# SUPPORTING GENERAL AVIATION PILOTS DURING REROUTING PROCESS DUE TO SUDDEN WEATHER CHANGES

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# SUPPORTING GENERAL AVIATION PILOTS DURING REROUTING PROCESS DUE TO SUDDEN WEATHER CHANGES

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*To my extraordinary family and Utku Eren.*

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# ABBREVIATIONS

**ADDS** Aviation Digital Data Service

**AH** Abstraction Hierarchy

**AHAS** Airborne Hazard Awareness System

**AOPA** Aircraft Owners and Pilots Association

**ATC** Air Traffic Control

**ATCT** Air Traffic Control Tower

**ATIS** Automatic Terminal Information System

**ASOS** Automated Surface Observation System

**AWIN** Aviation Weather Information System

**AWOS** Automated Weather Observation System

**CWAM** Convective Weather Avoidance Model

**CWA** Cognitive Work Analysis

**DAD** Decision Action Diagram

**DRs** Design Requirements

**DUATS** Direct User Access Terminal System

**EFBs** Electronic Flight Bags

**FAA** Federal Aviation Administration

**FSS** Flight Service Station

**GA** General Aviation

**GTRI** Georgia Tech Research Institute

**GWIS** Graphical Weather Information System

**HITL** Human-in-the-loop

**HTA** Hierarchical Task Analysis

**IMC** Instrument Meteorological Conditions

**IFM** Information Flow Model

**IFR** Instrument Flight Rules

**IRB** Institutional Review Board

**NASA** National Aeronautics and Space Administration

**NASA-TLX** NASA Task Load Index

**NTSB** National Transportation Safety Board

**NWS** National Weather Service

**PDRs** Possible Design Requirements

**SID** Standard Instrument Departure

**STAR** Standard Terminal Arrival Route

**WDA** Work Domain Analysis

**VFR** Visual Flight Rules

# SUMMARY

General aviation pilots need different types of flight information in order to follow events and the changes related to the aircraft environment while flying. However, general aviation cockpits have some limitations as space to install flight displays to provide flight information beyond the basics to the pilot. Additionally, more sophisticated instrumentation is often expensive to install and maintain. With the development of the tablet-based software applications (such as ForeFlight, WingX Pro7 or Garmin Pilot applications for iPad), general aviation pilots have started to use them instead of paper documentation. These software applications provide essential flight information such as weather forecast, aviation charts, flight documents, etc. Unfortunately, the expectations for their capabilities are changing with the increased demand and popularity of these software applications. Therefore, these flight planning software applications are compared to find what is missing and what have not met the expectation of pilots.

First, how the software applications support their decision-making process was described and demonstrated to choose the appropriate flight parameters to change flight path while handling with the other cockpit responsibilities. Finally, these design requirements were validated via Human-in-the-loop tests in a part-task flight simulator. The results provided that the suggested design requirements are found highly useful for both novice and expert general aviation pilots. Specifically, novice general aviation pilots might be able to get visualization to compare real-time weather and weather forecast, and then they might gain experience to improve their success for a in-flight re-planning. On the other side, expert pilots might prefer to use this system if they fly an airspace which they are not familiar to weather features of that region.

# CHAPTER I

# INTRODUCTION & MOTIVATION

In General Aviation (GA), poor pilot reaction to adverse or deteriorating weather conditions has historically been the cause of a significant number of accidents and fatalities. The National Transportation Safety Board (NTSB) reported that 4% of total accidents from 1975 to 1986 (which resulted in 19% of the total general aviation fatalities) were a result of Visual Flight Rules (VFR) into Instrument Meteorological Conditions (IMC) accidents [15]. Additionally, weather caused approximately 100 of the accidents and was accounted for over 200 fatalities each year, between 1995 and 2000 [20]. A summary of the combined fatal accident rates and inclement weather factors are shown in Table 1 and Table 2, respectively. These results shows that the fatality rate of VFR accidents significantly greater that they cannot be ignored.

**Table 1:** The accident & fatality rates caused by weather between 1995 and 2000 [15, 20].

| Year | Fatalities | Accidents | % of Total |
|------|-----------|-----------|-----------|
| 1995 | 32.5% | 17.31% | 49.81% |
| 1996 | 29.63% | 17.75% | 47.38% |
| 1997 | 29.09% | 12.92% | 42.01% |
| 1998 | 29.8% | 15.78% | 45.58% |
| 1999 | 24.42% | 10.94% | 35.36% |
| 2000 | 28.23% | 14.48% | 42.71% |

While flying, a pilot needs several types of flight information to follow the events and the changes related to the aircraft environment. However, as a result of the limited space in the cockpit and operating costs, many entry-level general aviation aircraft include only the core flight displays in addition to radio and engine displays (see Figure 1), which do not provide the weather information to the pilots in flight.

The high accident and fatality rates suggest that general aviation pilots do not

**Table 2:** Weather Factors in accidents and fatalities caused by weather between 1995 and 2000 [15, 20].

| Weather Factor | Average Percentage |
|:---:|:---:|
| Fog | 63% |
| Wind/Turbulence | 18% |
| Icing | 8% |
| Rain/Snow | 5% |
| Thunderstorm | 5% |
| Other | 1% |



**Figure 1:** The core flight displays of Cessna 172 Skyhawk.

have, or do not correctly interpret sufficient weather information [15]. Consequently, advanced display technology might be a solution to improve pilot's situation awareness about weather. With the development of flight planning software applications for an electronic tablet and/or a smart-phone, general aviation pilots have started to use these devices before and in flight (mostly electronic tablets) instead of paper documentation gathered before flight [4]. These flight planning software applications available for these devices aim to provide essential flight information such as weather forecast, aviation charts, flight documents. In addition, some of these flight planning software applications provide federal aviation regulations. Further, as the applications are capable of tracking the aircraft in near-real time, pilots often use them during flight as well as for flight pre-flight planning.

In this thesis, the scope for general aviation is that

- General aviation pilots fly with single engine aircraft for single pilot operations. It is further assumed that pilot have been trained to fly with the basic six electromechanical, round dial formatted instrumental, requiring minimal "heads-down" time.

- The flight planning and in-flight re-planning processes are performed under Visual Flight Rules environement.

This population use case represents a significant proportion of the general aviation community, those most in need of additional support.

As the popularity of flight planning software applications has increased, so general aviation pilots have high expectations for their capabilities. However, interviews indicate these new flight planning software applications are not necessarily meeting the needs or expectations of general aviation pilots.

Current flight planning/re-planning steps for VFR can be summarized as:

- During pre-flight, the flight plan is determined depending on weather forecasts and the air traffic density for the chosen route.

- After take-off, flight rerouting/re-planning is demanded either by unexpected rapid weather changes or air traffic.

- In flight, such flight rerouting/re-planning is initiated with visual updates (looking out of cockpit windows) by the pilot, and then the communication with Air Traffic Control (ATC) is engaged for the remainder of the rerouting procedure.

To understand in-flight rerouting/re-planning procedures as real-life pilots perform and formalized process by federal aviation guidances (how FAA prescribes it), interviews were performed with volunteer pilots as detailed in Chapter 3. These interviews reflected the increased use of tablet-based flight planning software applications. However, one challenging part of the rerouting/re-planning is that there is limited information available: pilot has only visual confirmation of the weather by looking

out the cockpit window and updates to weather forecast information via communication with ATC and automated weather reports. This forces the pilot to determine the best possible option to reroute the flight without any graphical representation of the rerouting options. A complementary analysis of aviation magazines [26, 27] found that the flight planning software applications are not easy to apply to in flight rerouting/re-planning.

Given the importance of correctly responding to external weather conditions, the goal of this thesis is to develop design requirements for tablet-based applications designed to support pilot rerouting due to changes in weather. Specifically, this thesis seeks to understand a flight planning during pre-flight and a flight rerouting/re-planning in flight due to sudden weather changes, and to describe the design requirements to improve the flight planning software applications to meet the major needs of general aviation pilots. It concludes with guideline about how to reroute/re-plan the flight using the electronic tablet's software applications. The proposed design requirements are validated using an user interface design prototype on an iPad for the general aviation pilot. The final design requirements for this tool are then developed based on the feedback of general aviation pilots.

The research questions for this study are:

1. How does the use of flight planning software applications on an electronic tablet affect the decisions of general aviation pilots for rerouting in response to sudden weather changes?

2. What are the design requirements that aid General Aviation pilots with safely rerouting due to weather changes?

The first research question aims to understand the impact of the electronic tablet use on the pilot decision making process during the rerouting/re-planning caused by rapid weather changes. General aviation pilots currently deal with limited built-in flight instrumentation such as a graphical weather forecast overlayed with alternative flight path options; therefore, they are mostly using software application on the electronic tablet besides the paper checklist or any other paper document usage. Based

on interviews and the iPad Pilot News aviation magazine articles [26,27], the software applications on the electronic tablet are a helpful tool for general aviation pilots; and they can be improved upon for specific situations such as synthetic vision overlayed with weather forecast or weather changes in real-time domain.

The second research question aims to improve/support pilot decision making and subsequent safe alteration of flight plans in response to changes in weather by the specification of design requirements for flight planning and navigation aids for use in an electronic tablets.

## 1.1  Objectives

The objectives of this thesis are to:

- Examine the impact of a tablet-based software application on pilot rerouting/re-planning in flight.

- Develop the design requirements for a user interface for flight planning software applications on an electronic tablet which displays weather changes relative to the best alternative flight path to support the pilot's in-flight rerouting/re-planning.

- Validate the design requirements empirically through Human-in-the-loop (HITL) testing of existing and prototype displays.

The first objective aims to analyze qualitatively how the software applications support pilots' decisions during in-flight rerouting/re-planning while handling with the other cockpit responsibilities such as communication with Air Traffic Control and other pilots.

The second objective aims to improve existing design features for flight planning software applications and develop the design requirements to support the pilot for performing in-flight rerouting/re-planning.

The third objective will validate the design requirements with a HITL experiment in a part-task flight simulator. The evaluation will leverage existing software that lack

of the required elements. Where no existing software incorporates required elements, a new prototype software application will be developed.

## 1.2   Research Overview

This thesis is structured as shown in Table 3. Chapter I provides an introduction and presents the motivation behind this thesis. Chapter 2 provides the necessary background to understand the flight planning and in-flight re-planning for general aviation, and the methodology proposed for this study. Sections cover Federal Aviation Guidance for limitations of the cockpit system and the pilot, and popular flight planning software application on an electronic tablet including relevant studies performed by other institutes. Chapter 3 discusses how general aviation pilots plan their flights and re-plan when they need while flying. The results of interviews with general aviation pilots are discussed using document and cognitive task analysis. Chapter 4 provides the description of design requirements including user description, and also explains how the design requirements are used to design an user interface prototype for tablet devices. Chapter 5 explains how the design requirements were evaluated and discusses the results of HITL to support the description of final design requirements. Finally, Chapter 6 summarizes this thesis including possible future research avenues.

**Table 3:** Thesis content.

| Chapter | Title |
|---|---|
| Chapter I | Introduction & Motivation |
| Chapter II | Literature Review |
| Chapter III | Understanding How to Plan & Re-Plan The Flight |
| Chapter IV | The Description of Design Requirements |
| Chapter V | Validation and Development of Design Requirements |
| Chapter VI | Conclusion |

# CHAPTER II

# LITERATURE REVIEW

This chapter discusses the existing literature relevant to research questions which are defined for this thesis. The first section, General Aviation flight planning and in-flight re-planning, reviews the procedures of flight planning and rerouting/re-planning which are described by FAA. The second section, Flight Planning Software Application on an Electronic Tablet, reviews why these flight planning software applications have been used before and during a flight, what the popular flight planning software applications are and the comparison between these software applications. Then, task analysis and process charting methods are identified. Finally, the literature on a display design relevant to flight rerouting/re-planning due to sudden weather changes are discussed.

## 2.1 General Aviation Flight Planning and In-Flight Re-planning

Federal aviation described flight planning and in-flight re-planning for each class of aviation. For this thesis, flight planning and in-flight re-planning are examined and discussed under Visual Flight Rules (VFR) for single engine aircraft and single pilot operation. FAA developed 3-P Model for weather flight planning, and adapted this model for both pre-flight and in-flight phases according to FAA's *General Aviation Pilot's Guide* [8].

In the following parts of this section, VFR flight planning and in-flight re-planning for pre- and in-flight phases will be discussed in detail.

### 2.1.1 Pre-Flight Phase: Flight Planning

Flight planning is a process to produce a flight plan which includes the description of proposed flight path information (destination, origin airports, way-points, so on.).

It involves the fuel calculation to ensure that the aircraft can safely reach the destination point. Additionally, accurate weather forecasts must be analyzed so that fuel consumption calculations can account for the effects of head, or tail winds and air temperature [8,34]. Safety regulations require aircraft to carry fuel beyond the minimum needed to fly from origin to destination, allowing for unforeseen circumstances or for diversion to an alternate airport if the planned destination becomes unavailable due to weather changes [8,34]. Before providing details about flight planning, the nomenclatures are provided.

A *flight route* is a description of the path followed by an aircraft when flying between airports and way-points on airways under the direction of air traffic control [34].

For VFR operations, pilots may use *way-points* to check where they are while flying. *Way-points* use five letters (e.g., PILOX), and those that double as non-directional beacons use three or two (e.g., TNN, WK) [34]. Additionally, an aircraft is able to change its airway from one to another at such points. An *airway* which is not physical way, starts and finishes at a way-point. Flight route does not have to be only one airway; it can use several airways. Most of the airways are classified as:

- A named way-point appears on aviation charts with a known latitude and longitude, and are on one or more airways. Those way-points have an associated radio beacon that the pilots can easily check where the aircraft is [34].

- A geographic way-point is a temporary position used in a flight plan, is also known as no named way-point [34].

As a fundamental purpose of flight planning, how much trip fuel is needed to fly from origin airport to destination airport is calculated based on the air navigation process [34]. A step-by-step process for the flight plan is broke down into pieces (and the decision-making elements are demonstrated in Figure 2):

1. Identify the destination airport,
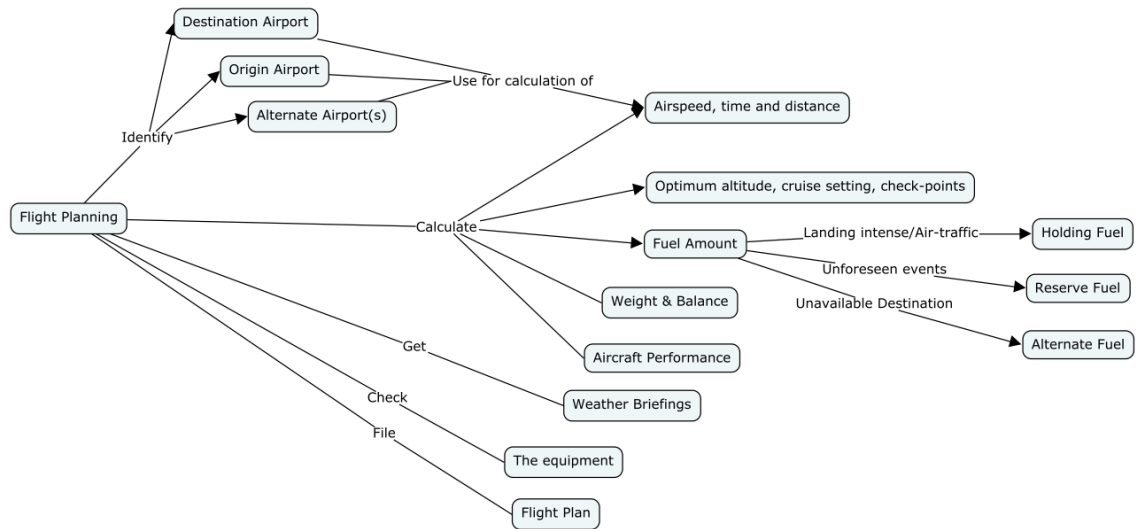
**Figure 2:** Flight planning decision-making path.

2. Identify the alternate airport: The pilot should also identify an alternate airport close to the destination airport. An alternate airport becomes a requirement for the pilot when the destination airport becomes unusable while the flight is in progress (due to weather conditions, a strike, a crash, terrorist activity, etc.).

3. Identify the route including an optimum altitude, cruise setting, checkpoints,

4. Get weather briefing,

5. Compute airspeed, time and distance,

6. Calculation of fuel amount: An aircraft must carry some reserve fuel for unforeseen circumstances, such as an inaccurate weather forecast, or ATC requiring an aircraft to fly at a lower altitude than optimum [34]. Addition to reserve and holding fuel which is required to circle for a while (typically 30 minutes) near the alternate airport while a landing slot is found, an aircraft must have alternate fuel and alternate reserve available to fly on to the alternate airport [34]. Most of domestic flights in United States are not required to have alternate fuel to proceed to an alternate airport when the weather forecast at the destination is better than 2,000-foot (610 m) ceilings and 3 statue miles of visibility [34].

However, the 45-minute reserve fuel at normal cruising speed applies all the time [34].

7. Check the equipment,

8. File a flight plan: Before take-off, the pilot must fill the flight plan document (see Figure 3). VFR flight often do not require filing a flight plan; however, the pilot has to make sure that there will be sufficient fuel amount on-board for the trip and sufficient reserve fuel for unforeseen circumstances. The pilot must prepare an alternate flight plan if the destination airport is not possible for landing.



**Figure 3:** The flight plan record document for VFR flights [33] (see Appendix A for item descriptions).

One of most important parts of the flight planning is the weather forecast analysis. FAA uses 3-P model to support the pilot to make a better weather decision-making in flight. 3-P model, Perceive-Process-Perform risk management framework, is a
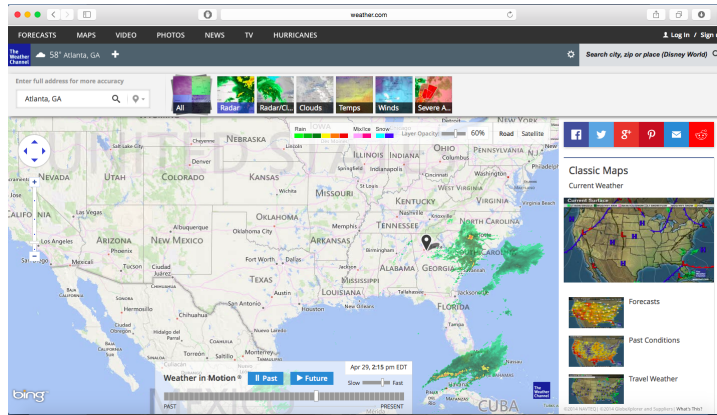
**Figure 4:** Weather in motion for past and future provided from The Weather Channel website (04/29/2015 2:39pm) [31].

guideline for pre-flight weather flight planning and in-flight weather decision-making [8].

Pre-flight 3-P model [8]:

•*Perceive–Understanding Weather Information:* The first major pre-flight task is to perceive the flight environment by collecting information about current and forecast conditions along the route the pilot intends to take, and then using the information to develop a good mental picture of the situation the pilot can expect to encounter during the flight.

The first challenge of flight planning is to know where and how to look for weather information that the pilot need. For general aviation pilots, the FAA Flight Service Station (FSS) remains the single most widely used source of weather information. FSS provides weather products as package derived from National Weather Service (NWS) data and other flight planning information into a convenient, user-friendly package [8]. Other weather information sources available are:

1. The Weather Channel (TWC) which is not approved by FAA is used for long-range weather planning. It has both television and online versions; and offers tactical and strategic summaries and forecasts up to 10 per day [8].

