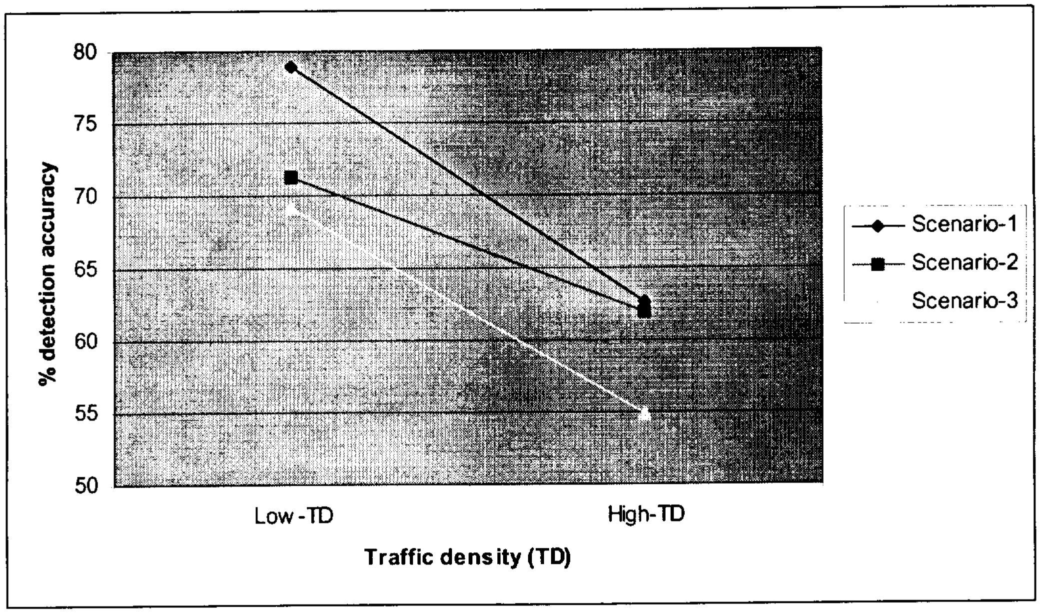

Figure 14. Mean percentage detection accuracy by student pilots on climbing task.

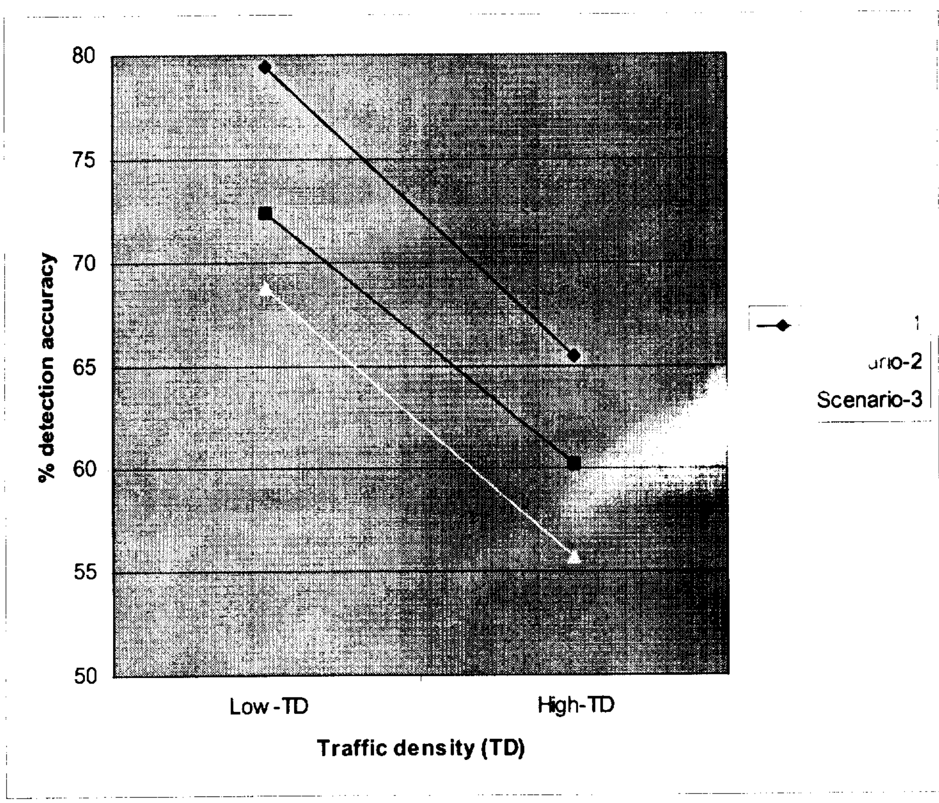

Figure 15. Mean percentage detection accuracy by student pilots on climbing task.

3.3.2. Analysis of Conflict Detection Time Data

The flight data for conflict detection time in each scenario was summarized as shown by means and standard deviations on Tables 14-16.

Table14. Mean and Standard Deviation Summary of Detection time for Scenario-1

	Traffic Density							
	Low				High			
	Near Proximity		Far Proximity		Near Proximity		Far Proximity	
Experience	Climb	Descend	Climb	Descend	Climb	Descend	Climb	Descend
Pilots	110.6 (6.24)	96.24 (8.29)	98.64 (6.67)	119.2 (6.92)	116.29 (5.62)	121.41 (11.49)	106.34 (15.14)	101.43 (9.21)
Student Pilots	136.54 (10.94)	128.33 (15.66)	133.21 (19.24)	120.4 (10.65)	138.62 (18.24)	136.24 (21.24)	120.66 (20.09)	130.92 (18.42)
Non Pilots	138.6 (11.62)	124.93 (20.44)	136.4 (21.39)	110.41 (6.9)	140.36 (12.35)	13866 (14.25)	136.21 (28.6)	133.7 (21.31)

(mean, std

Table15: Mean and Standard Deviation Summary of Percentage Accuracy for Scenario-2

	Traffic Density							
	Low				High			
	Near Proximity		Far Proximity		Near Proximity		Far Proximity	
Experience	Climb	Descend	Climb	Descend	Climb	Descend	Climb	Descend
Pilots	121.66 (4.6)	104.62 98.24)	108.1 (6.33)	120.36 (5.89)	136.45 (6.24)	138.11 (9.33)	123.6 (6.42)	128.43 (12.62)
Student Pilots	139.21 (11.45)	140.91 (8.01)	137.45 (7.45)	135.63 (12.31)	140.33 (6.240	139.01 (8.39)	142.33 (10.14)	136.84 (5.36)
Non Pilots	143.24 (7.38)	145.6 (6.41)	139.33 (8.24)	139.8 (7.31)	146.24 (8.09)	140.80 (7.02)	148.22 (6.19)	138.3 (4.22)

(mean, std.)

Table16: Mean and Standard Deviation Summary Detection Time for Scenario-3

	Traffic Density							
	Low				High			
	Near Proximity		Far Proximity		Near Proximity		Far Proximity	
Experience	Climb	Descend	Climb	Descend	Climb	Descend	Climb	Descend
Pilots	128.51 (10.42)	126.67 (15.30	128.6 (9.2)	136.4 (13.6)	140.32 (10.25)	143.1 (9.66)	138.6 (10.62)	140.25 (13.1)
Student Pilots	148.25 (9.26)	143.64 (11.27)	140.66 (13.1)	139.21 (8.04)	143.89 (12.13)	146.24 (11.42)	148.36 (8.33)	141.9 (7.62)
Non Pilots	154.41 (20.36)	150.69 (24.9)	149.71 (11.36)	145.66 (18.4)	156.31 (21.45)	158.14 (16.24)	151.36 (21.64)	148.62 (9.55)

(mean, std.)