2. Aviation Weather Center which is provided by The National Weather Service (website is available at [30]) is another useful weather information source.
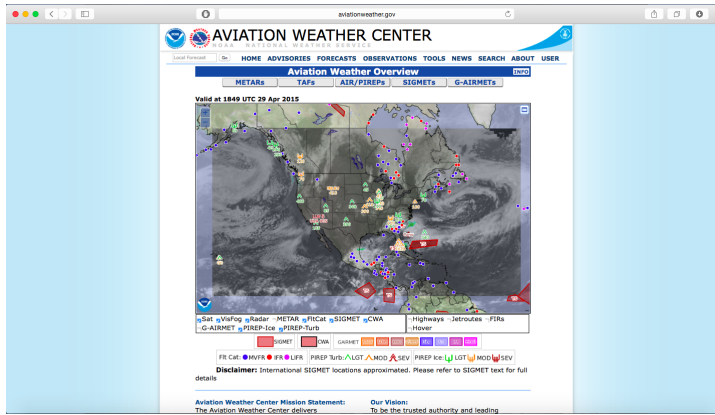
**Figure 5:** Weather information (on 04/29/2015) [30].
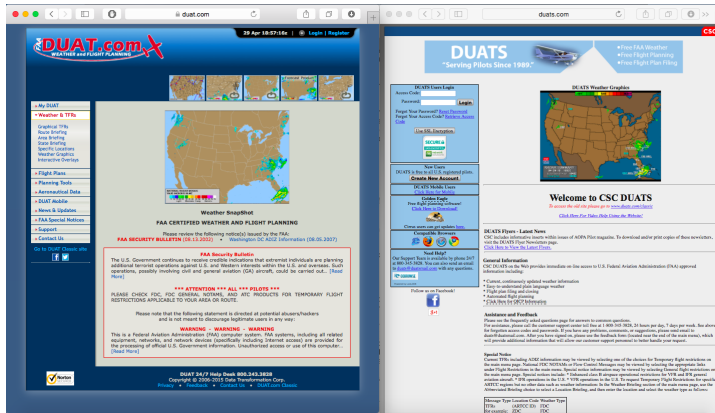


**Figure 6:** Weather forecast and resource which is provided from *http://www.duat.com* or *http://www.duats.com* at 04/29/2015.

3. Direct User Access Terminal System (DUATS) is provides FAA approved weather information format and records the transaction as an official weather briefing [8] that the pilots have free access at *http://www.duat.com* or *http://www.duats.com.*

4. Aviation Digital Data Service (ADDS) is a joint effort of NOAA Forecast Systems Laboratory, NCAR Research Applications Program (RAP), and the National Centers for Environmental Prediction (NCEP) Aviation Weather Center (AWC) [8]. It combines weather information from National Weather Service (NWS) aviation observations and forecasts, and makes them available on online with visualization tools to help pilots use all those information for practical

flight planning.
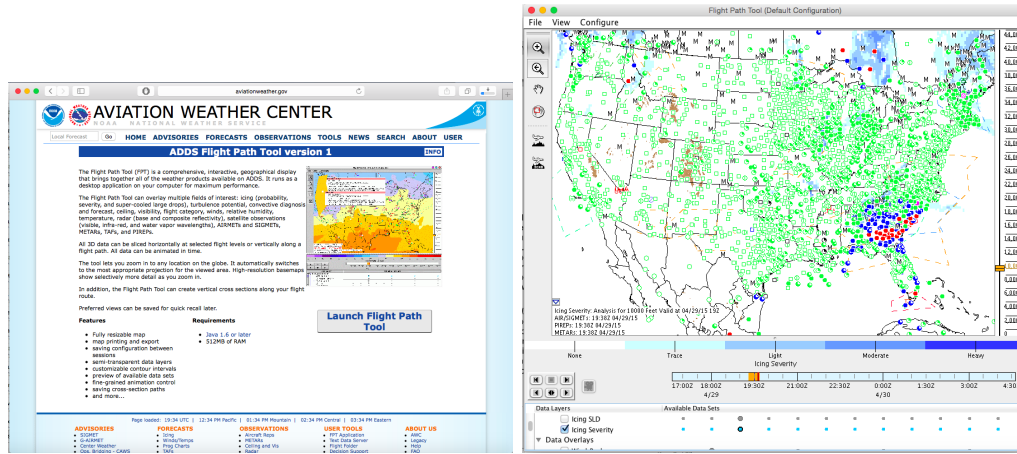


**Figure 7:** Weather planning tool from ADDS at 04/29/2015 [19].

•*Process–Analyzing Weather Information:* After obtaining the weather forecast, the forecast information is evaluated to understand what it means where the evaluation depends on experience and understanding the tool. This is step is a critical step to use weather information to plan safer flight.

Poor weather evaluation can cause conditions that affects the pilot, and weather can affect the pilot with three elements fundamentally: (1) reduced visibility, (2) turbulence, (3) reduced aircraft performance [8]. Therefore, the pilot must check the temperature, wind as a vector with speed and direction, moisture (humidity).

•*Perform–Making a Weather Plan:* The last step is the practical flight planning which requires the evaluation of information using the capability of aircraft and the experience of the pilot. If the pilot flies with a model aircraft which doen not have weather avoidance equipment, the pilot must have necessary flight experience to deal with weather conditions. Otherwise, they need to obtain sufficient flight information for strategic flight planning such as terrain information, minimum safe altitude for each segment, weather-related hazards [8].

### 2.1.2 In Flight: Flight Rerouting/Re-planning

Similar to pre-flight, the FAA describes the 3-P model for in-flight weather decision-making as [8]:

•*Perceive–Obtaining In-flight Weather Information:* In general, the pilots choose to take off and to evaluate the weather as they go if weather is not bad to make no-go decision. However, there are safety requirements to stay alert for any weather changes [8]. In-flight updates are vital for general aviation pilots; therefore, the pilot has to check the updates while flying. The in-flight information sources:

1. *Visual Updates:* One of the most important things is the out-of-window scan to survey the weather changes; because the weather can change rapidly in some areas. Literally, the weather conditions around the aircraft can be sensed by watching outside. The reason is that some local deviations in weather conditions may not be known by the weather information sources or may not appear on weather forecast products [8].

2. *Automatic Terminal Information System (ATIS)/Automated Surface Observation System (ASOS)/Automated Weather Observation System (AWOS):* Another way to monitor weather conditions is to listen to ATIS and ASOS/ AWOS broadcasts in flight to get updates and to validate the weather forecast [8].

3. *En route Flight Advisory Service (EFAS, or Flight Watch):* Available on 122.0 in the continental United States from 5,000 AGL to 17,500 MSL, EFAS, addressed as Flight Watch, is specifically designed as a service to provide en-route aircraft with timely and meaningful weather advisories pertinent to the type of flight intended, route of flight, and altitude [8].

4. *Air Traffic Control (ATC):* Monitoring ATC frequencies which are available on aeronautical charts along the way is one way to keep updated of changing weather conditions [8]. The pilot can request and follow the information about other aircraft which request rerouting, the present location of weather.

5. *Datalink and Weather Avoidance Equipment:* Some of devices such as radar, lightning detectors and weather avoidance tool have been available in some general aviation aircraft for many years [8]. The number of aircraft which are being equipped with weather datalink equipment –these equipment are using

ADS-B In devices [25] to transmit and receive weather data such as METARs, TAFs, and NEXRAD radar to the cockpit– are increasing [8].

- *Process–Evaluating and Updating In-flight Conditions:*

1. *Visual Updates:* The pilot must follow the outside condition to perceive any weather changes on the flight path. It is not always possible to perceive the changes with the eyes; but the pilot should check and estimate the in-flight visibility to enhance the ability of the weather condition evaluation [8].

2. *ATIS/ASOS/AWOS:* In-flight weather conditions obtained from ATIS and ASOS/ AWOS broadcasts can contribute useful information pieces to the en route weather picture; but it is important to understand that this information is only a weather "snapshot" of a limited area [8]. These broadcasts primarily obtain the weather information for airport vicinity.

3. *En route Flight Advisory Service (EFAS, or Flight Watch):* If the pilot suspects deteriorating conditions during flight, the pilot must contact the En route Flight Advisory Service (EFAS - Flight Watch) for additional information [8]. The key point is to understand where the weather impact zone is in relation to the aircraft position and flight path, where and how fast it is moving [8]. The aviation chart will help the pilot visualize where the weather conditions are in relation to the aircraft's current position and intended route of flight, and determine whether (and where) the pilot needs to deviate from the original flight path [8].

4. *ATC:* ATC radar can detect areas of precipitation; however, it does not detect clouds or turbulence. A critical element in interpreting weather information obtained from ATC is a thorough understanding of pilot-controller communications [8].

5. *Datalink and Weather Avoidance Equipment:* While analyzing the weather information, it is important to know that the quality of the information depends

upon update rate, resolution, and coverage area [8]. For strategic decision making, the pilot must perceive and analyze the information which is obtained as high quality weather data; although, datalink does not provide real-time information. For tactical decision making, the pilot must receive and analyze accurate and most updated weather data [8].

•*Perform–Putting all together:* During the flight, the pilot must use the data to make tactical weather decisions which require the pilot to perceive the conditions around the aircraft, and to process/interpret their impact on the flight [8]. If the conditions has effect which pose a risk for the flight, the pilot takes steps to avoid the risk. During the decision-making process, the pilot can request help from ATC if they specifically does not have weather avoidance equipment.

## 2.2 Flight Planning Software Application on an Electronic Tablet

In the 1990s, the Electronic Flight Bags (EFBs) came into the cockpits by individual pilots using their own laptops with common software to perform the calculation of weight & balance, filing the flight operations. This brought a discussion on the table for Federal Aviation Administration that FAA has recognized those devices as Electronic Flight Bags (EFBs), and described that *an electronic display system intended primarily for cockpit use and a device that can display a variety of aviation data or perform basic calculations, such as performance data, and fuel calculations; and an electronic information management device that helps flight crews perform management tasks more easily and efficiently, in a less-paper environment* [5].

With the development of electronic tablet devices, pilots have started to use software applications which were developed to use with iPads for weight & balance calculation, airport charts, checklists, instrument approach plates [4]. Although, iPad is not any of classified devices as EFBs; it is realized that the use of iPad software applications has increased the functionality of EFBs and its definition [4].

Primary advantages of an electronic tablet such as iPad are that a tablet can display radar and satellite weather maps with rich color codes, whether the pilot is

in the office or on the ramp, and it can download and store up-to-date airport charts, approach plates, taxi diagrams, and checklists [23]. Software developers have been taking the advantage of electronic tablet technology, and have started to develop flight planning programs with weather maps, radar displays, and download-able airport and flight documents. In *Aircraft Owners and Pilots Association (AOPA) Pilot* article [23], ForeFlight (version 6.6.1) Co-founder Tyson Weihs stated the advantages of using electronic tablet such as iPad or android tablet that they can be listed as cost, unique capabilities, user interactions, high-graphic engine, connection of internet and so on.

Electronic tablets including smart-phones built specifically for aviation must meet minimum performance standards set by the FAA. Although, the electronic tablets are not certified as EFBs, the use of any of them does not require any specific authorization if the EFBs are not replaced with any system or equipment required by the federal regulations [23]. However, the tablet's capabilities can save the pilot and passengers from a potential plane crash. For example, a pilot and his wife used their iPad to fly about 80 miles in the dark and land safely without landing gear at Rapid City Regional Airport in February,2015 [2]. Their plane experienced an electrical system failure and compromised the single-engine plane. Their plane was damaged; but they landed successfully using iPad to navigate their aircraft.

### 2.2.1 Popular Flight Planning Software Applications

The number of flight planning software applications expands with thousands of options for flight planning, weather briefings, weather forecast, flight plan filing and so on. When the list of those applications is narrowed down to the popular flight software applications, the list includes three top applications: ForeFlight (version 6.6.1), Garmin Pilot (version 6) and WingX Pro7 Version 8 according to the user comments and the study of iPad Pilot News aviation magazine [1, 26]. In Figure 8, the average ranking shows that ForeFlight (version 6.6.1) is in the top, Garmin Pilot (version 6) and WingX Pro7 Version 8 are following it battling for second [26].

These software applications have different features and capabilities to provide

**Table 4:** The comparison between the most popular flight plan software applications [1, 26].

| Capability | ForeFlight | Garmin Pilot | Hilton WingX |
|---|---|---|---|
| VFR Sectionals | ✓ | ✓ | ✓ |
| IFR En Route Charts | ✓ | ✓ | ✓ |
| Instrument Approach Charts | ✓ | ✓ | ✓ |
| Geo-referenced Instrument Approach Charts | ✓ | ✓ | ✓ |
| Data-driven (dynamic) En Route Charts | | ✓ | ✓ |
| FAA A/FD | ✓ | ✓ | ✓ |
| FBO Directory | ✓ | ✓ | ✓ |
| Canadian Charts | ✓ | | |
| Mexico Charts | ✓ | | |
| Caribbean Charts | ✓ | ✓ | |
| Worldwide Charts | | (Europe) | |
| Flight plan filing | ✓ | ✓ | ✓ |
| NWS WX Imagery | ✓ | ✓ | ✓ |
| Fuel Prices | ✓ | ✓ | ✓ |
| Terrain/Obstacle Alerts | ✓ | ✓ | ✓ |
| Synthetic Vision | ✓ | ✓ | ✓ |
| Split Screen chart option | | ✓ | ✓ |
| Track up option | ✓ | ✓ | ✓ |
| Backup flight instruments | ✓ | ✓ | ✓ |
| Flight Data Recording | ✓ | | ✓ |
| Connected Panel | Aspe, Dyson | Garmin | Aspen |
| ADS-B In Support | Stratus | Garmin GDL 39 | Clarity, Dual, iLevil, NavWorx, PathFinder, SkyRadar |
| ADS-B Traffic | ✓ | ✓ | ✓ |
| ADS-B Weather | ✓ | ✓ | ✓ |
| Document Viewer | ✓ | | ✓ |
| Scracthpad | ✓ | ✓ | ✓ |
| Compatibility | iPhone/iPad | iPhone/iPad, Android | iPhone/iPad |
| Annual Subscription [26] | $74.99 standard, $149.99 Pro: georeferenced approach plates and airport diagrams, terrain/obstacle hazard advisor, $24.99 to add synthetic vision | $75.00 standard; $49.99 to add VFR premium, $74.99 extra to add IFR premium (adds georeferenced approach charts and terrain) | $74.99 standard; $74.99 extra to add georeferenced charts, $99.99 to add synthetic vision, $29.99 to add fuel prices |
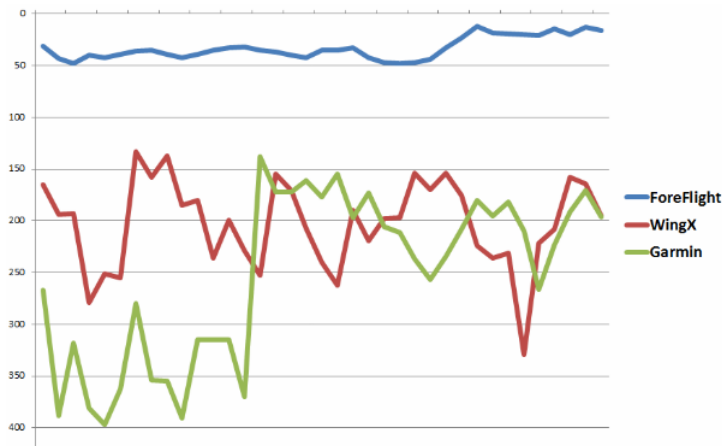
**Figure 8:** The average ranking for three flight applications (the data was collected between July-August,2013 for 30 days) [26].

necessary information to the pilot, and have been modified based on the crash reports and user feedback. The comparison between ForeFlight (version 6.6.1), Garmin Pilot (version 6) and Hilton WingX Pro7 Version 8 are provided in Table 4.

Another critical factors for these software applications are ease of use and support. The pilots rave about how easy to use the ForeFlight (version 6.6.1) application is, with thoughtfully-designed menus and automatic chart downloads that make updates simple [26]. Also the downloads can be done with screen-off mode, and there have been almost never seen application crash. If any problem occurs, ForeFlight (version 6.6.1) provides customer support and training resources.

Garmin Pilot (version 6) enables the download process easier and more robust. Also this software application copes with the WiFi connections. But one of the most important feature of it is how it uses the storage space. Garmin indicates iPad's overall capacity at the download tab, and shows the planning for document coverage area. Additionally, it offers three different terrain resolutions depends on iPad's free space capacity. However, this application has some complaints about the application crash [26].

The third software application, WingX Pro7 Version 8, has a more aggressive approach to add new features and capabilities into the application [1, 26]. There are some complaints about learning the application. Therefore, Hilton Software released

19

training documents and web links for the pilot. Also, there are some complaints that the application crashes occasionally [26].

iPad Pilot News magazine has discussed about the strengths and weaknesses of those applications using the user comments and their experience with the applications [26], and the list is provided in Table 5.

**Table 5:** The list of strengths and weaknesses of three popular applications [26].

| Company | Strengths | Weaknesses | Flight Phase |
|---|---|---|---|
| **ForeFlight** | Powerful route and Altitude Advisors, lots of weather overlays, flight plan filing integration, best FBO information, all-in-one search box. | Needs more options for customizing performance profiles. Limited icing forecasts on the Imagery tab. | Pre-Flight |
| | Smoothest track up display, best rubber band flight planning, handy ruler tool, detailed terrain maps. | No split screen options like Garmin Pilot and WingX Pro7 offer, no synthetic vision display, no data-driven maps. | In-Flight |
| **Garmin Pilot** | Exclusive SafeTaxi diagrams, solid fuel price information and the only app with widgets. The new preferred routes tool is also a major enhancement. | No user-generated comments, less detailed FBO information. No altitude advisor in the File & Brief tab. No graphical turbulence forecast in WX imagery. | Pre-Flight |
| | Pop-up terrain alerts, good split screen options, only app with panel page, only app with data-driven maps. | No synthetic vision, no aerial map, no Canadian or helicopter charts. | In-Flight |
| **Hilton WingX Pro7** | Good radar imagery overlays, extensive airport data, updated fuel prices available in flight, E6B calculator built-in. | Route advisor lacks preferred routes, no graphical TFRs, no icing or turbulence forecasts, fewer weather overlay options. | Pre-Flight |
| | Most options for split screen, full synthetic vision, good terrain and obstacle features. | Track up is not as smooth as ForeFlight, no international charts, no data-driven maps, split screen can be confusing. | In-Flight |

These software applications require that pilots must pay subscription fees annually or monthly. When the amount of fees are compared with panel-mounted system installation and maintenance, having one of these software applications is cheaper than other systems. Even a pilot buys a portable datalink device to get real-time weather information, the total amount of payment should be still reasonable. Therefore, this thesis focuses on describing the design requirements for tablet-based software application.

## 2.3  Cognitive Task Analysis

### 2.3.1  Hierarchical Task Analysis (HTA)

Hierarchical Task Analysis (HTA) was originally developed by two industrial psychologist, John Annett, and Keith Duncan, in 1960s [24, 28]. Their intention was to prescribe a method of examining work which combined describing human activity with understanding the purpose of work in-terms of the organizations and systems in which it was undertaken [24]. Any effort to improve human performance in a work or recreational setting must start by some understanding of what people are required to do and how they achieve their goals [24].

Although HTA acts as an input into numerous human factors analyses methods, HTA cannot deal with every human factors decision without reference to other methods and ideas, but it can be used to guide an examination of tasks so that other methods and ideas can be used to greater benefit [24].

HTA involves the activity description under analysis in terms of a hierarchy of goals and sub-goals, operations and plans [24, 28]. Plans are crucial to generate a HTA. A plan only makes sense in conjunction with the sub-goals it is governing [24]. The presentation of HTA is based on the hierarchical relationship between the tasks.

The procedure for HTA generation can be listed for this thesis as:

1. *Define task under analysis:* As a first step, the tasks should be identified under the analysis based on the purpose of the task analysis.

2. *Data collection process:* The data can be collected with observations, interviews

with subject matter experts, questionnaires and walkthroughs.

3. *Determine the overall goal of the task:* The overall goal is used to determine the hierarchy and the sub-goals of the system.

4. *Determine sub-goals and their decomposition:* As a next step following the determination of overall goal, the meaningful sub-goals should be identified regarding to achievement of the overall goal. The sub-goals should be ordered to reach the goal in an appropriate way.

5. *Plans analysis:* Plans dictate how the goals are achieved. It means that the sub-goals and the overall goal should be planned in the appropriate order.

### 2.3.2   Abstraction Hierarchy (AH)

Cognitive Work Analysis (CWA) offers a comprehensive framework for the design, development and analysis of complex socio-technical systems [28]. The primary modeling method of CWA is Abstraction Hierarchy (AH), which is known as Abstraction Dimension [32]. Abstraction Hierarchy is used to describe the work environment and to illustrate the concept of the work domain. Abstraction Hierarchy describes the work domain with different levels of abstraction using a means-ends relationship, which answers the questions of how a function can be accomplished and why a function is necessary. Traditional Abstraction Hierarchy with five levels is described on Table 6 [14, 21, 32]. In this thesis, the Abstraction Hierarchy was adapted from its usual role in WDA to instead describe the generation of the proposed work domain. The AH was used to demonstrate how the prototype application has changed the work domain.

## *2.4   Process Charting Methods*

Process Charting Methods represents activity or processes in a graphical format to demonstrate the task sequence under analysis. The first use of process charting methods was done by Gilbreth and Gilbreth in 1920s [28]. Process charting methods have

**Table 6:** The description of Abstraction Hierarchy levels [18, 22].

| AH | Definition of the level | Example |
|---|---|---|
| Functional Purpose (FP) | Represents the purpose of the work system | Re-plan an existing flight |
| Abstract Function (AF) | Represents the criteria to measure how the work system progresses to FP and to compare and to direct the resources to the generalized functions | Flight route monitoring |
| Generalized Function (GF) | Represents the relations concepts and characteristic of the physical process with regards to physical forms | Manage tablet-based flight planning software application |
| Physical Function (PF) | Represents the process and the functional limitations and capabilities related to the parts or physical forms of the work system | Decision on flight reroute option |
| Physical Objects (PO) | Present the physical world or physical reality that is available for the visualization of the work system; and PO can include tools or equipment, geography, personal categories, infrastructure, drawings, etc. | iPad, software application |

been used in a number of difficult domains to provide graphical format of task sequences in an activity. There are several Process Charting Methods: (1) Process Charts, (2) Operator Sequence Diagrams, (3) Event Tree Analysis, (4) Decision Action Diagram (DAD), (5) Fault Tree Analysis, (6) Murphy Diagrams.

For this thesis, Information Flow Model (IFM) to demonstrate organizational model which is another representation of Process Charts and Decision Action Diagram are described to provide a brief background about the methods.

### 2.4.1 Decision Action Diagram (DAD)

Decision Action Diagram (DAD)s are used to graphically depict a scenario process in terms of the decision required and actions to be performed by the operator involved in the activity [28]. The output of DAD should display all of possible outcomes at each task step in a process. DAD method can be used to evaluate existing systems

or to inform the design of system's and procedures.

Decision Action Diagram have similar demonstration as functional work flow except decision points. Functions are expressed as a verb-noun combination with modifiers, and decision points are written in question forms in diamond-shaped outline symbols [7]. The questions must be binary, answerable by a *yes* or *no* response [7,28]. Another important factor is trace-ability for functional flow that symbols on the diagram are labeled with reference number. Decision Action Diagram can be developed and used at different levels of detail. The functions – described in diagram – are performed by human, machine, software or combination of these.

### 2.4.2 Information Flow Model (IFM)

Information Flow Model (IFM) is used to graphically describe the interaction between individuals and teams in relation to the performance of the activities under tasks [28]. IFM includes Information Modeling, the user, other individuals/teams, responsibilities and breakdowns in the work system. Those elements represents the communication and action flows with decision-making process. IFM elements are:

1. *Artifacts – Information modeling –* are shown in boxes, and can be documents, tools or message [6]. It represents the need of information visualization on the screen (Figure 9). It has three representational needs as information need, information format and information emphasis [13].Fundamentally, their definitions are:

    - *Information need* is modeling the information which is related to the recent and near-term events,

    - *Information emphasis* is the determination of which selected information should receive increased display emphasis, and

    - *Information format* is modeling the determination of how information is relevant and possibly emphasized should be displayed [13].

2. *Other individuals* may not be close to the work environment or the location which the issue occurs (demonstrated in bubble with job title [6]). Therefore,

**Figure 9:** Information modeling [13].
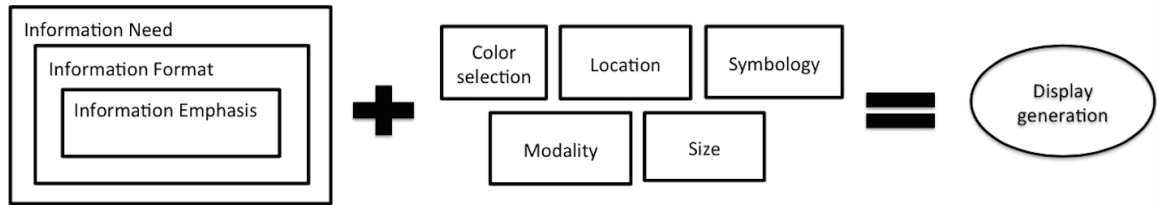


other individuals must provide essential information which the user has no idea or knowledge about them for the user. During this information flow, the user and those individuals should have two-way or one-way communication. One-way communication is mostly radio, broadcast based, and two-way communication occurs between two people at least.

3. *The user* is the main character or element of the IFM which performs decision-making using other elements. For example, information modeling provides advanced awareness about the environment and the problem, and communication with other individuals provide complementary information which the user might not realize. Ultimately, the user can combine and synthesize all information to make a better decision.

4. *Groups* are represented when an individual has the same interaction with all its members [6].

5. *Responsibilities* of the individuals or groups are annotated in bubbles of each individual or group [6].

6. *Flow* the communication between people to complete tasks, is shown as arrows between individuals [6].

7. *Communication topic or action* is representing the detail of the communication or actions on the flow [6]. It is written on arrows without a box.

8. *Breakdowns* are represented with a lightning bolt which indicate a problem in communication or coordination on the flow [6].

For this thesis, the software design terminology has been used to generate the work models to be consistent about vocabulary. For example, the *"Tab"* term is used for the options/menu instead of the *"Focus Area"* term.

## *2.5   Related Works*

In the relevant literature for flight planning and in-flight re-planning, there are studies relevant to flight path optimization algorithms and weather flight planning systems. Several researchers have worked and developed flight path optimization algorithms that generate flight routes around airspace based on the weather changes. Windhorst et. al. [35] have developed that a system generates a new flight route if this system predicts that a flight will enter a weather-impacted airspace within a predefined time horizon. This system requires pre-defined sets to start the generation of new flight routes. The uncertainty of weather forecast has caused that this system regularly generates new flight routes using most updated weather forecasts and radar tracks [35]. Their system is called as Convective Weather Avoidance Model (CWAM); and their study results show that their algorithm generates successfully the flight routes only 75% to 85% of the time [35].

As an example study relevant to weather flight planning system design, Latorella and Chamberlain [16, 17] worked on the Graphical Weather Information System (GWIS) based the weather cues that general aviation pilots use to make a decision. Their display presents surface weather observations (provided by METAR) in text and symbolic form for reporting the stations in mid-Atlantic region, airport identifiers, present position, track symbol, creation time stamp for radar product, a scale legend, and indicates missing data [16, 17]. The implementation of GWIS showed that this display is too old to be useful; also their preliminary results of the implementation suggested that IMC with a GWIS provides pilots with a similar levels of support as do the out-the-window visual cues in VFR, both of which are significant improvements over that available in conventional IMC [16].

Stough et.al. [29] stated that pilots need more than just weather information

to make a decision in flight. Pilot needs can include the information on flight-path-relevant terrain, aircraft capabilities, pilot capabilities,obstacles, air space restrictions, and traffic [29]. Based on the needs, National Aeronautics and Space Administration (NASA), Georgia Tech Research Institute (GTRI) and Rockwell Collins developed a prototype Aviation Weather Information System (AWIN) with the capability to combine information from both on-board system sensors and data-links and to display graphical and textual weather information for the general aviation pilots [29]. This system was called as Airborne Hazard Awareness System (AHAS) that can automatically parse text and weather data, convert it to graphics, evaluate both tactical and strategic hazards in the weather data stream and provide alerts to general aviation pilots (see Figures 10 & 11) [29].
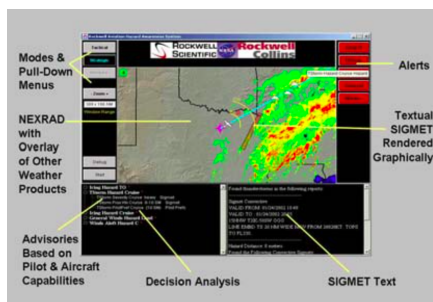


**Figure 10:** AHAS Strategic Display [29]
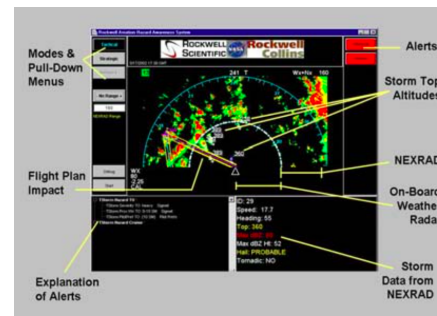


**Figure 11:** AHAS Strategic Display [29]

In addition to the studies provided by Windhorst et. al. [35], Latorella et.al [16,17] and Stough et.al. [29], there are several research to improve and develop the decision support system that helps general aviation pilot to make a better decision for avoiding weather impact zone on planned flight path. These example studies only shows that the cockpit mounted system. However, this thesis focuses on the decision support system designed for portable graphical display as an electronic tablet.

# CHAPTER III

# UNDERSTANDING HOW TO PLAN & RE-PLAN THE FLIGHT

This chapter discusses how to use tablet-based flight planning software applications to make a decision for flight rerouting in flight. The method for the first research question includes two parts: (1) Document Analysis, and (2) Interviews (called Examination Experiment on the Institutional Review Board (IRB) documents). The purposes of document analysis and interviews are to contrast how flight planning and rerouting/re-planning should be performed by the description of FAA with how flight planning and rerouting/re-planning are performed by general aviation pilots in real-life. Interviews were performed in parallel with document analysis which has the intention to classify and provide fundamental knowledge about general aviation weather flight rerouting/re-planning and electronic tablet use in general aviation cockpit.

For document analysis, documents such as annual reports, aviation magazines, research project reports were examined and analyzed. For interviews, volunteer general aviation pilots were invited to participate in in-person interviews or online surveys.

Using the results of those two parts, the description of design requirements and the design of user interface prototype on an iPad were intended to support general aviation pilots for in-flight planning due to sudden weather changes. In the following sections, the document analysis and interview procedures are provided, and their results are represented using methods of cognitive task analysis to indicate what general aviation pilots need to make a better decision.

## 3.1 Document Analysis

The fundamental step for this research is to understand the procedure and federal aviation guidances about flight planning and in-flight re-planning, and also the information resources used to plan and re-plan the flight. For this purpose, FAA resources including federal aviation guidances and other studies which have been developed by different institutions are searched and examined. The analysis of FAA resources and other research relevant to FAA resources aims to provide the primary understanding of the environment.

Federal Aviation Administration provides the information in annual reports, advisory circulars and the electronic code of federal regulations. The advisory circulars are selected using parts related to electronic flight bag use, portable flight bag, ADS-B systems and flight planning/re-planning. Electronic code of federal regulations are selected using parts related to VFR & IFR flight planning and in-flight re-planning, and weather information.

Additionally, the scientific literature was reviewed including articles about electronic tablet use in cockpits, the impact of weather changes during the flight, the examination of federal aviation guidances for electronic tablets. Chapter 2 summarized those studies. In this section, the results of those studies are compared and combined to map the flight planning and in-flight re-planning procedures.

To finalize the document analysis, the results obtained from the federal aviation guidances and research documents are compared and combined to create a general map to support and develop cognitive task analysis.

### 3.1.1 Categorization of Documents

There are several resources that can be examined to understand the current application of general aviation flight planning and in-flight re-planning with or without tablet-based flight planning software. In this thesis, relevant documents are categorized as seen in Table 7.

All categories include subcategories which are listed in Table 7. These subcategories are a kind of bridge between other categories. When these categories are

merged, they provide the big picture for the research question(s). Additionally, Table 7 covers the keywords which were used to classify the documents into exact category.

**Table 7:** The document categorization for document analysis.

| Category | Subcategories | Document type | Keywords | Number of documents |
|---|---|---|---|---|
| Impacts of Electronic Tablet Use | Information Needs, Accident and Incident Rate, Human Perception, Decision Support System, Flight Re-planning Support | Aviation Magazines, FAA annual reports, Aviation agency reports | Flight planning with iPad, Flight re-planning caused weather changes, effects of iPad app in flight, use of electronic tablet in the cockpit | 15 |
| Self-reported Human Performance | Human perception, Interaction with device, warning/alert system, decision-support | Aviation Magazines, News, Accident and Incident reports | Human performance during flight re-planning | 5 |
| Software & Hardware Development | Updated weather forecast, Updated flight documents and charts, Human input opportunity, decision-support system, Warning realization, Less interaction with device | Aviation Magazines, Software company product reports and user feedback | iPad flight app, Comparison of recent flight apps, portable electronic display, electronic flight bag, weather re-planning, alternative flight path | 3 |

In total 23 documents were examined and evaluated; Table 7 shows how many documents were relevant for each category. As mentioned before, several online aviation magazines, federal aviation guidances, aviation agency reports, and relevant technical reports were analyzed for document analysis. The selected time range for online aviation magazines was selected between Jan, 1, 2000 to May, 1, 2015. Two different aviation magazine resources were used: *iPad Pilot News and AOPA*. Those aviation magazines also contained user forums where the recent aviation technology with pros & cons and the aviation future are discussed. Those discussions include user posts which provide user feedback, concerns about technology and useful attachments to reflect their perspectives. This information was also included.

Current Federal Aviation Guidances were included as well as aviation agency reports and relevant technical reports which were published in the last 15 years.

## 3.2  Interview With General Aviation Pilots

As a complement to the document analysis, the interviews with several general aviation pilots were performed to understand any missing parts and any mis-interpretation of the flight rerouting/re-planning due to sudden weather changes in flight. The interviews offered a flexible approach to data collection and the collection of user perceptions and reactions to the re-planning process [28]. In addition to in-person interviews, an online survey was also used to reach more pilots who live at different parts of world.

### 3.2.1  Experiment Procedure and Design

The steps for the interview preparation are listed as:

- *Step 1 - Definition of the interview purpose:* The purpose of interview was to examine and understand what kind of information sources General Aviation pilots use and how they re-plan the flight while flying to the destination airport. Additionally, the use of flight software applications on an electronic tablet was examined for flight re-planning in flight.

- *Step 2 - Question development:* Questions types included multiple choice (when the participant was required to to select a specific response for it), rating scale (when the participant was asked to provide his/her opinion), open-ended (when the participant was asked to present own opinion about a specific topic), closed (when the participant was required to select one or more than one response(s) for it), and filter questions (for the need of specific knowledge or experience of the participant).

- *Step 3 - Designing interview:* Figure 12 demonstrates the experiment procedure as a diagram. The interview has three questionnaire sets. First set is applicable for all participants which asks about their demographics and flight background. Second set is applicable if the participant has experience with flight planning software application on an electronic tablet and/or smart-phone. It asks about which application the pilot uses, since when, and so on. Third set is applicable if the participant does not have experience with flight planning software application.

- *Step 4 - Redesigning interview based upon pilot interviews:* The questions were modified after pilot interviews.

- *Step 5 - Selection of appropriate participants:* The participants were recruited if they have at least private pilot license.

- *Step 6 - Conducting and recording the interview:* The interviews were conducted as in-person interviews and online survey. For the in-person interviews, the participant was invited to the experiment location. For the online survey, the participant was invited with an e-mail. The survey was conducted via Google Form. Both in-person interviews and the online survey have same procedure as explained in Step 3.

- *Step 7 - Data gathering and transcription:* All participant responses were collected and saved. The responses were classified based on interview method and fthe use of flight planning software application.
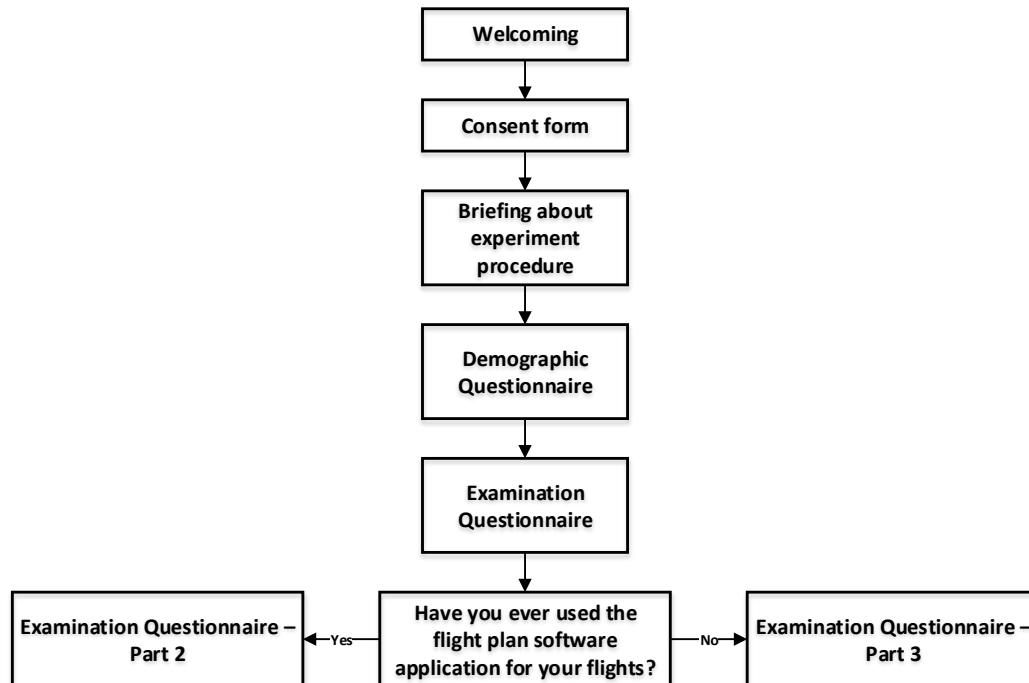
**Figure 12:** The interview procedure.

- *Step 8 - Data analysis:* The data collection includes both qualitative and quantitative data types. Therefore, qualitative and quantitative data were analyzed separately. Quantitave data is used to support the outcomes of qualitative data.

**Detailed Experiment Procedure:** The interview starts with welcoming the pilot and briefing by using the Consent form. Even the participants were informed before the experiment day, they have been told about the details and their rights using the Consent form. The Consent form provides the detailed information for the pilot before running experiment. As a first step, the demographic questionnaire was provided for the pilot to collect information about the pilot's flight experience and background. Demographic and background questionnaire includes age, gender, total flight hours (IFR and VFR), pilot certification, ratings, flight region(s), aircraft model. The following part of demographic questionnaire asks whether the pilot has ever used any of flight planning software application on an electronic tablet. They

were then provided different questionnire according to their experience with tablet-based software application.

Interview Questionnaire Part 2 includes questions about the pilot's flight experience using flight planning software application on the electronic tablet. This part aims to learn more about:

- When and why they have started to use the tablet-based flight software applications,

- Which tablet-based flight software application(s) they have used,

- What the level of their familiarity with the tablet is,

- What their purposes of use are,

- Which information sources they use for flight planning/re-planning other than flight planning software application.

Once the pilot completed this part, the pilot was asked to demonstrate how he/she would use the flight planning software application and what the features of it are useful for his/her flights.

If the pilot had never used any flight planning software application on an electronic tablet, he/she was asked to complete Interview Questionnaire Part 3. This part requires to learn about

- Why the pilot does not use any of flight planning software application on an electronic tablet,

- Which information resources the pilot uses for the flight planning/re-planning.

After this part was completed, the pilot was not asked to give any demonstration.

Same interview procedure was also performed as online survey. The primary purpose of online survey is defined as the pilots might have different experience about weather flight re-planning, and it can affect to the results if only the pilots who fly on one particular area are interviewed.

Online survey was prepared with Google Form documents to collect the data online (see Appendix B.4). The participants were invited to the study sending the announcement to the e-mail list of flight schools and social media.

### 3.2.2 Participants

The criteria for participation was that the participant is a general aviation pilot (must hold at least a private pilot license) and must have flight experience other than training flights. 16 pilots (3 Women, 13 Men) from different parts of the world participated. 11 of pilots (68.75% of total) participated for online survey, the rest of them participate for in-person interviews. Their total flight hours ranged from 55 to 1350 hr (average flight hour=288.925 hr) (see Figure 13).