3.3.2.1. Effect of Weather Conditions on Conflict Detection Time

3.3.2.1.1. Scenario-Based Performance Differences

The null hypotheses investigated for each weather Scenario are as follows:

H_{01}: The mean conflict detection times are the same for both the commercial (Expert) and student pilots
$H_{02:}$ There are no statistical differences in mean conflict detection times for tasks performed in low or high traffic density conditions.
$H_{03:}$ The proximity levels of the ownership and intruder aircraft have no effect on mean conflict detection times.
$H_{04:}$ There are no mean differences in mean conflict detection times during climbing or descending tasks

Results for Scenario-1

The result of ANOVA for Scenario-1 is shown in Table 17. The experience levels of the pilots were significant (F (1,48)=6.27, p <0.0001); Traffic density was significant (F (1,48) = 4.18; p <0.0021). There were some interaction effects: Level of experience of pilots and traffic density (F (1,48) = 6.58; p<0.0019); Level of experience of pilots and tasks (F (1,48) = 4.29; p<0.006);traffic density and proximity of the aircrafts (F (1,48) = 4.83; p<0.01); Experience levels of the pilots, traffic density, and proximity (F (1,48) = 4.36 p<0. 0001; Traffic density, proximity, and the flying tasks (F (1,48) = 4.83; p < 0. 001).

Table 17: ANOVA for Scenario-1 Conflict Detection Time

Source	DF	SS	MS	F value	Pr>F
Experience (E)	1	11.744	11.744	6.27	0.0001
TD	1	7.829	7.829	4.418	0.0021
Proximity	1	6.986	6.986	3.73	0.167
Task	1	3.58	3.58	1.91	0.235
E*TD	1	12.32	12.32	6.58	0.0019
E*Proximity	1	4.945	4.945	2.64	0.096
E*Task	1	8.04	8.04	4.29	0.006
TD*Proximity	1	9.05	9.05	4.83	0.001
TD*Task	1	3.901	3.901	2.104	0.367
Proximity*Task	1	6.799	6.799	3.63	0.001
E*TD*Proximity	1	8.167	8.167	4.36	0.0001
E*TD*Task	1	5.638	5.638	3.01	0.341
TD*Proximity*Task	1	9.05	9.05	4.83	0.001
E*TD*Proximity*Task	1	6.874	6.874	3.67	0.075
Error	48	89.904	1.873		
Total	62	194.827			

Results for Scenario-2

The result of ANOVA for Scenario-2 is shown in Table 18. The experience levels of the pilots were significant (F (1,48)=5.66, p <0.001); Traffic density was significant (F (1,48) = 4.81; p <0.037). The proximity of intruder and ownership aircraft was significant

(F (1,48) = 4.37; p <0.043 There were also some interaction effects: Level of experience of pilots and traffic density (F (1,48) = 4.29; p<0.001); Experience level of the pilots and proximity of the aircrafts (F (1,48) = 5.38; p<0.051); traffic density and proximity of the aircrafts (F (1,48) = 4.36; p<0.01); type of task and proximity of intruder aircraft (F(1,48) = 6.13;p = 0.0001); Experience levels of the pilots, traffic density, and proximity (F (1,48) = 4.72 p<0. 01; Experience levels of the pilots, traffic density, and task (F (1,48) = 5.23 p<0. 047);Traffic density, proximity, and the flying tasks (F (1,48) = 4.167; p<0. 024); and interaction between all four levels of the main effect (F (1,48) = 4.38; p<0. 006).

Results for Scenario-3

The result of ANOVA for Scenario-3 is shown in Table 19. The experience levels of the pilots were significant (F (1,48)=4.39, p <0.0413); Traffic density was significant (F (1,48) = 4.26; p <0.051). The proximity of intruder and ownership aircraft was significant (F (1,48) = 4.62; p <0.037. The proximity of intruder and ownership aircraft was significant (F (1,48) = 4.62; p <0.037. There were also some interaction effects: Level of experience of pilots and traffic density (F (1,48) = 4.834; p<0.039; Experience level of the pilots and proximity of the aircrafts (F (1,48) = 4.68; p<0.0001);

Table 18: ANOVA for Scenario-2 Conflict Detection Time

Source	DF	SS	MS	F value	Pr>F
Experience (E)	1	12.1	12.1	5.66	0.001
TD	1	10.284	10.284	4.81	0.037
Proximity	1	9.343	9.343	4.37	0.043
Task	1	6.094	6.094	2.85	0.169
E*TD	1	9.172	9.172	4.29	0.001
E*Proximity	1	11.502	11.502	5.38	0.051
E*Task	1	3.763	3.763	1.76	0.33
TD*Proximity	1	9.32	9.32	4.36	0.001
TD*Task	1	4.04	4.04	1.89	0.395
Proximity*Task	1	13.11	13.11	6.13	0.0001
E*TD*Proximity	1	10.09	10.09	4.72	0.01
E*TD*Task	1	11.182	11.182	5.23	0.047
TD*Proximity*Task	1	8.892	8.892	4.16	0.024
E*TD*Proximity*Task	1	9.343	9.343	4.37	0.006
Error	48	102.624	2.138		
Total	62	230.861			

traffic density and proximity of the aircrafts (F (1,48) = 4.38; p<0.0471); type of task and proximity of intruder aircraft (F(1,48) = 4.29;p = 0.006); Experience levels of the pilots, traffic density, and proximity (F (1,48) = 4.94; p<0. 0001; Experience levels of the pilots, traffic density, and task (F (1,48) = 4.17; p<0. 047);Traffic density, proximity, and the flying tasks (F (1,48) = 4.167; p<0. 043); and interaction between all four levels of the main effect (F (1,48) = 4.07; p<0. 035).

Table 19: ANOVA for Scenario-3 Conflict Detection Time

Source	DF	SS	MS	F value	Pr>F
Experience (E)	1	13.771	13.771	4.39	0.0413
TD	1	13.364	13.364	4.26	0.051
Proximity	1	14.493	14.493	4.62	0.037
Task	1	6.067	6.067	1.934	0.233
E*TD	1	15.164	15.164	4.834	0.039
E*Proximity	1	14.681	14.681	4.68	0.0001
E*Task	1	3.645	3.645	1.162	0.094
TD*Proximity	1	13.74	13.74	4.38	0.0471
TD*Task	1	3.297	3.297	1.051	0.429
Proximity*Task	1	13.458	13.458	4.29	0.006
E*TD*Proximity	1	15.497	15.497	4.94	0.0001
E*TD*Task	1	13.081	13.081	4.17	0.043
TD*Proximity*Task	1	11.33	11.33	3.613	0.268
E*TD*Proximity *Task	1	12.768	12.768	4.07	0.035
Error	48	150.576	3.137		
Total	62	314.935			

3.3.2.1.2. Analysis of Effects of Scenarios On Conflict Detection Time

he null hypothesis investigated is that there are no statistical significant differences in mean conflict detection times between the three weather scenarios.