### 3.2.3 Data Collection

The pilots have provided their responses using questionnaires. This part of this thesis has two different approaches to collect the responses from volunteer pilots as online interview and in-person interview. The interview questions are provided in Appendix B.

### 3.2.4 Data Analysis: Interview

The purposes of data collection are to understand the need of GA pilots and to identify the needs under the description of design requirements. Data analysis has two parts: (1) Demographics & Flight Experience which provide the results of quantitative data as the background information about volunteer pilots, (2) Experience on Flight Rerouting/Re-planning which provide the information how volunteer pilots have made flight re-planning decisions using different information sources. In Appendix C, some results of descriptive data analysis are provided.

#### 3.2.4.1 Demographics & Flight Experience

*Age Groups:* Table 8 shows the different age groups of the pilots who participated. The age limitation for the participation is that they must be older than 18, and the

participants varied across different age groups to understand the flight rerouting/re-planning decision for different age groups.

**Table 8:** Age Groups.

| Age Group | Number of Pilot | Percentage |
|:---------:|:---------------:|:----------:|
| 18-20     | 1               | 6.25%      |
| 21-25     | 2               | 12.5%      |
| 26-30     | 5               | 31.25%     |
| 31-35     | 6               | 37.5%      |
| >35       | 2               | 12.5%      |

*Flight Hours:* Two of the pilots have significantly more flight hours than others. The reason is that they stated that they are also flight instructors. In addition to total flight hours, the comparison between VFR & IFR flight hours and Daytime & Night flight hours were represented to interpret their flight rerouting/re-planning decision process based on their flight environment and experience. This comparison provides to find whether there is any difference on decision making process and information sources they use. Although the time amount spent for the decision does not differ between daytime and night flights, the pilots stated that the only challenge of night flights is to distinguish the sudden weather changes.

*Rating & Certification:* The pilots have varied certification and ratings which are represented on Figure 14. 54% of volunteer pilots have "Airplane Single Engine Land". 50% of them have only private pilot license; the remaining 50% have higher level of certification through Airline Transport Pilot.

### 3.2.4.2  Flight Rerouting/Re-planning Experience

**With Flight Planning Software Applications:** The interview responses showed that 81% of the participants use flight planning software application on their tablets or smart-phones. In Figures 15 and 16, the ratio of tablet-based flight planning software application use and when the participants have started to use them are demonstrated. Since some flight planning software applications are becoming more popular, the ratio of use is increasing depending on the experience of the pilot.
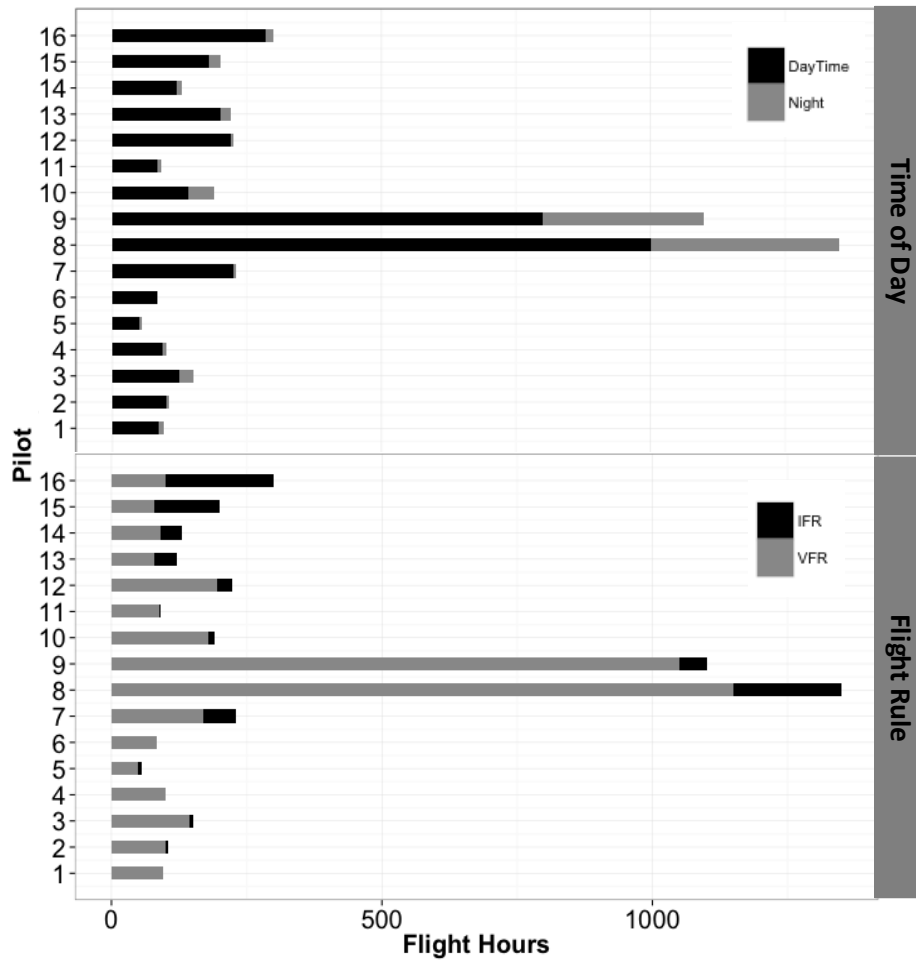
**Figure 13:** Flight hours.
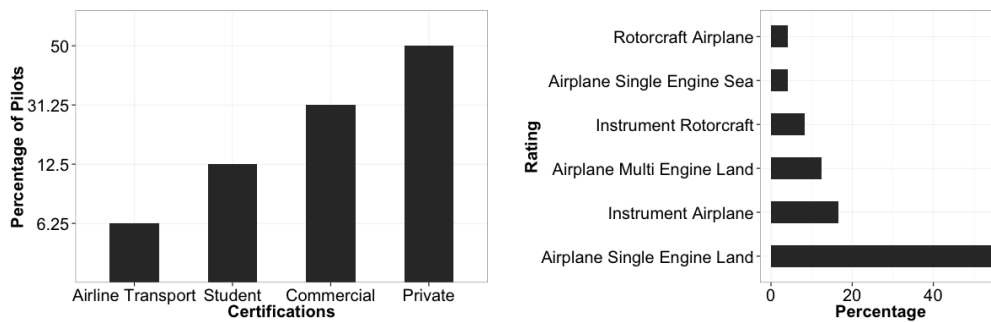


**Figure 14:** Certification and Rating types.

While interviewing, pilots stated that they were not allowed to use those applications during their training. Therefore, they only need to use them when they start to
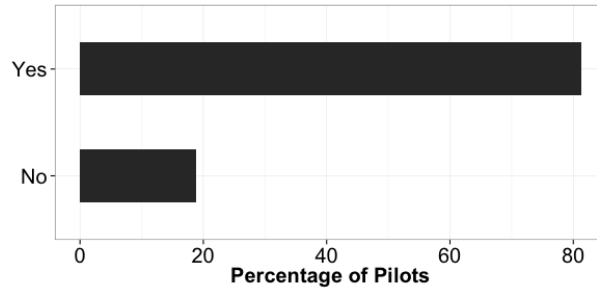
**Figure 15:** Flight software application use.
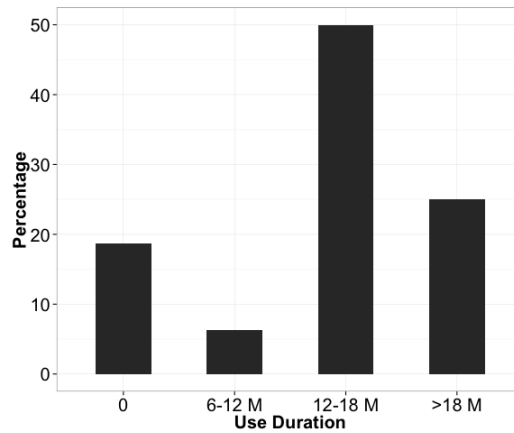


**Figure 16:** When the pilots have started to use them (M = Month).

fly solo or for cross-county flights. Besides this training rule, 38% of volunteer pilots have used them occasionally or at almost every flight excluding training flights (see Figure 17). Thus, their familiarity to use those software applications were questioned, and how much those software applications are useful for them before and in flight (see Figure 18).

*Having weather caused flight re-planning experience:* The pilots were asked whether they have flight re-planning experience caused by weather changes. Their responses were shown in Figure 19, and this graph does not exclude the number of pilots who have not used the flight planning software application yet.

To provide more insight about how the pilots made a decision about flight re-planning, the quotes were provided in Figure 20. As seen, volunteer pilots have diverted aircraft as first step. However, then they observed weather impact zone, and

40
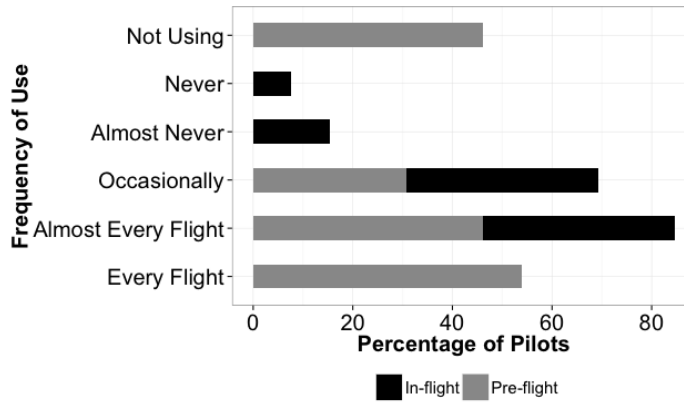
**Figure 17:** Frequency of flight planning application use for pre-flight and in-flight.
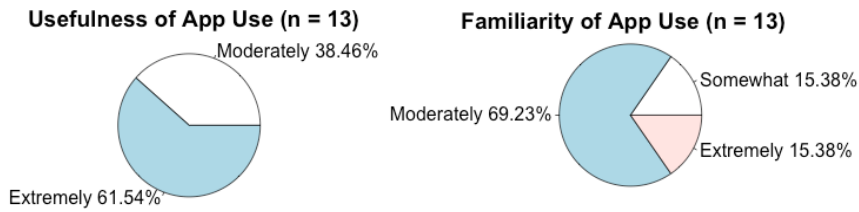


**Figure 18:** Familiarity of flight planning application use and usefulness rating.
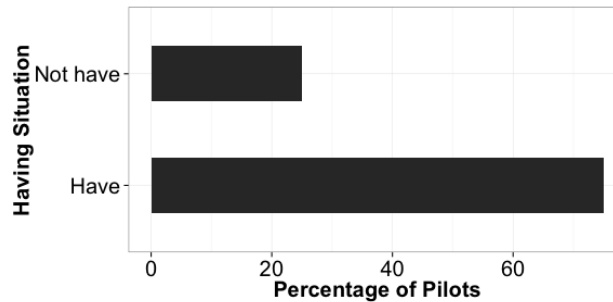


**Figure 19:** Having weather caused flight re-planning ratio.

they tried to land the selected destination if weather did not move toward them or the destination airport.

In addition to decision-making options of the pilots, the relationship between the causes of flight re-planning and decision were represented in Figure 21.
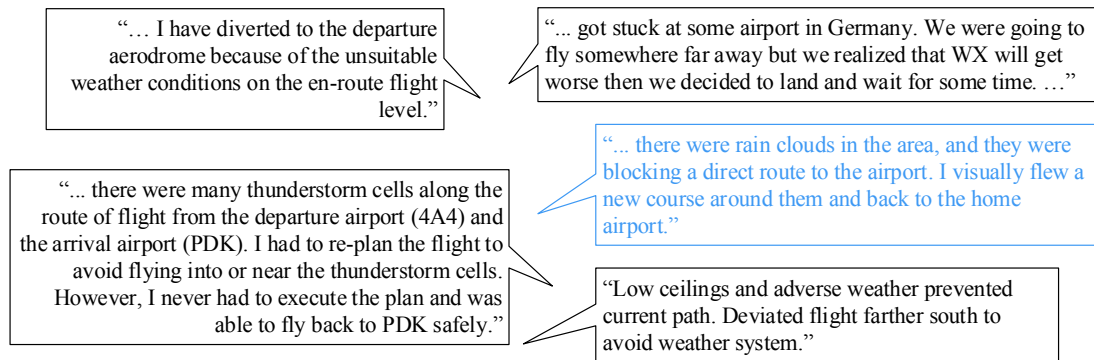
**Figure 20:** Weather caused flight re-planning situation quotes are provided by the pilots (blue box is stated by the pilot who does not use flight planning application).
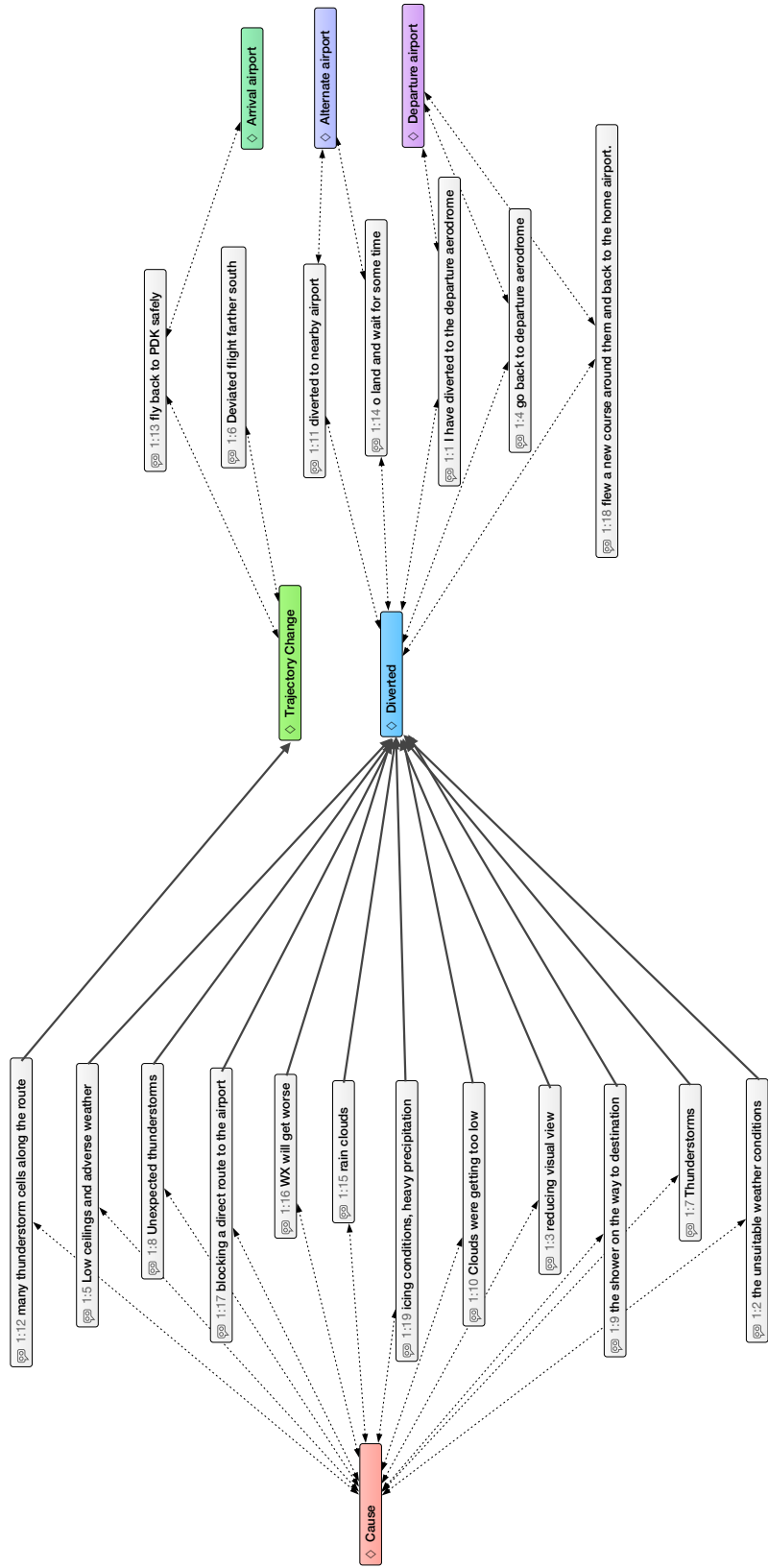
**Figure 21:** The network diagram for cause and effect of flight re-planning situations the pilots had.

**Without Flight Planning Software Applications:** 19% of volunteer pilots have never used flight planning software application on an electronic tablet (see Figure 15). Those pilots were asked why they did not use those software applications either flight planning or rerouting/re-planning. 100% of those pilots have same reasons not to use them that they stated:

1. *High cost for software application,*

2. *Not necessary to use it.*

Instead of tablet-based flight planning software applications, they use other weather and flight information sources as:

- METAR,

- TAFs,

- SIGMETs, AIRMETs,

- PIREPs,

- Communication with ATC,

- Communication with other closest aircraft,

- Listening radio,

## 3.3 Performing flight planning and in-flight re-planning

The interview and document analysis results are represented using Hierarchical Task Analysis (HTA) and Decision Action Diagram (DAD) to reflect the user/the pilot perspective which they provided how they plan and re-plan their flights, and which information source and/or tool they use. The results of the online survey and interview show similar results. The only difference is for online survey that the pilots were not able to demonstrate how they use their flight planning software applications on the electronic tablet during flight planning and in-flight re-planning.

While interviewing, volunteer pilots stated that there are environmental characteristics which have impact on the decision for flight re-planning. These environmental characteristics can be listed as:

1. *Rapid changes in weather:* (Usually deteriorating weather) According to volunteer pilots, the tools inside of the cockpit are not sufficient to support pilot reaction to unforeseen conditions such as rapid deteriorating weather. The rapid weather changes may cause the accidents if the pilot does not have enough experience or enough knowledge about the weather behavior to respond appropriately or to maintain control of aircraft inside of bad weather zone.

2. *The lack of cellular data service and/or wireless:* This factor is related with the aircraft equipment. The aircraft does not include wireless connection or cellular data for the pilot use. This requires the pilot to obtain up-to date weather information from other sources and mentally include (or manually enter/type) them when consulting the flight planning application. However, recent technology enables to install and maintain ADS-B In systems for aircraft to get datalink [25]. ADS-B In devices can be installed as portable or mounted system which depends on installation budget. Additionally, some of tablet-based software application companies produce portable ADS-B In devices such as Stratus which is a product of ForeFlight.

3. *Distraction:* The pilot distraction while interacting with electronic tablets can lead to accidents. While the pilot are interacting with the electronic tablet to decide the new flight path, he or she can become immersed and ignore the other cockpit displays. For example, the pilot can be distracted or lose his/her situation awareness while the pilot is checking the weather information by using electronic tablet software. Because of the interaction with the electronic tablet to search for alternative flight path and weather forecast, the pilot can miss flight information provided on the cockpit displays while dealing with unforeseen event.

Additionally, they defined what they expect from a tablet-based flight planning

software application in Figure 22. Thus, those items were used to generate Information Flow Model to meet their needs.
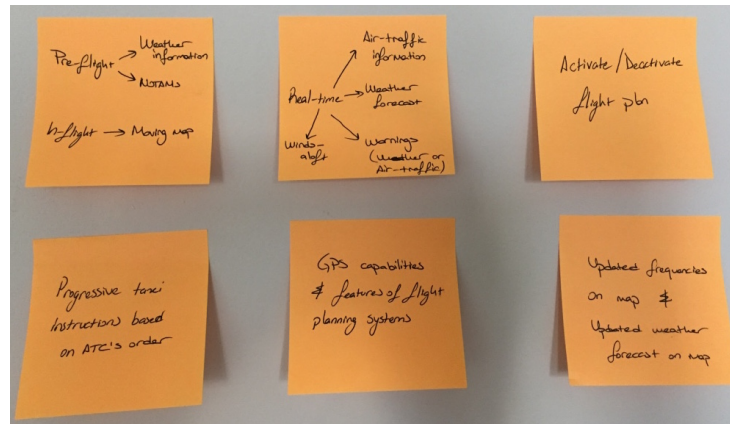


**Figure 22:** The expectations of volunteer pilots from a tablet-based flight planning software application.

In the following sections, task models are explained, and then the models are presented to demonstrate how the current flight planning and in-flight re-planning are performed. And the findings are discussed to develop the design requirements using Information Flow Model.

### 3.3.1 The Creation of Task Models

Task models – HTA creation – aim to demonstrate how general aviation pilots plan their flight and re-plan when they encounter with unexpected weather changes. Therefore, there are two separate HTAs that were generated for the flight planing and re-planning.

Both Hierarchical Task Analysis in Figures 23 and 24 illustrate how general aviation pilots perform and should perform a flight planning and in-flight re-planning. As seen on HTA for re-planning, general aviation pilots do not have any visualization for alternative flight path overlayed with real-time weather information. They currently use the information which are provided via communication with ATC and listening broadcast.
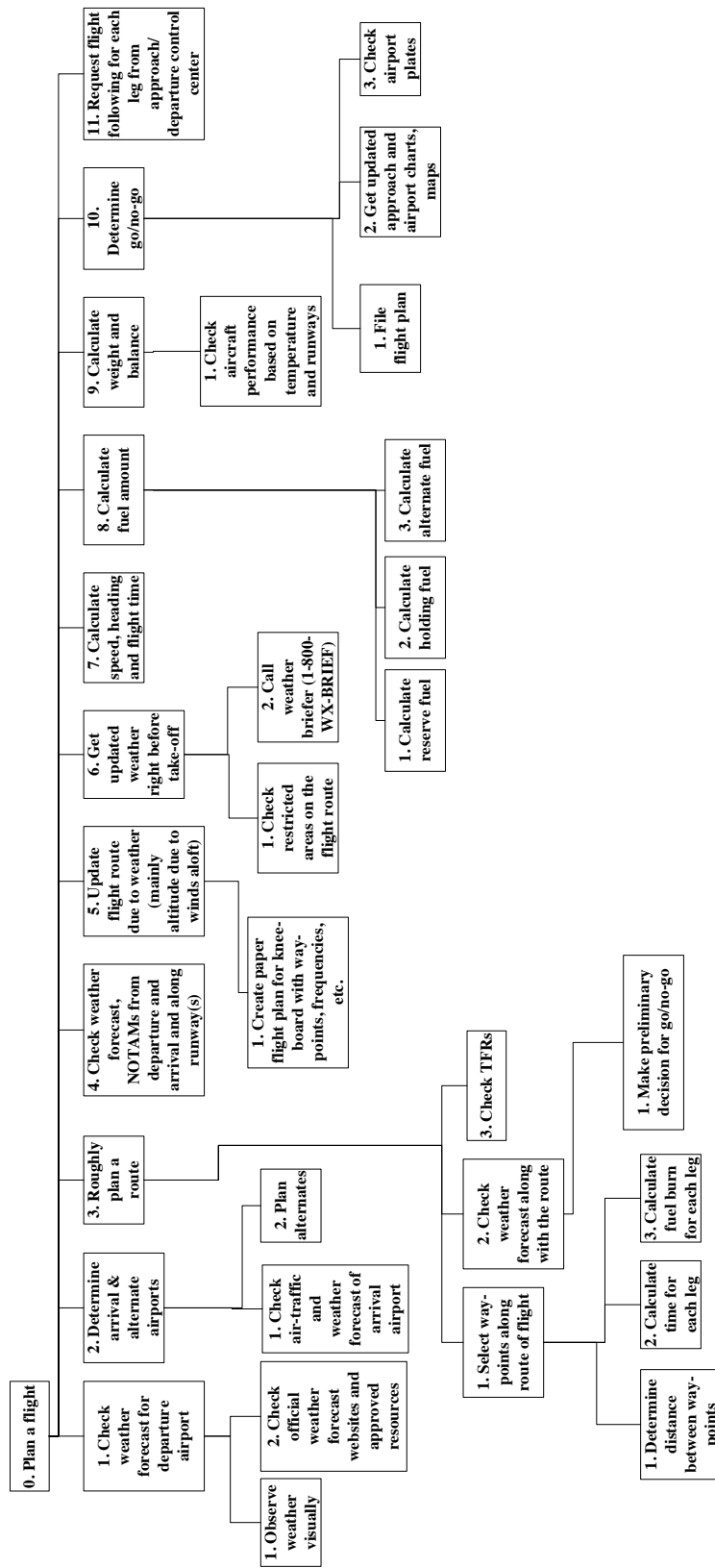
**Figure 23:** How general aviation pilots plan a flight.
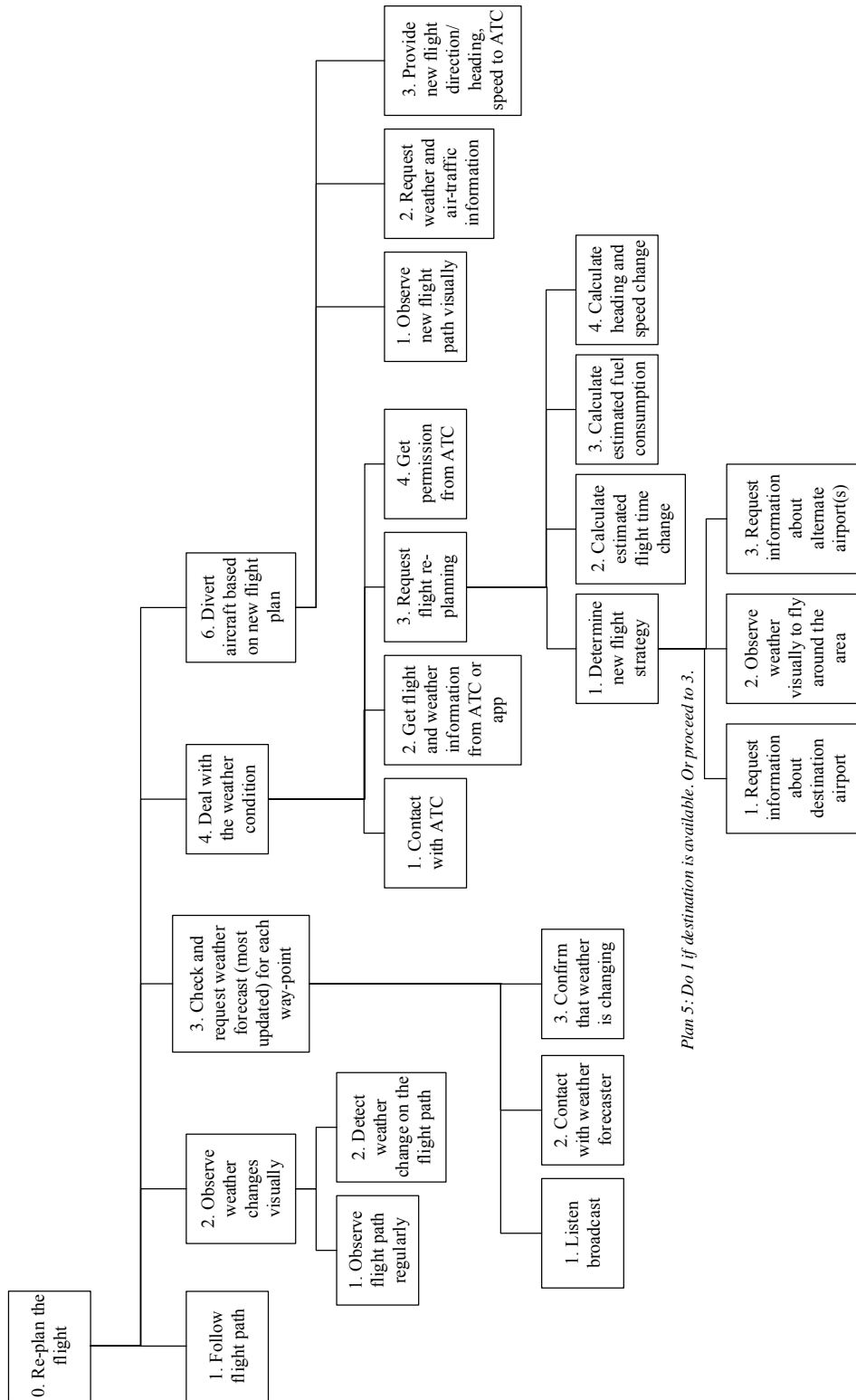
**Figure 24:** How general aviation pilots perform to re-plan a flight while flying.

### 3.3.2 The Creation of Decision-Action Diagram

How the recent flight planning and in-flight re-planning are performed by general aviation pilots and how they currently use technology to plan and re-plan their flights are demonstrated with Decision Action Diagram. Because, the common outputs of these diagrams aim to support the description of design requirements, and DAD can show what type of questions the pilots can ask and how their decision can be affected based on the environmental factors.

For this thesis, DADs include the tasks which are performed using any existing system (see Figures 25 and 26) and should provide an evidence about how the design of a new system and its additional tasks should be performed (see Chapter 4). To provide strong evidence, HTA is used as a supportive method to conduct DAD based on new scenario and its tasks. Another support is generating storyboards before conducting DAD.

To create Decision Action Diagram, each action associated with a decision should be represented with an exit line from the decision diamond shape [28]. Until all possible decision of each action should be inserted into the diagram to complete DAD.
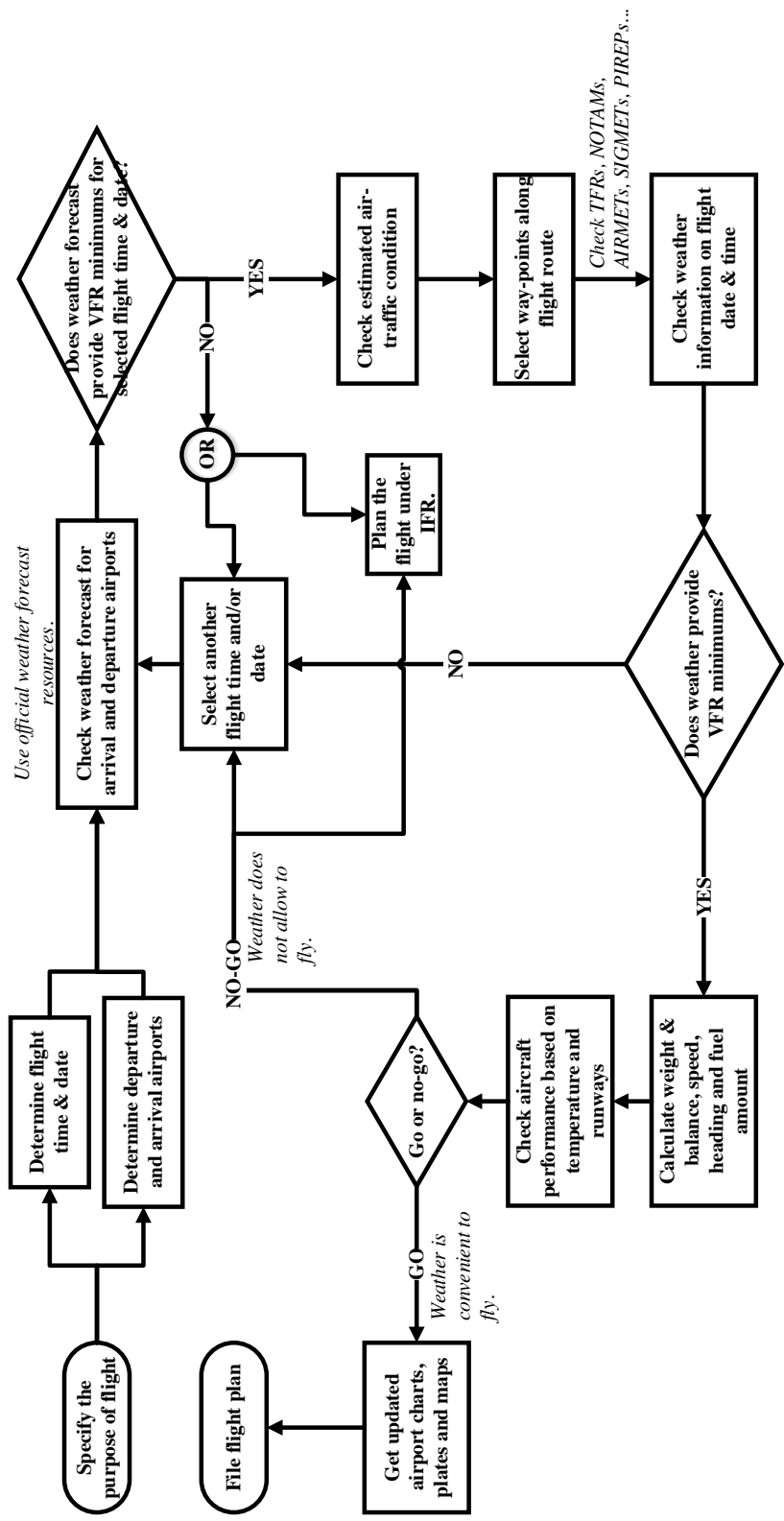
**Figure 25:** How to proceed and decide to plan the flight – Decision-Action Diagram
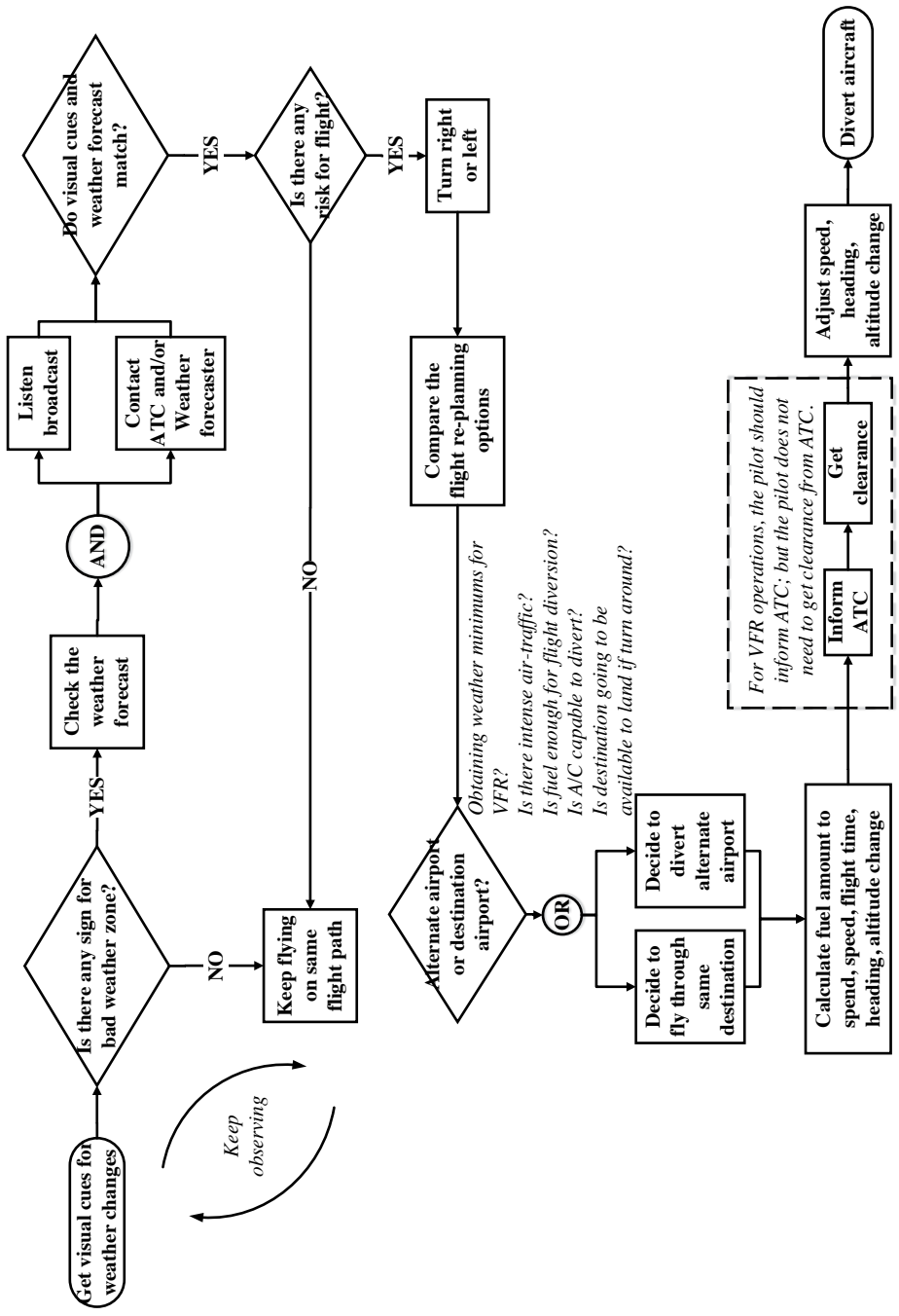
**Figure 26:** How to proceed and decide to re-plan the flight – Decision-Action Diagram

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### 3.3.3 How to Represent Information

The information management is provided with the communication and avionic displays in cockpit. However, general aviation cockpits may not have enough space to install these avionic displays. Therefore, a small aircraft has limited information availability. In addition to limited space in a general aviation cockpit, the installation and maintenance of a new display is expensive when it compares with tablet technology.

The IFM additionally provides the information that a tablet-based flight planning software application can help to support the pilot's decision for rerouting. The Information Flow Model includes the tablet support system (provides what a tablet-based display should represent), the communication between individuals and/or teams (including broadcast), mental support model. For information modeling of tablet support system, the federal aviation guidances and FAA procedures provide the main elements as standards. The procedural steps between each flight phase, which the general aviation pilot has to complete each task before take-off until landing to the arrival airport are determined by FAA guidances [9–12]. In accordance with interviews – which provide more information about the real-life implementation of procedure and FAA guidances – the Information Flow Model is demonstrated with the new perspective for the proposed user interface design in Figure 27.

In pre-flight phase, the alternate flight paths are planned in order to calculate alternate and reserve fuel amount (see Figure 2). If the alternate flight paths are saved as input into the flight planning software application while planning a flight, the pilot can provide the single input (getting weather forecast) while rerouting the flight. The real-life flight rerouting process due to sudden weather change is started with visual confirmation by the pilot. After the pilot evaluates visual cues about the situation, the pilot initiates the communication with ATC and other aircraft (if they are in the bound for visual contact).
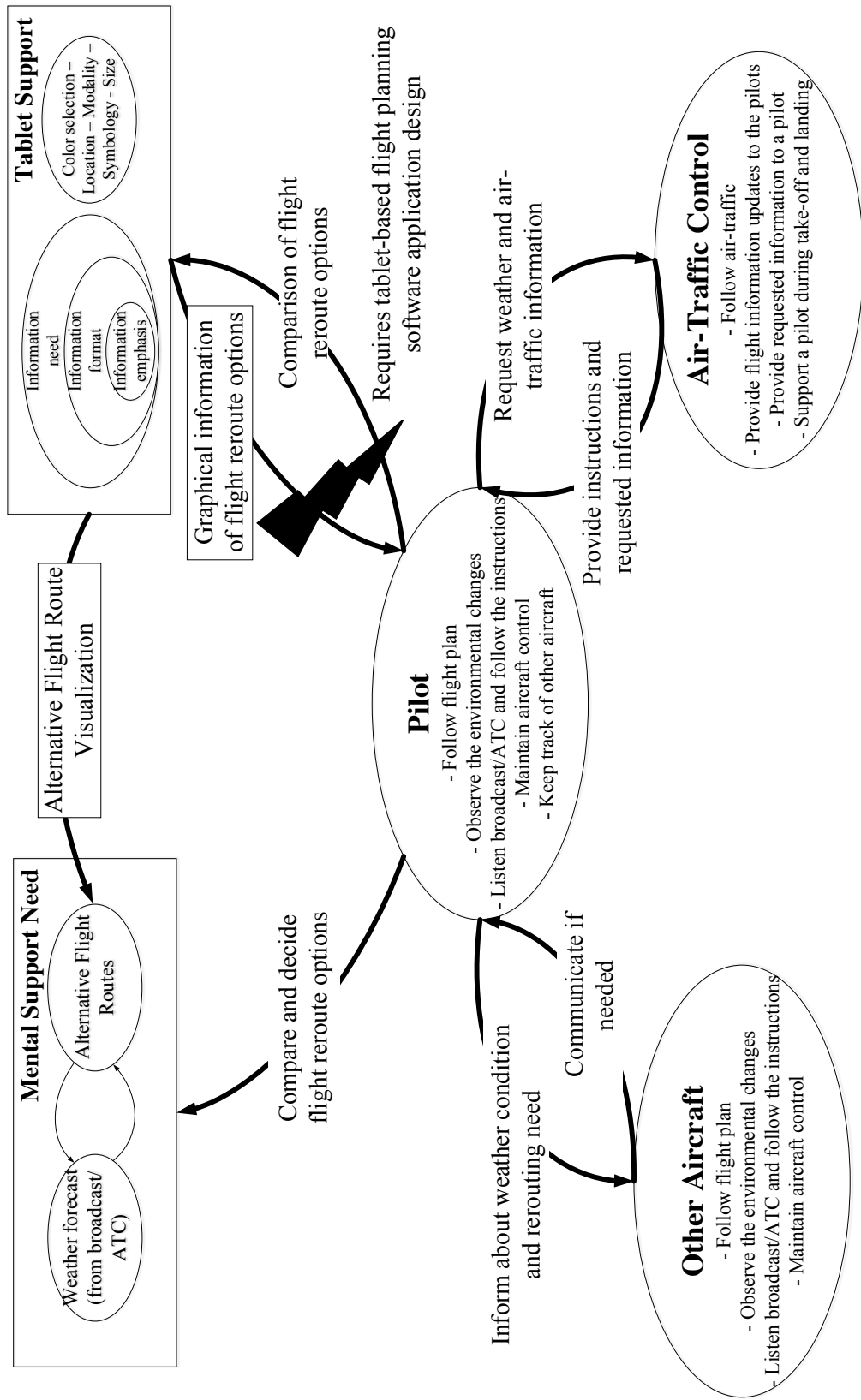
**Figure 27:** Information flow model for rerouting due to sudden weather change.