The data was analyzed with ANOVA using task data (climbing and descending) blocked since analysis indicated that weather did not show any significant effect on the type of flying task. The result was significant leading to the rejection of the null hypothesis ($F(2,144) = 32.95$; p , 0.0001) > 19.5 ($F(2,144$; $\alpha = 0.05$).

The expert data for climbing task failed to show any interactions for all scenarios (Figure 16). Descending task showed apparent interaction at low-density traffic between Scenario-1 and Scenario-2 (Figure 17). Scenario-3 showed degrading performance (increase in detection task) for both traffic densities.

For the student pilots, both climbing and descending tasks showed significant interactions between Scenario-1 and Scenario-2 for high-density traffic conditions (Figures 18-19). Scenario-3 showed higher incident detection times.

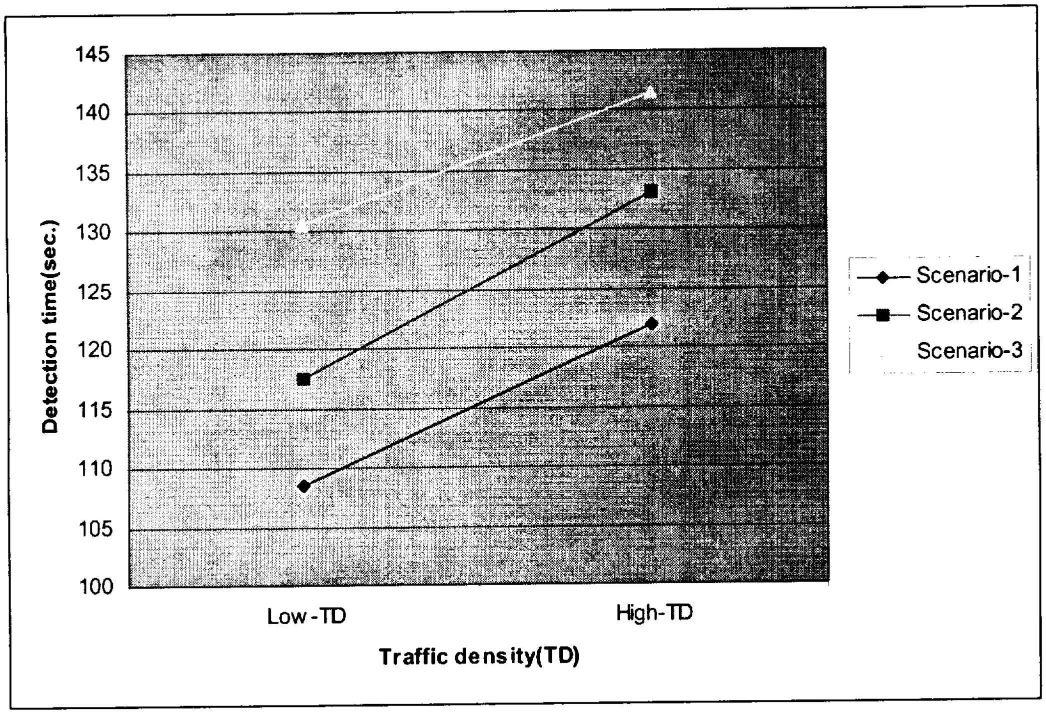

Figure 16. Mean incident detection times by expert pilots on climbing task.

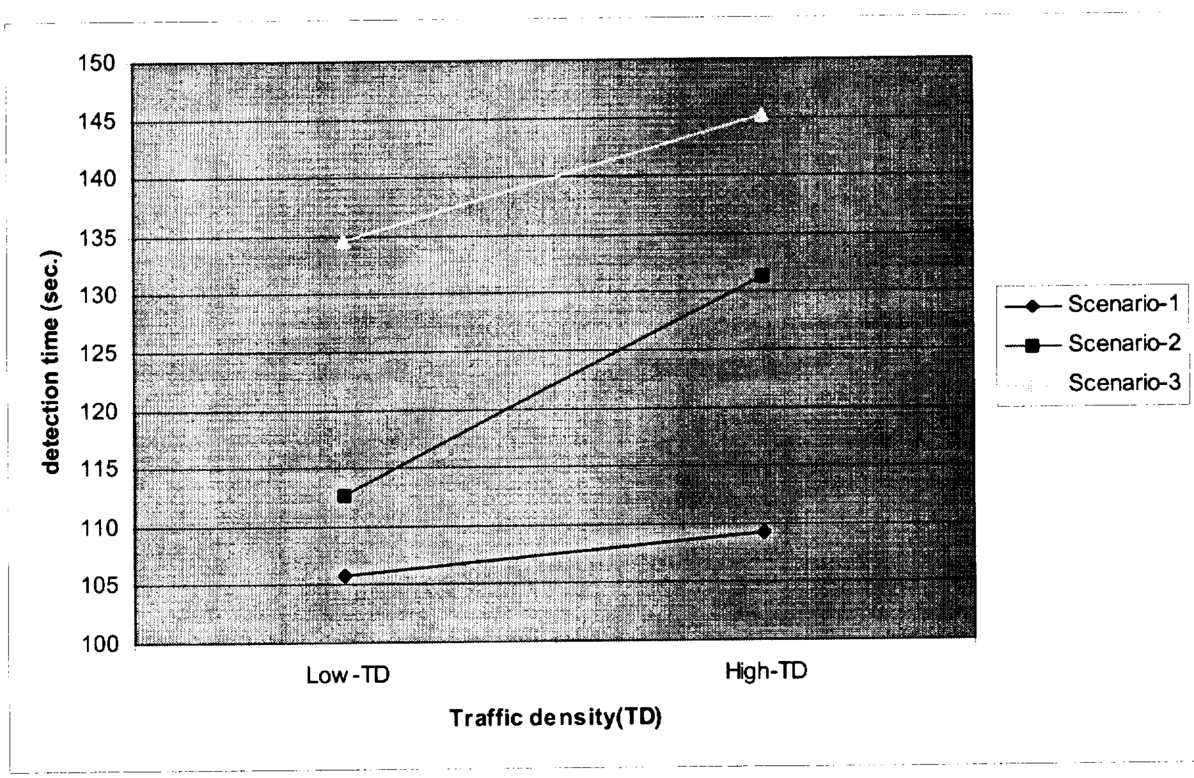

Figure 17: Mean incident detection times by expert pilots on descending task.