## 3.4  Summary

Both cognitive task analyses and process charting method provide that the fundamental understanding about how to plan a flight and how to re-plan a flight from the perspective of a general aviation pilot. Although the aviation rules are very restricted and cannot be changed based personal decisions, the interviews indicated that there are slight differences between real-life pilot processes and the processes described by federal aviation guidances. Task models and Decision Action Diagrams represent how general aviation pilots perform flight planning and flight re-planning to reflect the pilot perspective.

Information Flow Model indicates how the flight re-planning process should be adapted when a tablet-based support system is included into the work domain. IFM provides how the flight re-planning process can be updated using tablet-based flight planning software application. The visualiation of weather condition change with flight reroute options aim to support the mental of pilot. Thus, a pilot will be able to interpret information using tablet support system. In Chapter 4, these task and information flow models provided the evidence to describe the design requirements.

## 3.5  Limitations of Document Analysis & Interview

*Limitations on Document Analysis:* Documents which were selected to analyze were scanned based on keywords relevant to flight planning/re-planning and tablet use in-flight. Since the document scanning process is long and should be done carefully, there might be still missed information to include to the analysis. However, those results were aimed to compare with Validation Experiment. This comparison might provide to find where the information is missed.

*Limitations on Interview:* Interviews were completed in two parts as online survey and in-person interviews. Online surveys provide advantages as reaching more pilots to learn about their experience and reaching more pilots who are not living or flying close to the interview location. However, the interviewees and interviewer did not have any interaction. Therefore, the interviewer did not have a chance to ask complementary questions to learn how they use tablet-based flight planning software

applications in detail, and to complete gaps which the pilot did not provide. On the other hand, in-person interviews have advantages as interaction between interviewer and pilots, and opportunity to ask complementary questions and to request demonstration of their tablet flight planning software application use. These demonstrations and complementary questions were helpful to get more information about how the flight planning and in-flight re-planning process differ from the procedural rules.

# CHAPTER IV

# THE DESCRIPTION OF DESIGN REQUIREMENTS

In Chapter 3, the results of document analysis and interviews were discussed. With the information about how general aviation pilots perform flight planning and in-flight re-planning using tablet-based flight planning software application, a set of design requirements can be generated.

The approach for the second research question is:

1. to describe of possible design requirement,

2. to design user interface prototype of a tablet-based flight planning software application to use for validation experiments,

3. to evaluate and validate these design requirements with an user interface prototype,

4. to iterate the possible design requirements based on the results of validation experiment for the final design requirement list.

Chapter 4 discusses the design requirement generation process and the user interface prototyping process.

## 4.1  The Generation Process of Design Requirements

The description of design requirements for a tablet-based flight planning software application followed by the process as shown in Figure 28. When data were collected from volunteer pilots, the work domain restrictions and user profile were described clearly. Next, the task analysis and document analysis results are used to indicate general aviation pilots needs and how the flight planning and in-flight re-planning process should be adapted according to incorporate tablet technology. Then these needs were transformed into the design requirements. Those design requirements are

initially identified as the Possible Design Requirements (PDRs). After they are evaluated (see Chapter 5), they will be refined and identified as the Design Requirements (DRs). Once the PDRs are described, they aim to prioritize as the main design requirements and the supplementary design requirements.
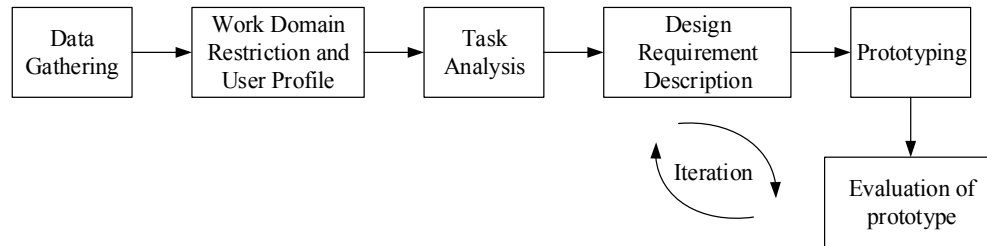


**Figure 28:** The iterative process for the design requirement description.

The PDRs should be used to design a user interface prototype to enable the system for the potential user. Once a prototype application is designed, the testing process starts to evaluate and validate each design requirements based on given tasks to volunteer pilots.

When the experiments are completed, the outcomes are used for the iteration process which uses the results and evidence based on the user tests. In this thesis, the validation involved user testing of user interface prototype to fulfill the design requirements. In the iteration process, the user inputs and responses were analyzed to understand which part of the system requires to be changed or modified.

### 4.1.1 Possible Design Requirements

The crucial step in describing the Possible Design Requirements is to analyze what the users, who have experienced the problem, needs from existing system domain which is flight planning software application on an electronic tablet.

#### 4.1.1.1 How to Describe the Possible Design Requirements

The results of interviews and document analysis describe how to perform the flight planning and in-flight re-planning, and the results of task models and IFM represent the user needs and demands for modification/improvement of existing systems. As

seen in Figure 27, the work model has a breakdown as the need of tablet-based support system since the installation and maintenance of a new instrument are expensive in addition to limited space problem in a general aviation cockpit. The answer for what is missing between flight planning and in-flight re-planning processes is shown in Figure 29.
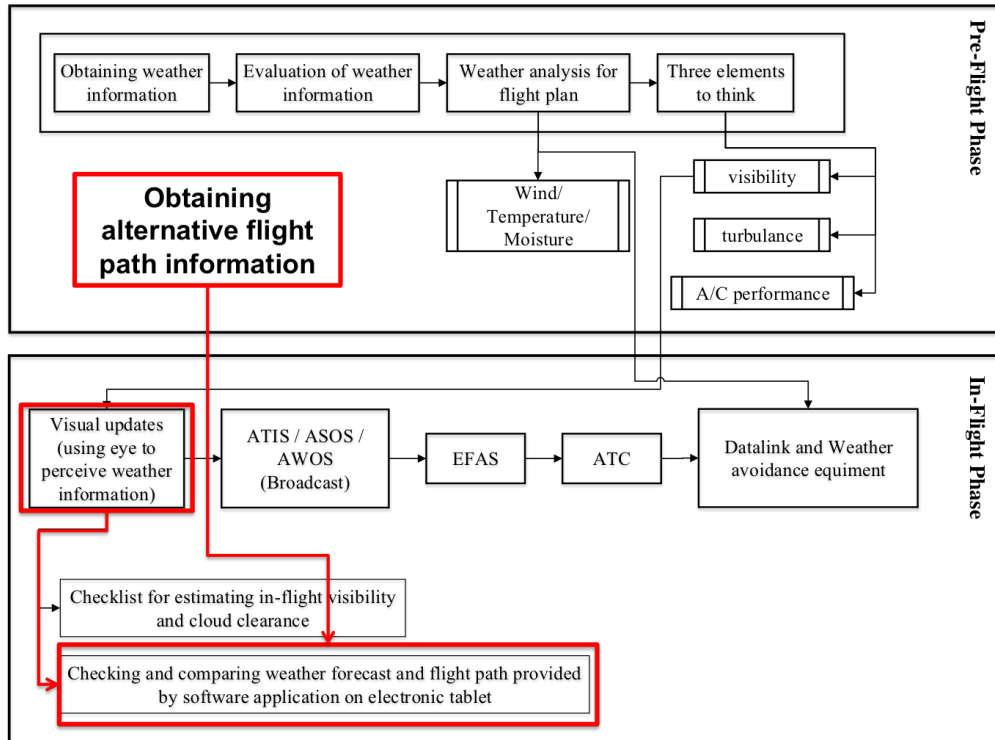


**Figure 29:** The proposed system.

The pilot shoud be aware of weather changes on the planned flight path. According to HTA and DAD of recent flight re-planning, the process starts with enough visual cues. Especially for naive pilots, this might be hard to understand those visual cues. They need a real-time weather information overlayed with flight path map which is described under PDR 10. The graphical information and the visual cues can be both interpretted to determine for rerouting. Furthermore, the pilot should be alerted for unexpected weather changes and the weather impact zone to provide more information which might affect the safety of flight. Thus, PDRs 11-12 and 13 are described.

The models for fligth re-planning process which are HTA and DAD do not include any plan or step for tablet-based support system. The tasks which are described under plan 0.4.3.1 in Figure 24, with *Compare the flight re-planning options* task which was described in Figure 26 were performed mentally by the pilots. Because, the pilots cannot use tablet-based software applications for rerouting recently. Thus, the first need is that the update/development of tablet-based software application support general aviation pilots with graphical information to compare the flight reroute options (see PDRs 3 to 7).

To suggest flight reroute options, a tablet-based software application requires input information from the pilot as a nature of software algorithm. This means that the pilot is required to provide inputs as flight plan information into this tablet-based software application. However, HTA and DAD for flight planning do not include any task or step to indicate the use of tablet-based software application. Therefore, PDRs 1 and 2 were described to use during flight planning.

Table 9 summarizes how the work models and Information Flow Model were interpretted using utterance of volunteer pilots to describe major needs and tasks. These tasks and major needs provided necessary functions to describe the Possible Design Requirements.

Once the evidence is transformed into PDRs, they can be listed and evaluated (see Table 10). These PDRs were specified only as user experience requirements. These design requirements are intended to update or replace an existing system which are recently used by several pilots.

## 4.2   The Prototype Application Design

Only showing the list of PDRs may not make sense to a volunteer pilot for evaluation and validation of them. To understand how the system should work, a pilot should interact with it and test it as a visual tool. Therefore, the Possible Design Requirements which were listed in Table 10 were used to design an user interface prototype. Thus, the prototype enables a pilot to interact with it to evaluate each of design requirement.

**Table 9:** How the Possible Design Requirements were described.

| Pre-Flight Planning | | |
|---|---|---|
| **Tasks** | **Major Needs** | **PDRs Number** |
| Tap on "Flight Plan" tab (focus area) | | |
| Decide and select origin, destination and alternative airports | Saving airport names, way-points, and flight plan | PDR 1 |
| Select way-points on flight route | | PDR 2 |
| Preview flight route information/map | | |
| Tap on "Rerouting" tab | | PDR 3 |
| Follow weather forecast update frequently | Getting weather updates and alerts | PDR 10 - PDR 12 - PDR 13 |
| Compare flight reroute options | Comparison between flight reroute alternatives under weather condition | PDR 4 - PDR 7 |
| Calculate new flight parameters (heading, speed, fuel amount) | Getting support with estimated flight parameters | PDR 5 |
| Select best possible flight reroute option | Checking fuel amount and flight time changes | PDR 6 - PDR 11 |
| Follow selected flight route | Update on flight map | PDR 8 - PDR 9 |

**Abstraction Hierarchy for Functional Interface:** Once the PDRs are described, the specifications and functionality of user interface prototype was identified using Abstraction Hierarchy. In this thesis, AH was used as a method that the representation of how the prototype application and proposed system can be fitted in current in-flight re-planning functions. In Figure 30, five levels of the AH were structured for the design of interface prototype. The structure of AH has been identified based on the purpose which general aviation pilots aim to achieve while performing in-flight re-planning. Levels of AH are identified what user interface prototype should include to achieve the purpose of system such as weather change warning, rerouting options which provide three flight path options (horizontal trajectory change, vertical trajectory change and alternate flight path), and what functions the pilots should

**Table 10:** Possible design requirement descriptions for the validation with General Aviation pilots.

| PDR # | Possible Design Requirements (PDRs) |
|---|---|
| **PDR 1** | Design the flight planning software application by adding a new tab as "Flight Plan". The user should be able to enter and save the flight plan data including alternative flight path info. |
| **PDR 2** | The "Flight Plan" tab should include: (1) Destination, (2) Origin, and (3) Alternate airports, (4) Flight date & time, (5) Options as weather, air-traffic, and fuel amount. |
| **PDR 3** | The design includes "Rerouting" tab. The user should be able to compare the possible flight paths to reroute or change the trajectory of the flight vertically or horizontally. |
| **PDR 4** | "Rerouting" tab must include the suggestions as vertical trajectory possibility, horizontal trajectory suggestion, alternative flight path. |
| **PDR 5** | "Rerouting" tab must provide the information of weather radar overlayed with map, and predicted fuel amount to arrive the destination. In addition to these, the user must be able to receive the location of the aircraft close to the flight path. |
| **PDR 6** | The weather zone, which causes the rerouting decision, must be depicted with the appropriate geometrical shape. This allows the pilot can recognize the weather zone impact to avoid the aircraft from that area to fly in safe. This requirement is currently applied on other applications; therefore, it is not special for this study. |
| **PDR 7** | The screen must demonstrate two different options to decide how to change the flight path. The user should be able to see the comparison between (1) Alternative Flight Path (AFP) & Vertical Trajectory of the flight path, (2) AFP & Horizontal trajectory of the flight path, (3) Vertical & Horizontal trajectory of the flight path. |
| **PDR 8** | Design the flight planning software application by adding a new tab as "Flight Track". |
| **PDR 9** | When the user taps/selects one of these flight path options on the "Rerouting" tab, the "Flight Track" tab must be updated with the selected flight path. |
| **PDR 10** | The user should be able to get weather forecast overlayed on the map. |
| **PDR 11** | The system should be able to provide the altitude difference between top and the bottom of the weather zone. This support the pilot to decide to descent or climb to pass the weather impact zone. |
| **PDR 12** | If the weather information has changed in a way that it might affect the safe of flight, the system must suggest warning message on the screen. |
| **PDR 13** | The user should be able to ignore the warning message and keep flying on the current flight path. Or the user should be able to go "Rerouting" tab to see options. |

take to use the system properly. This AH aims to demonstrate how the proposed system is targetted to adapt into current system. Furthermore, Figure 31 represents how the proposed system should perform using user interface prototype.

This prototype is not a dynamic system, is static which means that it cannot get datalink or send data. The prospective user can only interact with the items on its interface; however, the real systems would have datalink capabilities.
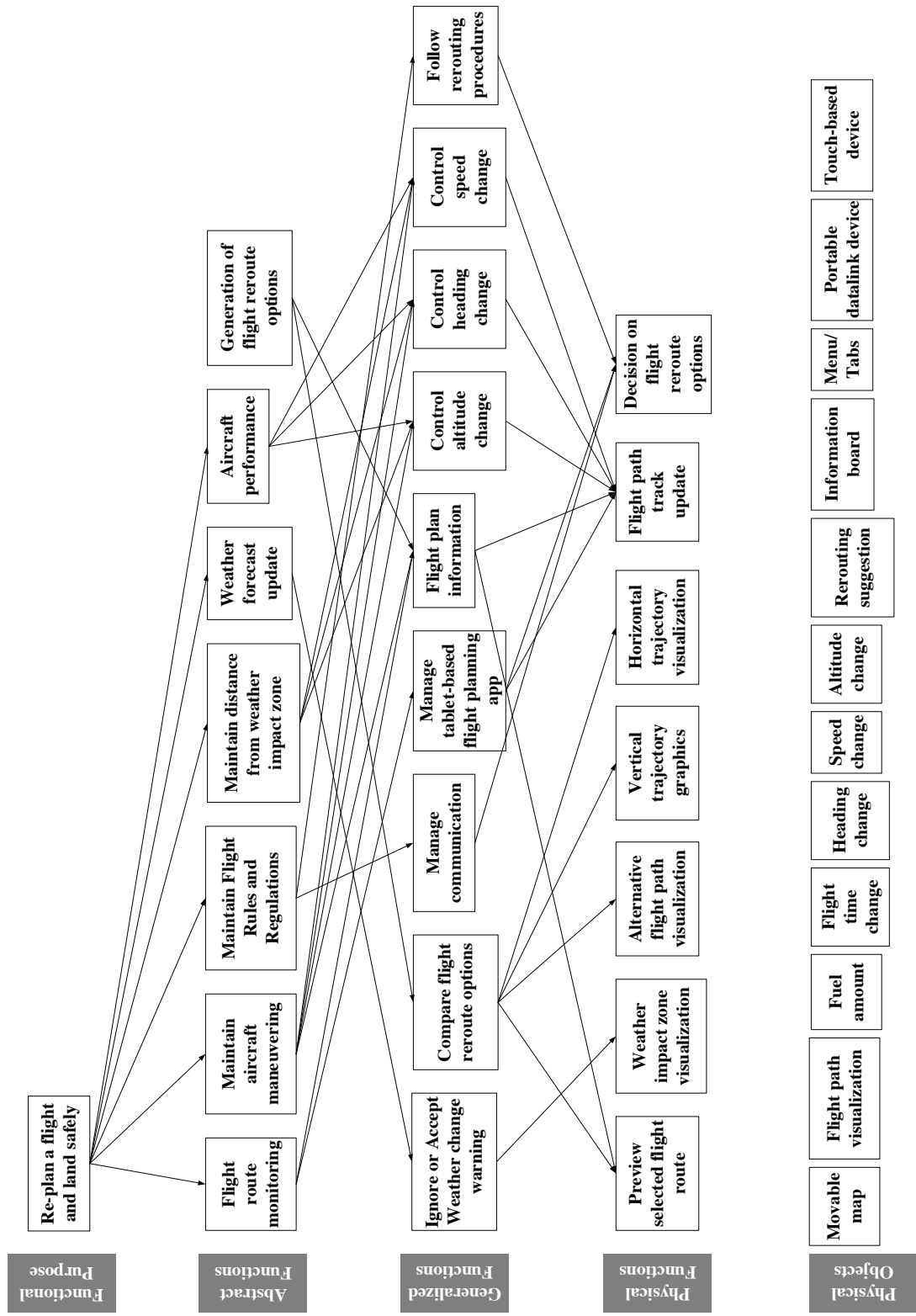
Figure 30: Abstraction Hierarchy of the user interface prototype.