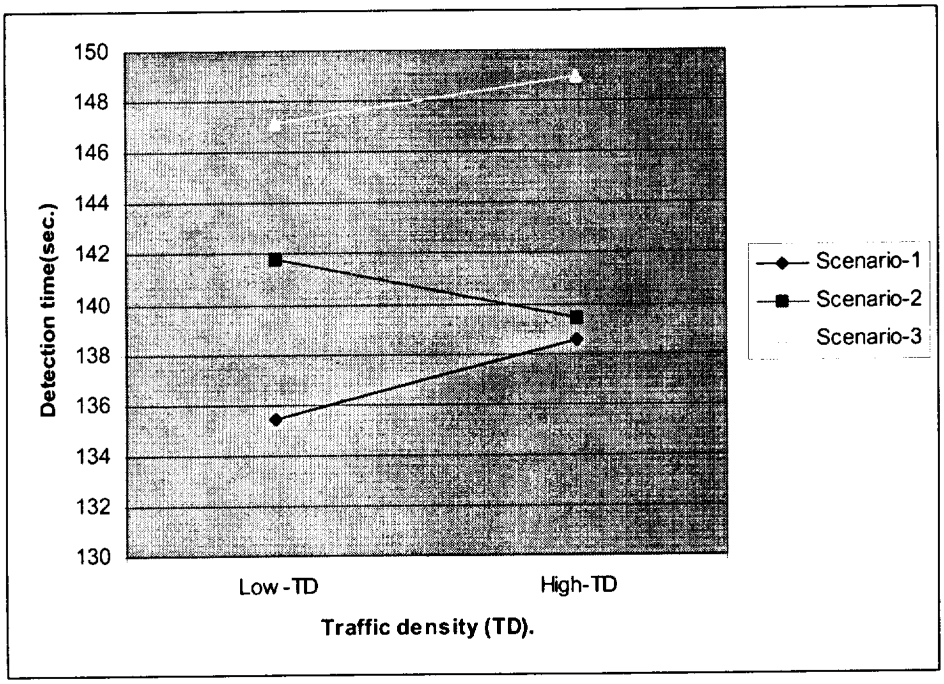

Figure 18: Mean incident detection times by student pilots on climbing task.

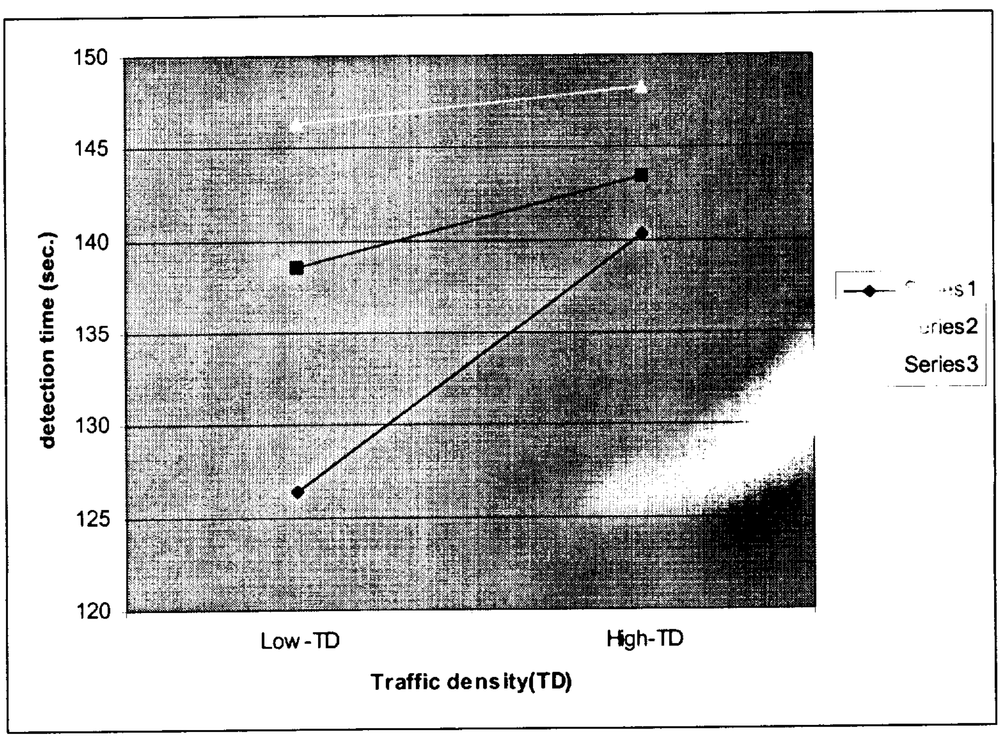

Figure 19: Mean incident detection times by student pilots on descending task.

3.4. Task 3: Separation Risk: Will pilots take more risks flying into weather under free flight decision making?

This part of the study investigated risk behaviors of the free flight pilots using visual flight rules (VFR) and instrument meteorological conditions (IMC). The pilot's decision to fly into adverse weather conditions was examined under two conditions: whether the pilot received a prior weather warning or no warning from the ATC. Under the prior warning, we examine the effect of distance to the location of the weather condition. Three distance levels were examined as follows: close to the weather event (1-4 miles), moderate closeness (4-6 miles), and far (6-10 miles). During the experiments, 52 pre-warning weather conditions were issued by ATC and 24 no warning conditions were randomly generated by the flight simulator. The participants were informed to watch the CDTI for random weather conditions. The dependent variable was the number of times the participants continue to fly into weather with or without warning.

3.4.1. Analysis of Expert (Commercial Pilot) Behaviors

Figure 20 shows the plot of the percentage of times expert pilots flight into weather conditions for the three scenarios under prewarning and no warning conditions. Scenario-3 showed more avoidance behavior (i.e., less occurrence to fly into weather). All main scenarios were significant in mean proportion of times the expert pilots flew into adverse weather (χ^2 = 8.39 ; 0.001 < χ^2 (2, 0.025) = 7.378). There were interactions between all three scenarios. Scenario-1 showed that pilots will fly more into adverse weather because of their perception of less risk. Scenario-2 leaves a puzzle as to why expert pilots will continue to fly into weather under no warning condition and less under prewarning condition. This observation needs further study for validation.

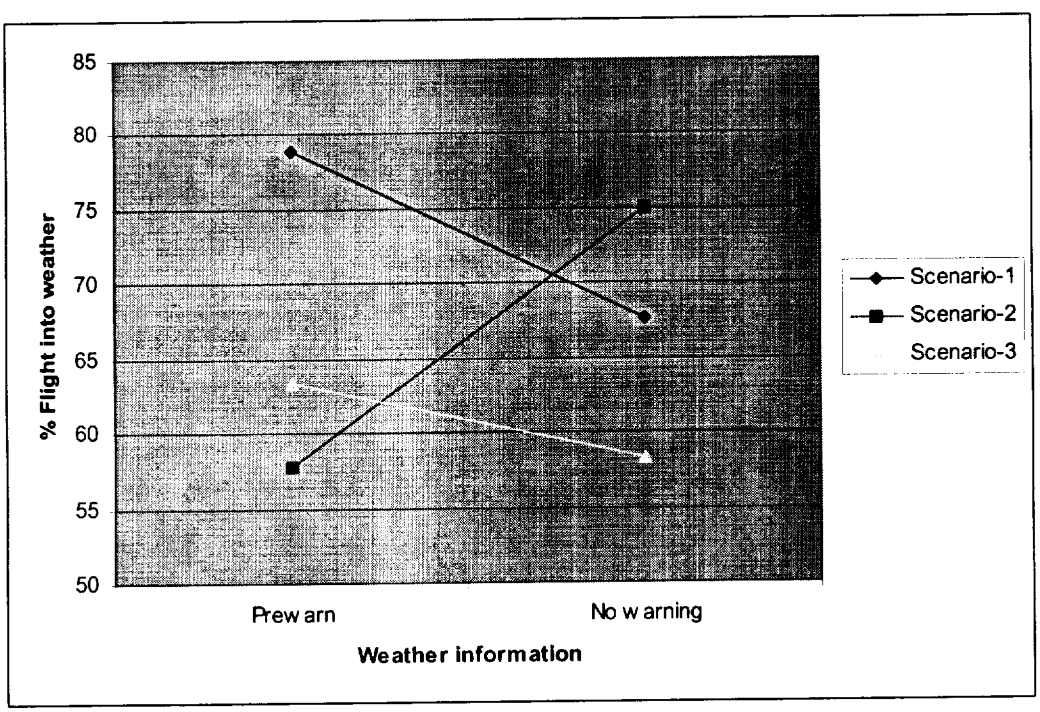

Figure 20: Display of mean percentage of cases expert pilots flew into adverse weather under different weather information conditions.

3.4.2. Analysis of Student Pilot Behavior

Figure 21 shows the plot of the percentage of times student pilots flew into weather conditions for the three scenarios under prewarning and no warning conditions. The main scenarios were significant in mean proportion the student pilots flew into adverse weather ($\chi^2 = 9.10; 0.017 < \chi^2 (2, 0.025) = 7.378$). Scenario-3 showed more avoidance behavior (i.e., less occurrence to fly into weather). Scenario-1 showed that the student pilots have the same probability of flying into an adverse weather in either prewarning or no warning situations. Again, Scenario-2, leaves a puzzle as to why student pilots will continue to fly into weather under no warning condition and less under prewarning condition. A further study to understand this unique results is desirable.

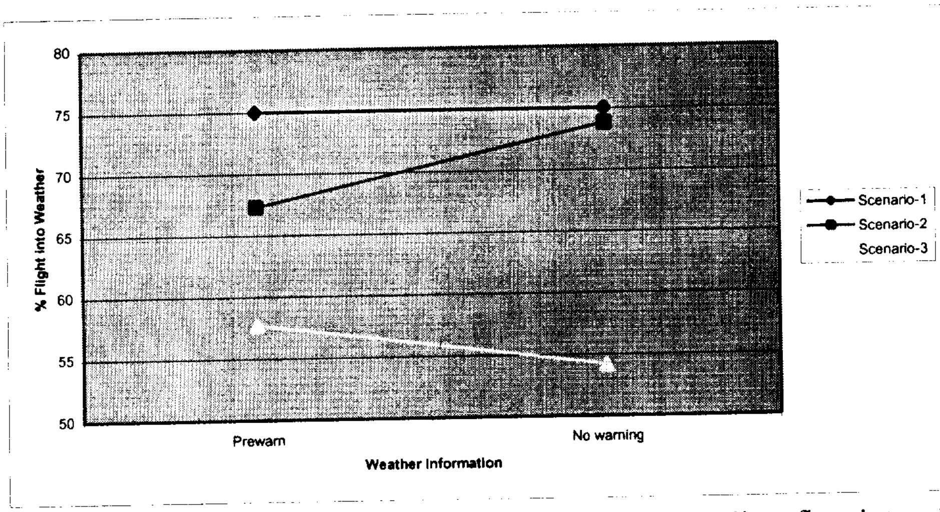

Figure 21: Display of mean percentage of cases student pilots flew into adverse weather under different weather information conditions.

3.4.3 Comparing Expert- and Student – Pilot Behaviors Under Pre-warning Weather Conditions

Figure 22 shows the plot of the percentage of cases the expert- and student- pilots flew into weather conditions for the three scenarios under all prewarning conditions. The differences were significant for Scenario-2 and Scenario-3. The student pilots showed a decreasing slope in judgment to fly more into Scenario-1 weather and decreasing in that intent as the weather conditions became more adverse. The expert pilots showed more flight into Scenario-1 weather and less into Scenario-2 weather. The expert's decision to fly more into Scenario-2 than Scenario-1 in no-warning condition remains elusive for explanation. One explanation, however, may be attributed to ability to estimate risk under this scenario O'Hare & Smitheram, 1995).

3.4.4. Comparing Expert- and Student-Pilot Behaviors Under No-warning Weather Conditions.

Figure 23 shows the plot of the percentage of cases the expert- and student- pilots flew into weather conditions for the three scenarios under no warning conditions. The student pilots showed a decreasing slope in judgment to fly more into Scenario-1 weather and decreasing in that intent as the weather conditions became more adverse. The expert pilots showed less flight into Scenario-1 and more into weather Scenario-2... The decision of the expert to fly more into Scenario-2 than Scenario-1 posits the same dilemma in interpreting behavior as the observations under pre-warning condition and desires further studies.

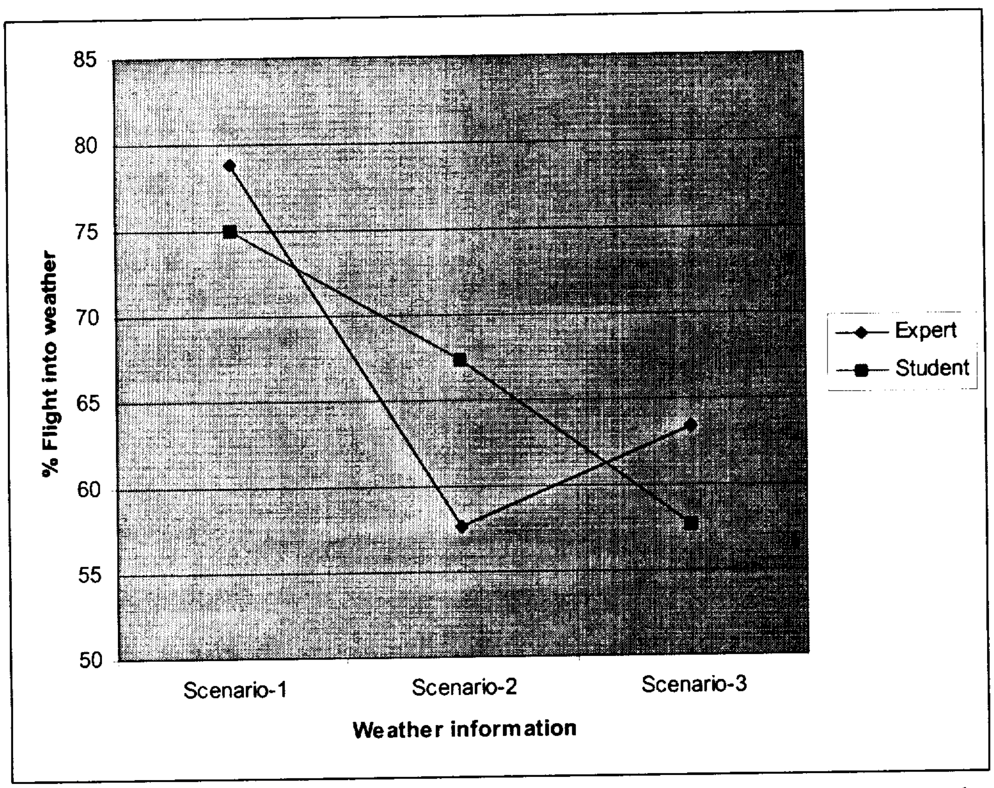

Figure 22. Comparing expert and student behaviors under prewarning weather conditions (52 Prewarning samples).