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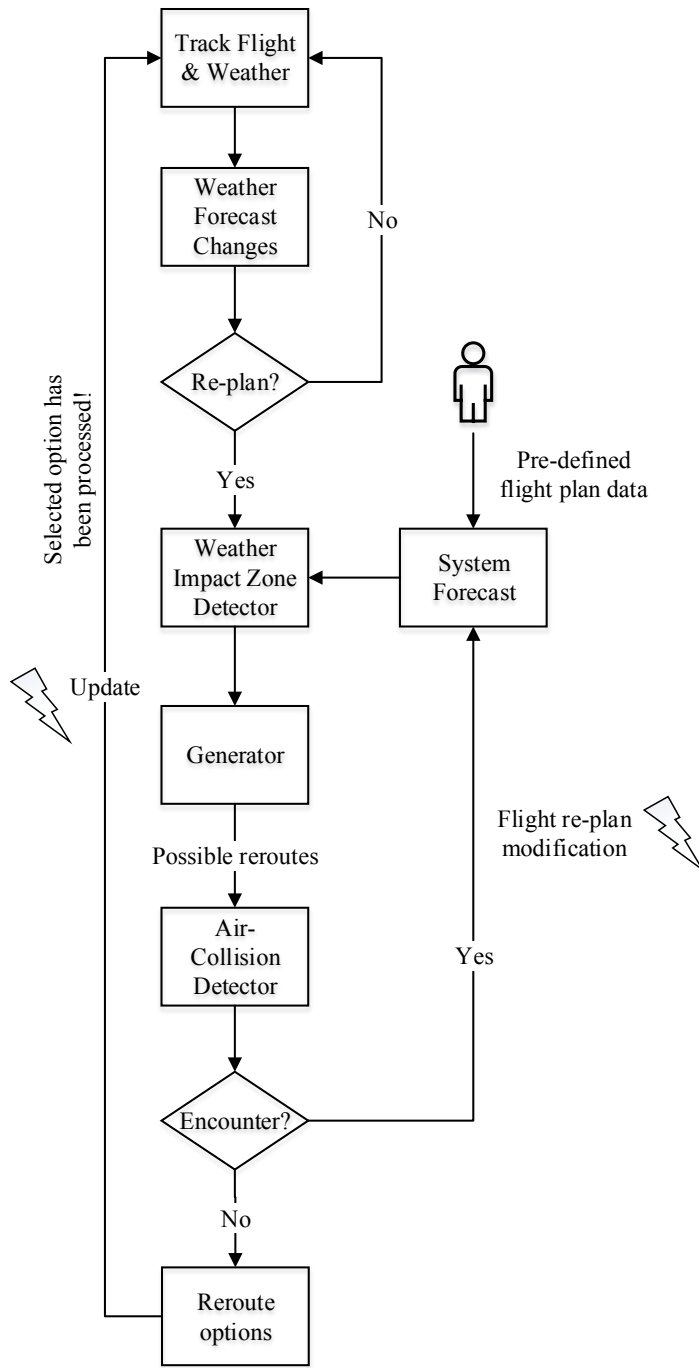
**Figure 31:** The system work flow.

### 4.2.1 Prototyping Process

The user interface prototype was designed to perform the two different flight scenarios during validation experiment. While the prototype was designed using the list of PDRs - Table 10 -, the current prototype does not include all PDRs. For example, PDR 6 was not implemented on the current interface prototype. Because of the limitation of design tool. Therefore, the participants were informed before the demonstration, and showed them how the system exactly should be and should work. In the validation experiment, there are two flight scenarios:

1. The flight from KATL to KLNP that the pilots will encounter an unexpected thunderstorm over KLNP airport,

2. The flight from KATL to KGWO where the pilots will encounter an unexpected thunderstorm with heavy rain before KGWO airport.

The prototyping process was started with storyboards. Storyboards were constructed to support the scenarios which a pilot will be asked to perform during validation experiment. The tools for prototyping: `Xcode-Storyboards` and AppCooker were used. `Xcode- Storyboards` were provided to play the system on Macbook devices and also it generated the code part while storyboards were generated. However, `Xcode` does not support uploading the prototype into an iPad without an evaluation process. Another user interface design tool - AppCooker - was used to upload the software application into an iPad. AppCooker does not provide the code part; however, it enables the prospective users to interact with the interface to understand how the tablet-based software application can be used before a flight and during a flight.

### 4.2.2 How to Use the Prototype Application

The purposes of this prototype design are (1) to enable the evaluation of the PDRs and (2) to find any interaction and/or design error during experimental flights.

In Figure 32, "Flight Plan" tab screen-shots were demonstrated with annotations. This tab enables a pilot to enter flight plan information: origin, destination and alternate airports, flight date and time. Additionally, a pilot can activate or deactivate

weather information, air-traffic information and fuel amount while saving the flight plan into tablet-based flight planning software application. When a pilot saves the flight plan information, the system provides a preview of flight path to confirm that flight plan information is correct. If the flight path preview is correct, a pilot should tap on "Fly" to activate tablet-based flight planning software application.

When the aircraft reaches a specific altitude level, tablet-based flight planning application should activate the "Flight Track" tab (focus area) automatically. As seen in Figure 33, this tab provides:

- The flight path on a map tracks the aircraft and includes broadcast information when a pilot zooms in,

- Updated information box shows the weather forecast which is unexpectedly changed in flight, the next and previous way-point information.

While flying on the planned flight path, the system gives updates about weather information on an information box. This update can serve to inform the pilot or it can warn the pilot of unexpected weather changes. This unexpected weather forecast update triggers the weather warning alert of the system. If the pilot does not take any action to change flight direction, the system gives a warning message to suggest the rerouting. This alert can be ignored or the pilot can tap on "Rerouting" tab (focus area) to see the rerouting options.

In "Rerouting" tab, there are six options as:

- Three of them – Alternative Flight Path, Vertical and Horizontal – represent the reroute suggestions as single demonstration.

- Three of them are the comparison between flight reroute suggestions. These comparisons are:

  1. Alternative Flight Path versus Horizontal Trajectory Change,

  2. Alternative Flight Path versus Vertical Trajectory Change,

  3. Vertical Trajectory Change versus Horizontal Trajectory Change.

- And if a pilot does not prefer to change flight path, he/she can cancel the options by tapping on "Flight Track" focus area.

The divided screen feature enables the display of the comparisons between flight reroute suggestions. Thus, the pilot can compare two flight reroute suggestions visually (one of them is on the right side, one of them is on the left side of the display screen) as seen on Figure 34.

When a pilot taps on the suggested flight reroute with three fingers, the flight reroute suggestions provide the information as:

- Current (cyan line) and suggested flight path lines (dark blue line) are shown together,

- The changes about estimated flight time, estimated fuel amount, heading and speed.

These estimated calculations can help to compare the options based on remaining amount of fuel and the direction of weather impact zone.

Once the pilot chooses one of the flight reroute suggestions, he/she should tap on the selected suggestion with two fingers. Thus, the selection is represented as a preview with new flight path information such as heading and speed changes (see Figure 34). Then a pilot should tap on "Reroute" to update the flight map on the "Flight Track" tab.

## *4.3  Summary*

Chapter 4 discussed how the Possible Design Requirements were derived and how the interface prototype was developed for the validation experiment. The Possible Design Requirements were defined based on the major needs of the pilots and tasks in accordance with the outcomes of AH and IFM. In total, there are thirteen Possible Design Requirements to evaluate, and twelve of them were used to design an user interface prototype.

This prototype application was designed for an iPad that a volunteer pilot used to understand the design requirements in visual format. Furthermore, the section

which was used as a training material for volunteer pilots – *How to Use the Prototype Application* – explains how the pilot should use it properly. This aims to help them to provide significantly more detailed comments for each.

A pilot should type origin, destination, alternate airport name with selected flight data and time.

Tab on "Save" to preview the flight plan on a map.

**Origin Airport:** text field

**Destination Airport:** text field

**Alternate Airport:** text field

**Flight Date & Time:** Today 8 29 AM

**Weather Forecast**

**Air Traffic**

**Fuel Amount**

These options can be activated while saving a flight plan or if they are needed to use in flight.

**All should be selected (recomended).**

**Flight Preview**

Fly

The flight plan information is shown on map as a basic format (only origin and destination airports).

Tab on "Fly" if the flight plan preview is correctly saved.

KLNP

KATL

**Figure 32:** Flight Plan tab.

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**Figure 33:** Flight Track tab.
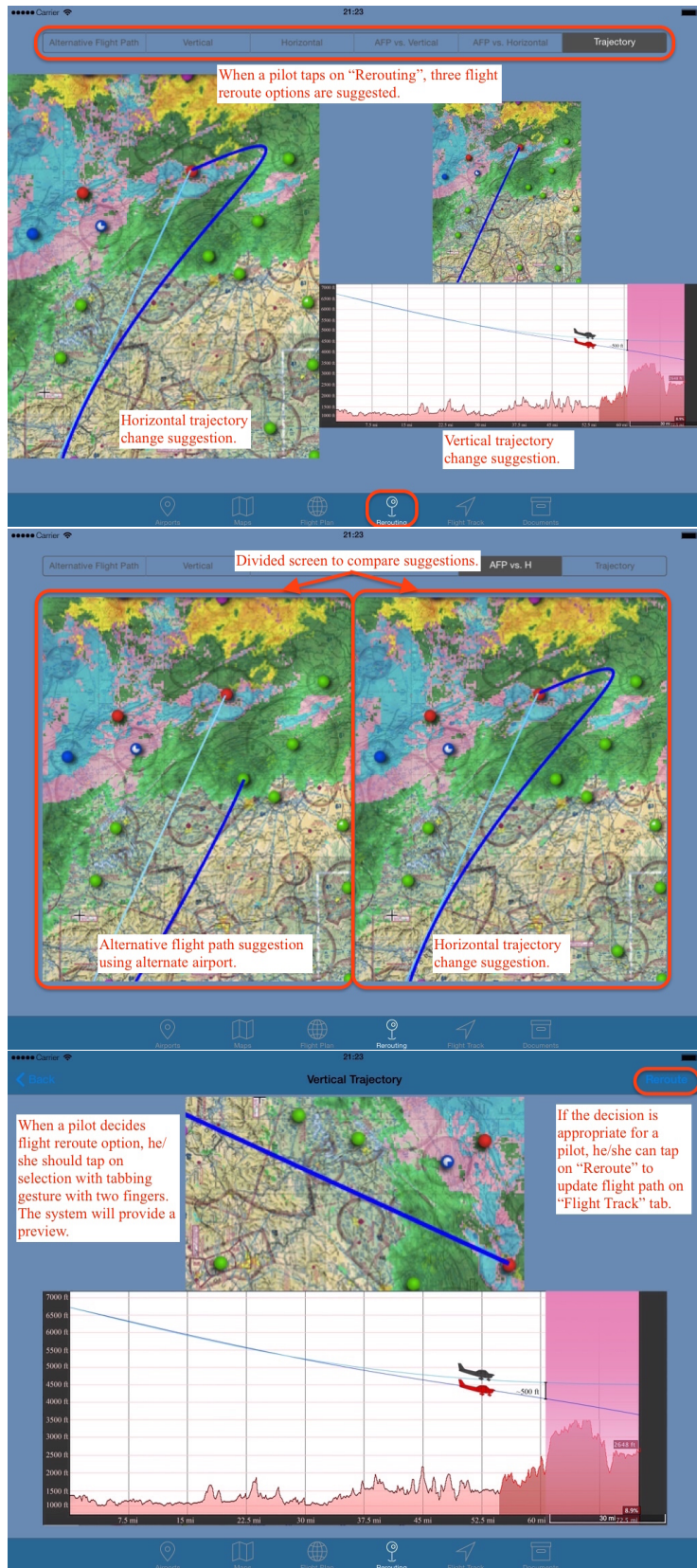
**Figure 34:** Rerouting tab.

# CHAPTER V

# VALIDATION AND DEVELOPMENT OF DESIGN REQUIREMENTS

Chapter 4 discusses the remaining steps of the approach – was described in Chapter 4 – as the validation of the Possible Design Requirements with the evaluation of prototype application. A HITL experiment was designed to evaluate the PDRs; then the results of data analysis aim to provide enough evidence to develop the Design Requirements (DRs) and to iterate the prototype application.

## *5.1 Validation Experiment*

The Possible Design Requirements were evaluated and validated with human-in-the-loop experiments. This experiment requires the pilot to perform tasks with the interaction of an existing software application and the prototype application.

In the following sections, the experiment procedure & design, participants and data collection are explained and discussed.

### 5.1.1 Experiment Procedure and Design

The purposes of this experiment are (1) to examine the impacts of using flight software application on an electronic tablet to reroute/change the flight trajectory in flight, and (2) to evaluate the design of user interface prototype for rerouting/trajectory changing due to weather changes. The major requirement to participate this experiment is that the participant must hold at least private pilots license and have flight experience other than flight training.

The experiment was designed to measure and discuss the impact of the prototype which was designed using Possible Design Requirements. Therefore, the experiment has complex structure.

In Figure 35, the experiment procedure is summarized. The experiment starts with
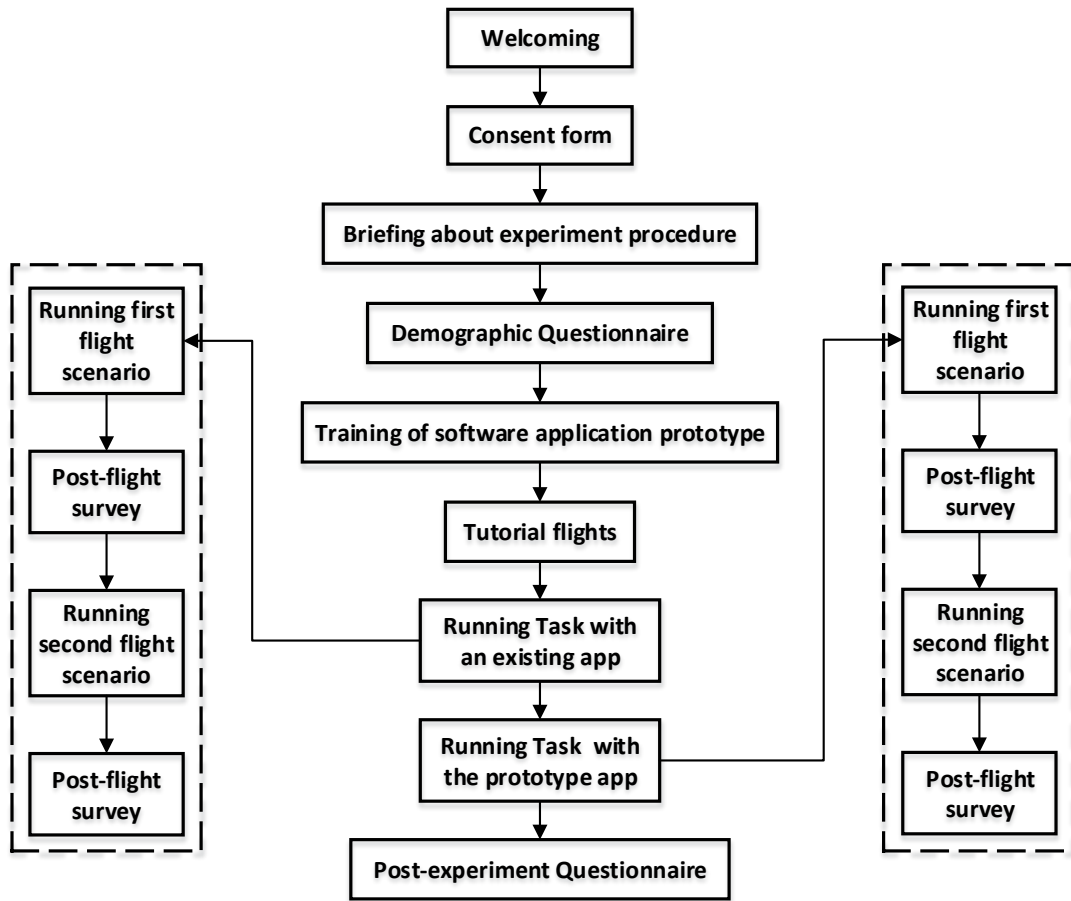
**Figure 35:** The validation experiment procedure.

welcoming the participant and providing brief information about the study. Then the details about the study is explained using the Consent form, and the participants were allowed to read and to sign the Consent form. After they were informed, the demographic questionnaire was provided to collect information including age, gender, pilot certification, flight hours, flight regions, type rating. The pilots were then asked about their flight experience with flight software application on an electronic tablet and their purpose of use.

Before running flight tasks, the pilot must be trained to use the flight software application prototype while flight tasks. The training material includes a training presentation (including the explanation on Section 4.2.2 and screen-shots from the

prototype application) and demonstration using the training prototype on the tablet device. As a part of training, the pilot was provided unlimited time to familiarize themselves with the prototype; they were allowed to fly and to play with the prototype application.

**Table 11:** Experimental flight scenario descriptions.

| Flight Code | A | B | C | D |
|---|---|---|---|---|
| Origin Airport | KATL () | | | |
| Arrival Airport | KLNP () | KGWO () | KLNP () | KGWO () |
| Time & Season | Afternoon & Winter | | Evening & Winter | |
| Weather | Thunderstorm **over the destination airport** (must be observed 36.5928N, 82.3163W nearby) | Thunderstorm **with intense dark cloudy weather before the destination airport** (must be observed 33.3405N, 88.2644W nearby) | Thunderstorm **over the destination airport** (must be observed 36.5928N, 82.3163W nearby) | Thunderstorm **with intense dark cloudy weather before the destination airport** (must be observed 33.3405N, 88.2644W nearby) |
| Other flight info | The flight starts in the air on the waypoint (36.4470N, 82.4055W), and the pilot flys at 3500 ft altitude with 33 degree true heading and 160 knots speed. | The flight starts in the air on the waypoint (33.3515N, 88.0249W), and the pilot flys at 3500 ft altitude with 269 degree true heading and 160 knots speed. | The flight starts in the air on the waypoint (36.4470N, 82.4055W), and the pilot flys at 3500 ft altitude with 33 degree true heading and 160 knots speed. | The flight starts in the air on the waypoint (33.3515N, 88.0249W), and the pilot flys at 3500 ft altitude with 269 degree true heading and 160 knots speed. |

When the pilot declares he/she feels comfortable using the prototype, the experimental flights are started; there are four different flight scenarios. Flight scenarios are summarized in Table 11. The destination (arrival airports) are limited to two;

because the prototype was designed using two different weather impact zone using real weather animation (the map images were provided from `www.skyvector.com`).

Experimental flights were completed under two conditions.

1. *Task 1:* This task requires the pilot to use **an existing flight software application on an electronic tablet** (if the pilot uses any of them). So, the pilot must complete two flight scenarios using any of existing flight planning software application on an electronic tablet.

2. *Task 2:* This task requires the pilot to use **the interface prototype of flight planning software application on an iPad**.