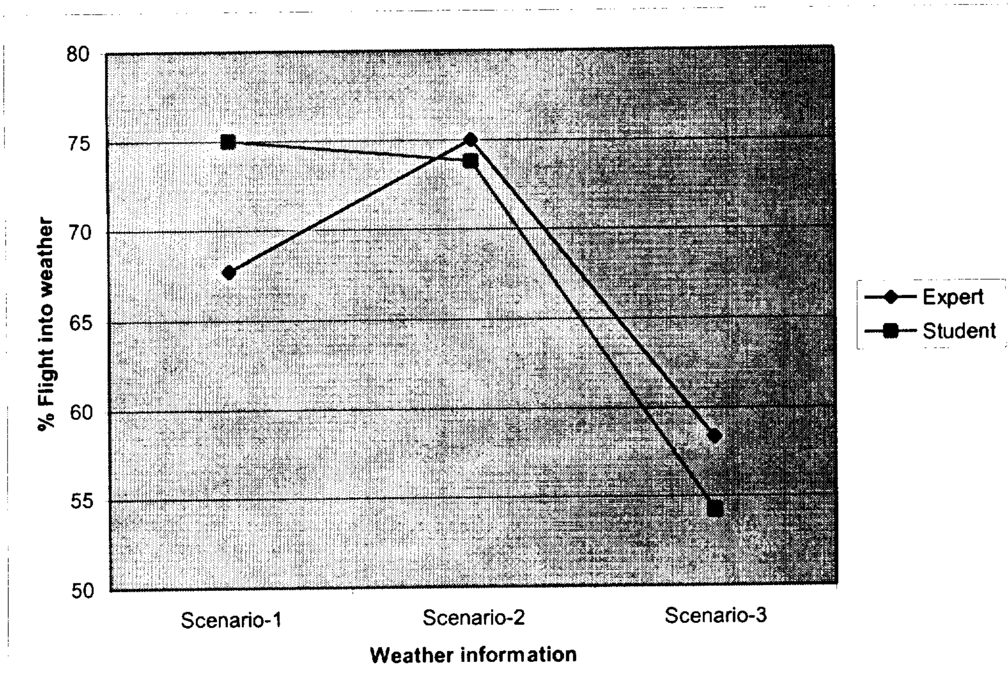

Figure 23. Comparing expert and student behaviors under no warning weather conditions (24 No warning samples).

3.4.5 Effect of Weather Warning Distance On Decision to Fly Into Adverse Weather Conditions

This section presents the result of effects of prewarning distance on the pilots' decision to fly into weather conditions. The hypotheses were investigated with the data collected on the number of instances that the pilots flew into weather. The hypotheses are:

H_{01}: The prewarning distance to weather conditions have equal effects on the pilots' decision to fly into weather conditions.
$H_{02:}$ There are no statistical differences in the mean number of times the pilots will fly into weather conditions under the weather scenarios.
$H_{03:}$. There are no statistical differences in the mean number of times commercial pilots (experts) and student pilots will fly into weather conditions under the weather scenarios.
$H_{04:}$. There are some interactions on pilots' decision behaviors as mitigated by prewarning distance, weather scenario, and experience of the pilots.

3.4.5.1 Results

The data was analyzed using within subject 3X3X2 ANOVA.(Table 20). There were three levels of warning distance, three levels of weather scenarios, and two levels of flight pilots (commercial and students). The result was significant for all main effects: Distance ($F(2,54) = 3.94$; $p = 0.0001$), Scenario ($F(2,54) = 3.54$); $p = 0.0231$), Experience ($F(1,54), = 4.73$; $p = 0.39$). The only interaction was between prewarning distance and weather scenarios ($F(4,54) = 3.97$; $p = 0.02$). Figure 24 shows the mean number of times that expert pilots flew into weather by prewarning information distance. Duncan's multiple-range test on the means show that the nearer the prewarning information to weather conditions, the less likely the pilots will fly into the condition. Duncan's test revealed no statistical differences between moderate and far distance (with mean number of flight into weather of 7.33 and 7.67; $p < 0.0025$). Prewarning distance nearer to the location of weather showed an average of 2.33 times that the pilots flew into weather conditions.

Table 20: ANOVA for Effect of Warning Distance Before Weather Using Number of Plan Continuation Events

Source of Variation	Sum of Squares	df	Mean Square	F-value	p
Distance (D)	8.56	2	4.28	3.93	0.0001
Scenario (S)	7.72	2	3.86	3.54	0.0231
Experience (E)	5.17	1	5.17	4.73	0.039
D*S	17.32	4	4.33	3.97	0.02
D*E	5.34	2	2.67	2.45	0.063
S*E	2.26	2	1.13	1.04	0.01
D*S*E	5.96	4	1.49	1.37	0.038
Error	58.56	54	1.09		
Total	110.89	71			

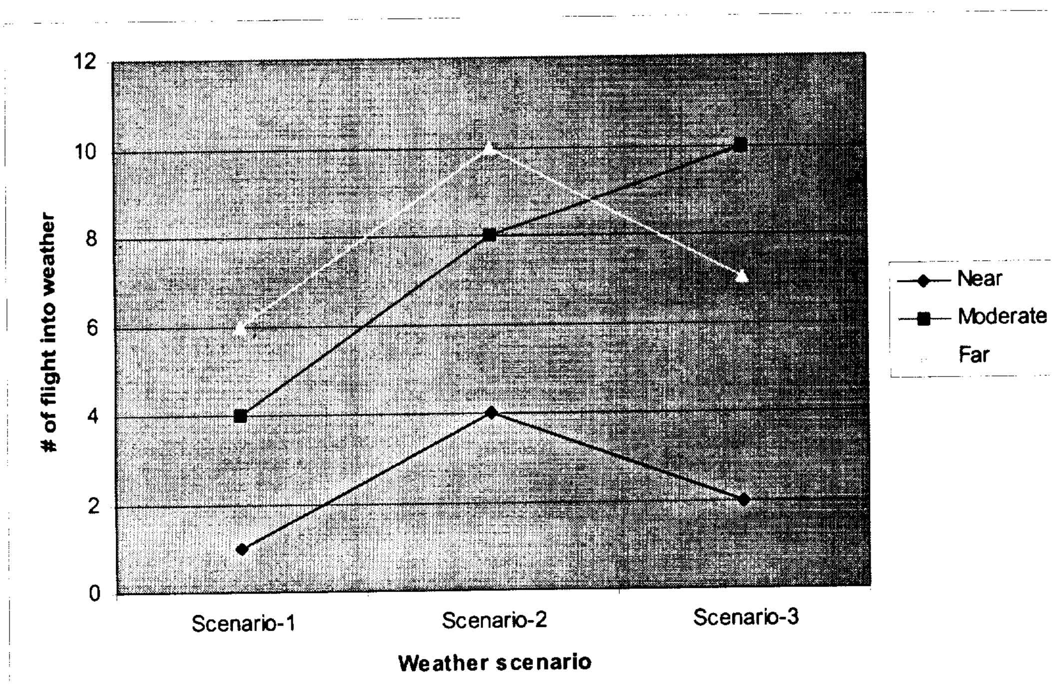

Figure 24. Mean distribution of the number of times expert pilots flew into weather by prewarning information distance.

Figure 25 shows the mean number of times that the student pilots flew into weather by prewarning information distance. Duncan's multiple-range test on the means show that the nearer the pre-warning information to weather condition, the less likely they will fly into the condition. Duncan's test revealed no statistical differences between moderate and far distance (with mean number of flight into weather of 8 and 7; $p < 0.0001$). Prewarning distance nearer to the location of weather showed an average of 2.7 times that the pilots flew into weather condition.

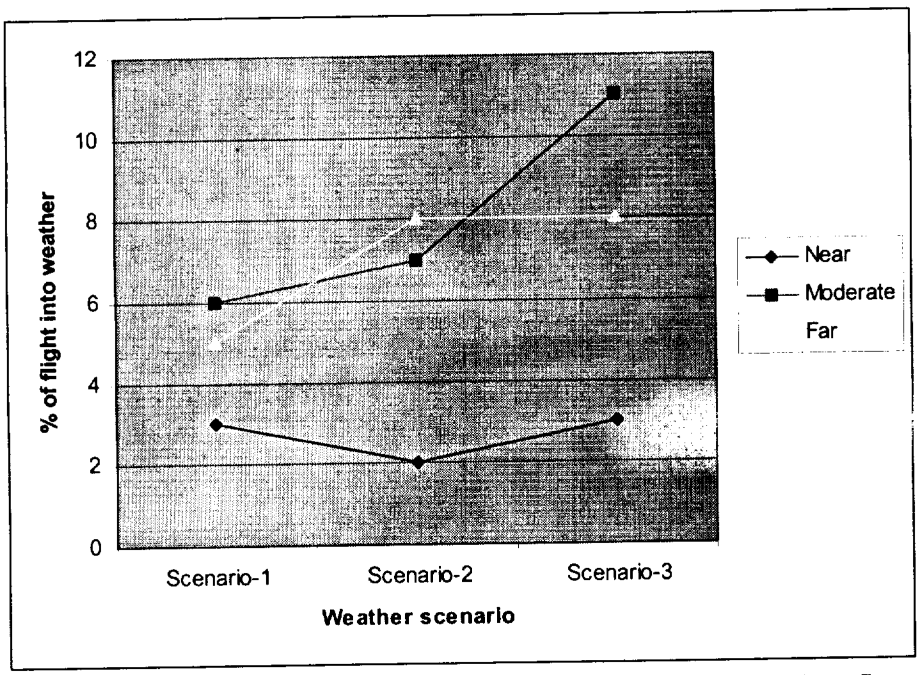

Figure 25. Mean distribution of the number of times student pilots flew into weather by prewarning information distance.

4. DISCUSSIONS AND SUMMARY

4.1. Discussions

4.1.1. Behavior Analysis of Pilots During Aircraft Separation Tasks

The followings behaviors were observed:

4.1.1.1. Expert Behavior:

(i) The intent of the intruding pilot and conflict reconciliation were viewed as only a concern to the expert pilot, but not worrisome to impact task performance.
(ii) The experts tended to rely on their mental models in recognizing conflict incidents and are less likely to consult the ATC.
(iii) They tended to use CDTI for situation awareness.
(iv) The expert pilots were more concerned with the possibility of collision (convergence) of ownership and intruder aircraft (all 4 pilots score the maximum of 3 points).
(v) The position and speed of the aircraft were not concerns to the expert pilots.
(vi) The expert pilots tended to rely on their mental models during spatial task executions and were less likely to consult the ATC.
(vii) The expert pilots were more concerned with altitude and trajectory maneuvering than the position and time of the aircrafts.
(viii) The expert pilots tended to rely on their personal approach to conflict management with the intruder pilots (69.6%); and 20.1% of the time, they more were likely contact ATC for help.
(ix) The expert pilots were more concerned with altitude and vectoring; aircraft type was a high concern, and aircraft proximity was a concern. The distance between intruder and ownership aircraft was somehow worrisome to the expert pilot.
(x) During critical decision making such as determining the intruder pilot's intent or closing separation angle, the experts tended to rely on their mental models (54%) and on CDTI (40.7%) in decision-making behaviors. The expert pilots interaction with ATC was very low (5.3%).

4.1.1.2. Student Pilot Behavior:

(i) The ability to recognize conflict incidents was more important, while the spatial knowledge of the intruding aircraft was deemed relevance.
(ii) The student pilots were more likely to consult the ATC operators for help during conflict recognition tasks.
(iii) They often used CDTI for information seeking, and were less likely to recognize aircraft conflicts without some support.
(iv) The student pilots were concerned with the position of their aircraft, followed by the possibility of their convergence.

(v) Both speed and altitude were scored between concerned and importance.

(vi) The student pilots tended to split their dependency on both the ATC and CDTI. During spatial information processing tasks.

(vii) The student pilot showed high concern on the relative position of the intruder aircraft.

(viii) During conflict resolution between intruder and ownership aircraft, the student pilot depended on ATC about 65% of the time, rarely used the CDTI, and 32% of the time, they depended on personal conflict management skills.

(ix) The student pilots indicated absolute important to altitude availability and proximity of the aircrafts, high concerns for distance and vectoring, and little worrisome on aircraft type and capabilities.

(x) During critical decision making such as determining the intruder pilot's intent or closing separation angle, the student pilots depended on CDTI about half the time (53.1%) and about one quarter of the time on ATC (28.5%), and depended on personal judgments about 18.4% of the time.

4.1.2. Effect of Weather on Free Flight Aircraft Separation

4.1.2.1 Intruder Aircraft Detection Accuracy Under Weather Conditions

In all weather scenarios, there were remarkable differences between expert and student pilots, however the expert pilots showed no statistical differences in the mean detection accuracy. The student pilots were difference in detection accuracy, with remarkable differences observed in Scenario-1 under high traffic density and near proximity of intruder aircraft. The weather did not show any effect on the type of flying tasks, indicating equal mean detection accuracy within the cohort groups either in climbing or descending tasks. The detection accuracy was observed to decrease along the axis of increasing traffic density and proximity of intruder aircraft. In weather Scenario-2, the effect of weather on either traffic density and proximity of aircraft did were not apparent and the performance of the experts and student pilots showed some interaction across traffic density and proximity. In Scenario-3, detection accuracy was better under low traffic density with no statistical differences in task type or proximity of the aircraft. In summary, weather scenarios were observed to affect intruder aircraft detection accuracies. There was interaction effects between weather Scenario-1 and Scenario-2 for climbing task data generated by both expert- and student-pilots at high traffic density. Scenario-3 weather condition provided a poor condition for detection accuracy. This may be associated to low visibility.

4.1.2.1 Intruder Aircraft Detection Time Under Weather Conditions

In all weather scenarios, there were remarkable differences between expert and student pilots in detection times. Within the cohort group, there were differences in detection times due to traffic density. Detection times were better in low traffic density and near proximity of the intruder of the aircraft for both expert- and student- pilots. Under Scenario-1 weather, proximity of the intruder aircraft and types of task did not show significant effect. In Scenario-2 and Scenario-3 the type of task was not significant.

In general, climbing and descending tasks that are mainly maneuvering tasks were not affected by the weather conditions. For the student pilots in Scenario-3, the type of task showed interaction in a high traffic density.

4.1. 3. Effect of Warning on Pilots Decision To Fly Into Weather Condition Free Flight

The following observations were derived in providing the pilots apriori information on weather and the subsequent decision to fly into the weather conditions:
(a). The experts tended to fly more into adverse weather when pre-warned at a distance "far" away from the weather location.
(b). The experts tended to avoid flying into adverse weather even if pre-warning and reminder were provided when the proximity was close to weather conditions.
(c). The student pilots practiced the same behavioral decision as the expert pilots, except that they were more cautious, flying more into weather Scenario- and less in more adverse weather scenarios.

We encounter behaviors that were some how inconsistent. For example, the expert pilots showed more flight into weather Scenario-1 and less in Scenario-2 under pre-warning condition, and fly more into Scenario-2 than Scenario-1 under no-warning condition. These decisions remain elusive for any useful explanation. One explanation, however, may be attributed to ability to estimate risk under the flight conditions (O'Hare & Smitheram, 1995). In general, when pilots were warned of the weather conditions, they were more likely to fly their aircraft into it, but mostly when the warning was not close to the weather location. This result is somewhat consistent with the finding by Goh & Weigmann (2001a), Peterson & Uhlarik (1999), and Orasanu, Martin, & Davison (2001).

4.2 Summary

Overall, the results obtained from the behavioral analysis showed that in general, the ability to recognize the conflict incidents, followed by the ability to acquire the spatial location of the intruder aircraft relative to ownership aircraft were judged to be the major cognitive tasks as perceived by the participants during self-separation. Further, the participants rarely used CDTI during conflict management related to aircraft separation, but used CDTI highly during decision-making tasks.

In all weather scenarios, there were remarkable differences between expert and student pilots in detection times. In summary, weather scenarios were observed to affect intruder aircraft accuracies. There was interaction effects between weather Scenario-1 and Scenario-2 for climbing task data generated by both expert- and student-pilots at high traffic density. Scenario-3 weather condition provided a poor condition for detection accuracy as well as detection time increase. This may be associated to low visibility. In general, intruder aircraft detection times were not affected by the weather conditions during climbing and descending tasks.

The decision of pilots to fly into the weather condition was dependent in part on the warning distance to the location of the weather. In general, when pilots were warned of the weather conditions, they were more likely to fly their aircraft into it, but mostly when the warning was not close to the weather location. There are many factors that may contribute to the behavior of the pilots to fly into weather conditions. These are the possibilities:

(a) With sufficient distance they can plan and develop coping strategies to deal with the weather.
(b) They may have forgotten the warning and depend only on the current expected state of information (Johnson & Tversky, 1984).
(c) It may be due to an intent to save cost, fuel economy, and/or arrival time to destination. This is attributed to the so-called "sunk-cost" effect (Wiegmann, Goh, & O'Hare, 2002).
(d) It may be attributed to risk taking behavior, in which case, the pilot group is said to be risk prone (Edwards, 1987).

While the current research provides important findings in effects of VFR flight into IMC, several tasks and unanswered questions remain. Therefore, additional research is needed to provide answers to such questions, such as,

(i) Whether intermittent weather warning will affect the decision of pilots to fly into weather. If so, what should be the optimal warning schedule and distance to weather location.
(ii) Why pilots who receive adverse warning closer to destination will divert or continue into the weather.
(iii) Why pilots depend less on ATC or CDTI in managing separation conflicts.
(iv) Why during critical decision making such as determining the intruder pilot's intent or closing separation angle, the experts tended to rely almost on their mental models and CDTI in decision-making behaviors. If so, how can CDTI be designed to capture the pilot's mental model and reduce cognitive workload?

It should be noted that the behavioral approach used to uncover the pilot's perception of separation tasks is not complete and less detailed. It is suggested that cognitive task analysis opined on behavior principles be used to study and develop more comprehensive model of pilot's behavior during separation at different weather and flying task scenarios.

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Appendix: Self-Report Questionnaire to Determine Pilot's Information Acquisition During Aircraft Separation Task.

Please answer the following questions as they are relevant to the all aspects of the flying and self-separation tasks you have just completed. List the resources the space provided according to the order of priority, with the highest priority first. The resources are Air Traffic Controller (ATC), Cockpit Display Traffic Information (CDTI), and self knowledge (SELF).

Question 1: Where do you get most of the information during the processing the following cognitive tasks in:

1. Determining aircraft converging headings:______ _______ ________
2. Determining aircraft speed differences: _______ ________ _______
3. Determining the relative spatial position of the intruder aircraft: ______ _____ _____
4. Determining the minimum lateral separation: _______ _________ _______
5. Determining the minimum longitudinal separation: _______ ______ _________
6. Determining the minimum separation height: ________ _________ ________
7. Determining the intruder pilot intent: _______ _______ _____
8. Negotiating for airspace right of way: ______ ________ _________
9. Deciding to divert your aircraft from the intruder: _____ _______ ________
10. Determining dead reckoning situation: ______ _______ ________
11. Closing the separation angles from the intruder: ______ ________ _______
12. Determining the vectoring space available: _______ ________ _________
13. Determining the available altitudes for maneuvering: ______ _________ _______
14. Determining the intruder aircraft characteristics: ______ __________ _________
15. Determining the proximity of your aircraft to that of the intruder: _____ _____ ____
16. Determining your aircraft distant from the intruder: ______ _______ _______
17. Determining your aircraft time to collision from the intruder: ______ _______ _____

Question 2: During the aircraft self-separation, rate the following cognitive tasks by its importance (3), relevance (2) , or concern (1) as it pertains to task performance:

18. Recognition of intruder conflict: ___________ ___________ _________
19. Knowledge of intruding aircraft: ___________ __________ ___________
20. Conflict reconciliation between intruder aircraft pilot and you: _____ ______ _____
21. Knowledge of intruder pilot intent: ________ __________ _________

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13. ABSTRACT *(Maximum 200 words)*
□□□□□The present study investigated effects of weather related factors on the performance of pilots under free flight. A weather scenario was defined by a combination of precipitation factors (light rain, moderate rain, and heavy rain or snow), visibility (1,4,8 miles), wind conditions (light, medium, or heavy), cloud ceiling (800ft. below, 1800ft above, and 4000ft horizontal). The performance of the aircraft self-separation was evaluated in terms of detection accuracy and detection times for student- and commercial (expert) pilots. Overall, the results obtained from a behavioral analysis showed that in general, the ability to recognize intruder aircraft conflict incidents, followed by the ability to acquire the spatial location of the intruder aircraft relative to ownership aircraft were judged to be the major cognitive tasks as perceived by the participants during self-separation. Further, the participants rarely used cockpit display of traffic information (CDTI) during conflict management related to aircraft separation, but used CDTI highly during decision-making tasks. In all weather scenarios, there were remarkable differences between expert and student pilots in detection times. In summary, weather scenarios were observed to affect intruder aircraft detection performance accuracies. There was interaction effects between weather Scenario-1 and Scenario-2 for climbing task data generated by both expert- and student-pilots at high traffic density. Scenario-3 weather condition provided an opportunity for poor detection accuracy as well as detection time increase. This may be attributed to low visibility. The intruder aircraft detection times were not affected by the weather conditions during climbing and descending tasks. The decision of pilots to fly into certain weather condition was dependent in part on the warning distance to the location of the weather. When pilots were warned of the weather conditions, they were more likely to fly their aircraft into it, but mostly when the warning was not close to the weather location.

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