In Figures 36 and 37, the storyboards for experimental flights are demonstrated. Based on Scenario # 2, the system does not suggest horizontal trajectory change. Because, the weather impact zone is too wide, and also the fuel amount is not enough to turn around the impact zone. Besides the Scenario # 2 cannot suggest horizontal trajectory option, the Scenario # 1 suggests all flight reroute options.
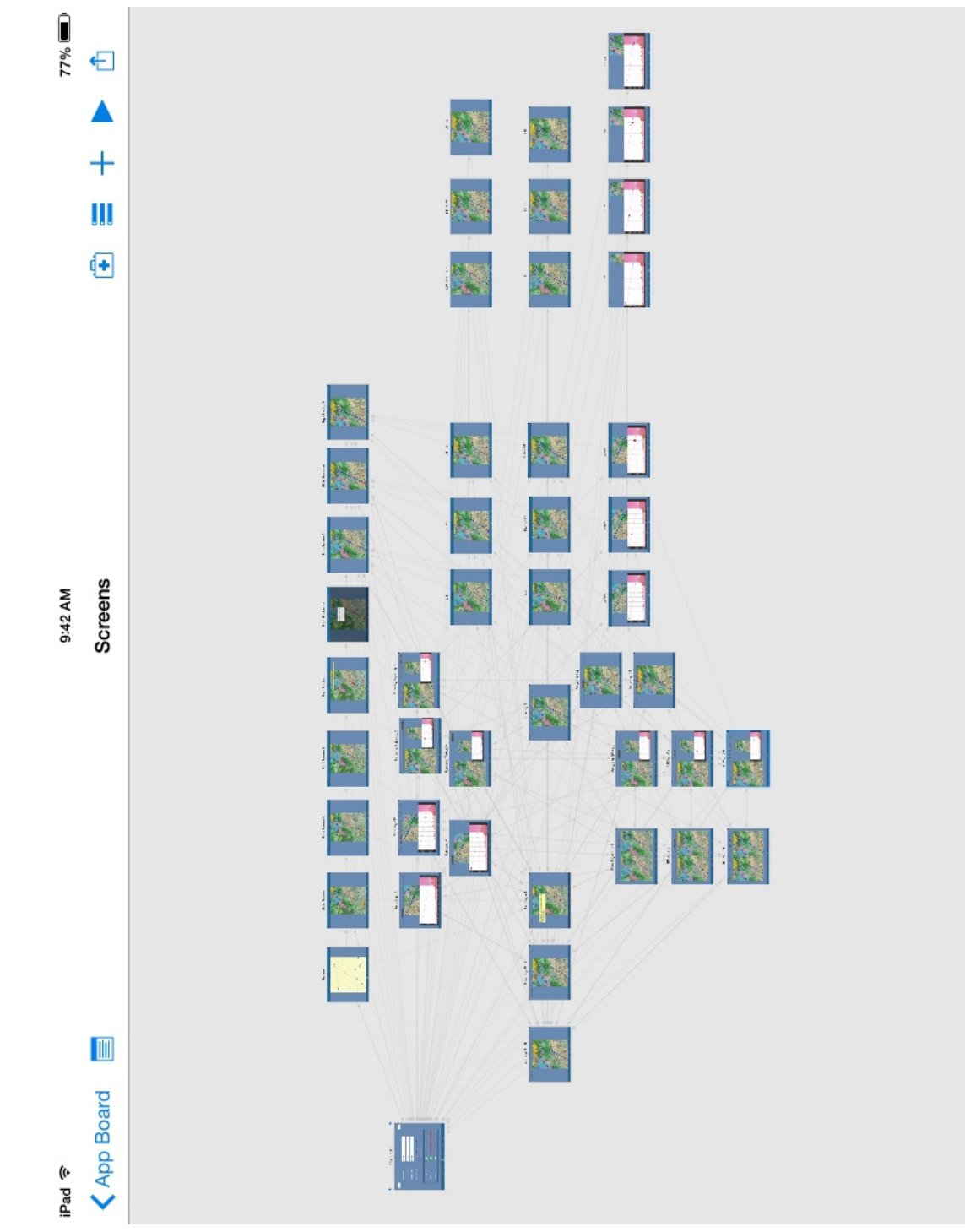
**Figure 36:** Scenario # 1: Flight from KATL to KLNP.
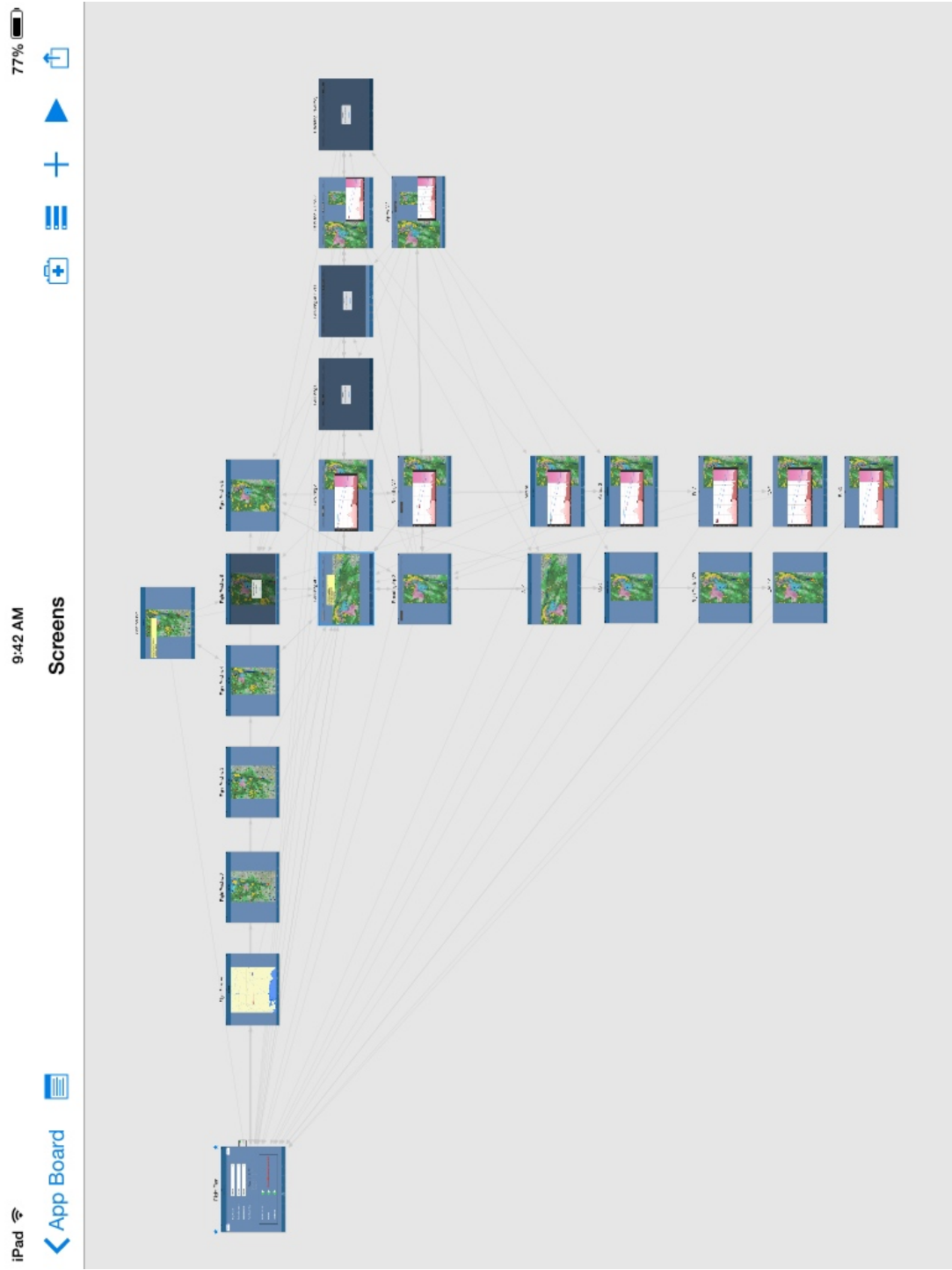
**Figure 37:** Scenario # 2: Flight from KATL to KGWO.

After each experimental flight, the pilot is asked to complete post-flight question-naire to measure and estimate the workload using NASA TLX scores. This question-naire also includes a question to compare the flights related to use of different flight software application.

As a final step, the pilot is provided a list of design requirements which was provided in Table 10, and must give a label for each as High, Medium and Low priorities with his/her comments about each. When the list is commented, the pilot is asked to fill post-experiment questionnaire to learn about the system usability.

### 5.1.1.1 Experimental Design

Latin square matrix for human-in-the-loop test is shown in Table 12 that the pilots did not run the flight simulation with same order and same software applications. The flights have varied time to encounter the weather impact zone. This time value will represent later a baseline for the measurement counted while the participant is performing.

### 5.1.1.2 Performance on Experimental Flights

Volunteer pilots were required to perform 4 experimental flights (see flight scenario descriptions in Table 11). While they were performing those flights, they were asked to complete post-flight questionnaires after each experimental flight. This questionnaire was structured to learn about pilot-defined performance and workload measurement that NASA Task Load Index (NASA-TLX) was used.

NASA-TLX is based on upon subjective ratings made on six different dimensions of workload as mental demand, physical demand, temporal demand, effort, perfor-mance and frustration level [3]. Volunteer pilots were asked to make pairwise com-parisons of the importance to workload of each possible pair of dimensions. These individual weightings are enabled to be developed for each dimension. NASA-TLX is used as a predictive tool by conducting ratings on the basis of detailed task descrip-tions rather than actual task performance [3].

During experimental flights, volunteer pilots were asked to think aloud. This

**Table 12:** Flight scenario run distribution (Bold scenarios were performed using the prototype application).

| Pilot # | Flight 1 | Flight 2 | Flight 3 | Flight 4 |
|---------|----------|----------|----------|----------|
| 1 | **D** | **A** | C | B |
| 2 | B | **D** | **A** | C |
| 3 | C | B | **D** | **A** |
| 4 | **A** | **C** | B | D |
| 5 | D | **A** | C | **B** |
| 6 | B | D | **A** | **C** |
| 7 | C | **B** | D | **A** |
| 8 | A | C | **B** | **D** |
| 9 | D | **A** | **C** | B |
| 10 | B | D | **A** | **C** |
| 11 | C | B | **D** | **A** |
| 12 | A | C | **B** | **D** |
| 13 | D | **A** | **C** | B |
| 14 | B | D | **A** | **C** |
| 15 | C | **B** | **D** | A |
| 16 | A | **C** | **B** | D |
| 17 | D | A | **C** | **B** |
| 18 | B | **D** | **A** | C |
| 19 | C | B | **D** | **A** |
| 20 | A | **C** | **B** | D |

provides to follow how they think and proceed the tasks, and when they realize weather changes. Once they report any changes in weather, time is counted for each trial. However, they were expected to realize bad weather changes which can have impact on flight rerouting decision. Timer is taken another lap to count how much time they spend to make a decision for flight rerouting and they were observed which actions they take when they report bad weather changes.

### 5.1.2 Experiment Apparatus

In this experiment a desktop simulator, the open source flight simulator FlightGear, will be used to emulate a private pilot flying in general aviation. The flight displays and underlying models of the aircraft dynamics and aircraft systems are based on a

Cessna 172 Skyhawk model; the cockpit of a Cessna 172 Skyhawk (1981 model). The controls on the flight deck could be controlled using the touchscreen. The participant is able to manually fly the aircraft using the installed yoke. For experimental flights, an existing flight planning software application and interface prototype on iPad will be provided to the participant. The basic flight simulation environment we have is shown in Figure 38.
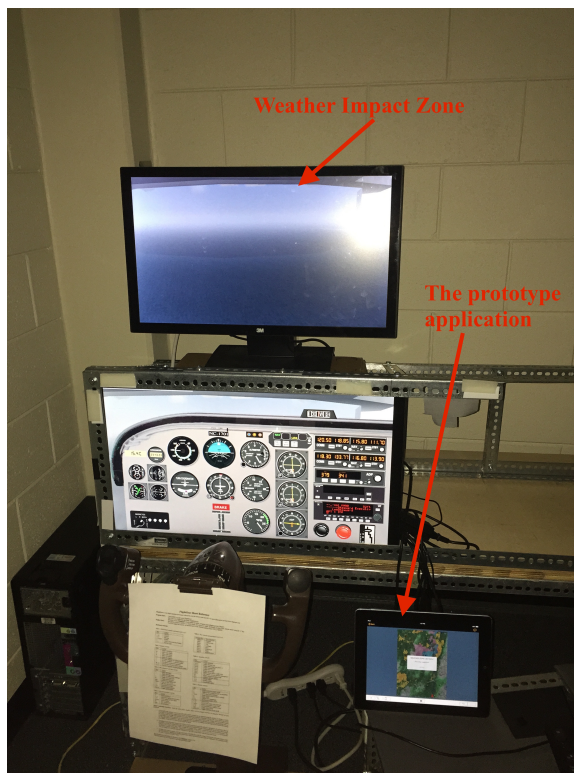


**Figure 38:** The experiment environment for flight simulation.

As tablet, the device is an iPad 2 to use an existing flight software application and the prototype. In addition to this device, the participants were allowed to use their tablet-based devices for an existing flight software applications. Additionally, a Macbook Air 13" was provided to present the training material and collect the questionnaire responses.

### 5.1.3 Participants

The criteria for participation was that the participant must hold at least a private pilot license and must have flight experience other than training flights. 20 pilots (1 women, 19 men) from Atlanta, GA-USA and Istanbul, Turkey participated in this study. The pilots hold varied pilot license including commercial (10 pilots of 20 pilots), private pilot license (5 pilot of 20 pilots). Their total flight hours ranged from 55 to 2500 hr (average flight hour=364.74 hr).

### 5.1.4 Data Collection

For validation experiments, both qualitative and quantitative data were collected from participants using questionnaires. *Questionnaires:* The demographic, post-flight and post-experiment questionnaires are provided in Appendix D. The purpose to collect both qualitative and quantitative data sets is that the quantitative data analysis aim to support the results of qualitative data analysis.

## *5.2  Data Analysis: Validation Experiment*

The results of data analysis are represented in parts as (1) Demographics & Flight Experience as the background information about the volunteer pilots, (2) Experimental Flight Performance which provides necessary evidence to understand how user interface prototype affects the decision of pilot, (3) Design Requirement Evaluation which provide the priorities of PDRs with the comments of volunteer pilots, and (4) Usability Test of Prototype.

### 5.2.1 Demographics & Flight Experience

*Age Groups:* Table 13 shows the different age groups of the pilots who participated. The age limitation for the participation is that they must be older than 18, and the participants varied across different age groups to understand the flight rerouting/re-planning decision for different age groups.

   *Flight Hours:* 1 of volunteer pilots has significantly more flight hours than others. The reason is that the pilot were also a jet aircraft pilot and a flight instructor. In

**Table 13:** Age Groups.

| Age Group | Number of Pilot | Percentage |
|-----------|-----------------|------------|
| 21-25     | 4               | 20%        |
| 26-30     | 11              | 55%        |
| 31-35     | 3               | 15%        |
| >35       | 2               | 10%        |

addition to total flight hours, the comparison between VFR & IFR flight hours and Daytime & Night flight hours were represented to compare their performance if there is significant difference on their decision-making performance. This comparison provides to find whether there is any difference on decision making process and information sources they use.

*Rating & Certification:* The pilots have varied certification and ratings which are represented on Figure 40. 36% of volunteer pilots have "Airplane Single Engine Land". 31% of them have only private pilot license; the remaining 69% have increased their certification through Airline Transport Pilot.

### 5.2.2   Flight Rerouting/Re-planning Experience

**With Flight Planning Software Applications:** The responses of volunteer pilots showed that 95% of the participants use flight planning software application on their tablets or smart-phones. Figures 41 and 42 shows the ratio of tablet-based flight software application use and when the participants have started to use them. Even some of volunteer pilots have started to fly before the invention of those software applications, they now prefer to use them before and in flight. However, the percentage of volunteer pilots who use tablet-based flight planning software applications is 40% which higher than expected.

90% of volunteer pilots use those flight software applications for weather information, airport database besides the remaining stated purposes (seen in Figure 43). 95% of them stated that they use them for flight planning and/or re-planning. However,
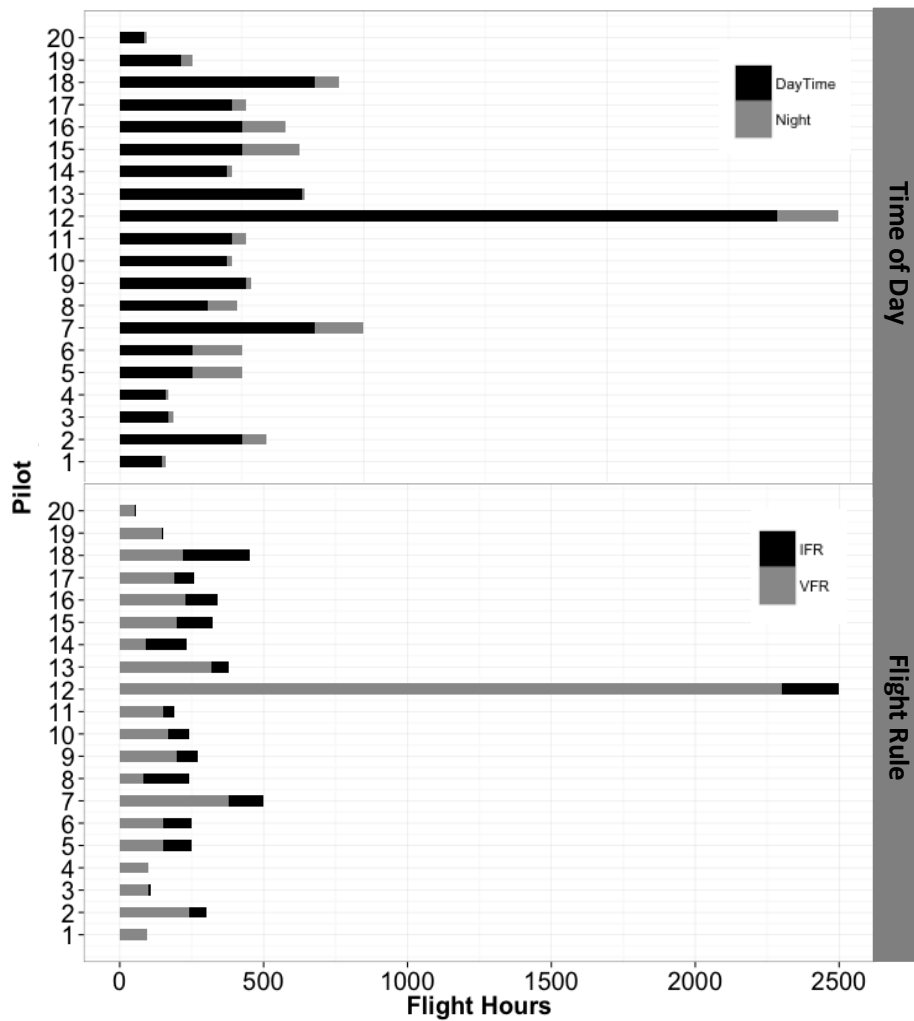
**Figure 39:** Flight hours.

42.75% of 95% of volunteer pilots are using them at almost every flight for flight planning (pre-flight phase), and 35% of volunteer pilots are using them at almost every flight for flight re-planning (in-flight phase).

Additionally, volunteer pilots pointed out that they only need them to use when they have started to fly solo or for cross-county flights. Thus, their familiarity to use those software applications were questioned, and how much those software applications are useful for them before and during flight (see Figure 45).40% of the volunteer pilots think that they are familiar to use those software application moderately besides 10% of them think that they are not familiar to use them at all.
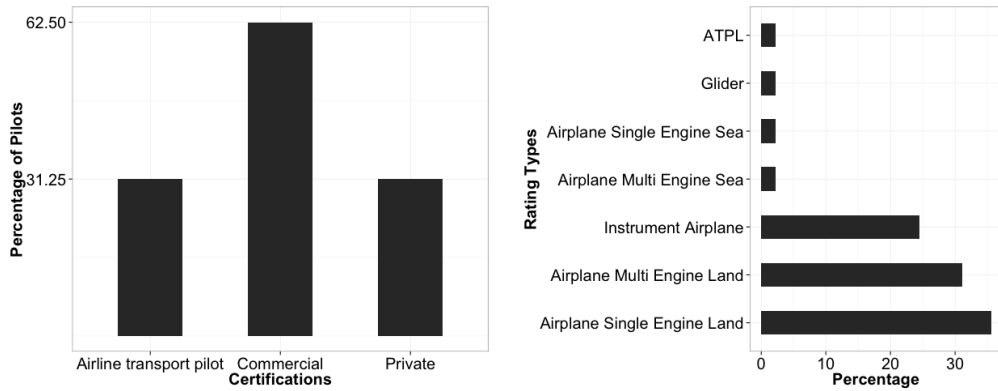
**Figure 40:** Certifications and Rating types.
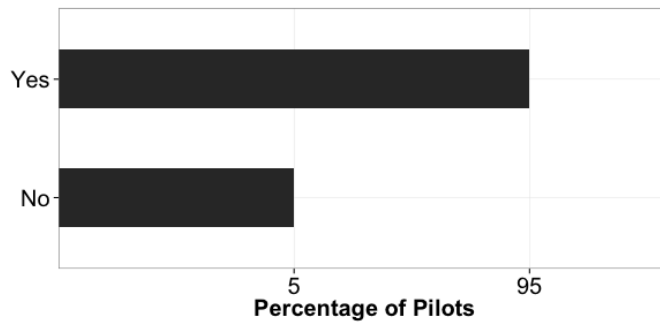


**Figure 41:** Flight software application use.

Since there are different software application brands on the market, volunteer pilots were asked to provide which platform and software application they prefer to use. As seen in Figure 47, skyvector.com, airnav.com and aviationweather.gov are not software application names; they are official websites which are suggested by FAA. However, volunteer pilots told that those websites can be available to check necessary information during flight if they have datalink access. Since 75% of volunteer pilots prefer to use iOS devices, ForeFlight (version 6.6.1) (33. 33% of volunteer pilots) and Garmin Pilot (version 6) (25% of volunteer pilots) are prefered to use before and during flight.

*Performance on Experimental Flights:* Self-reported NASA-TLX scores were analyzed based on each flight scenario and each task with different equipment. The
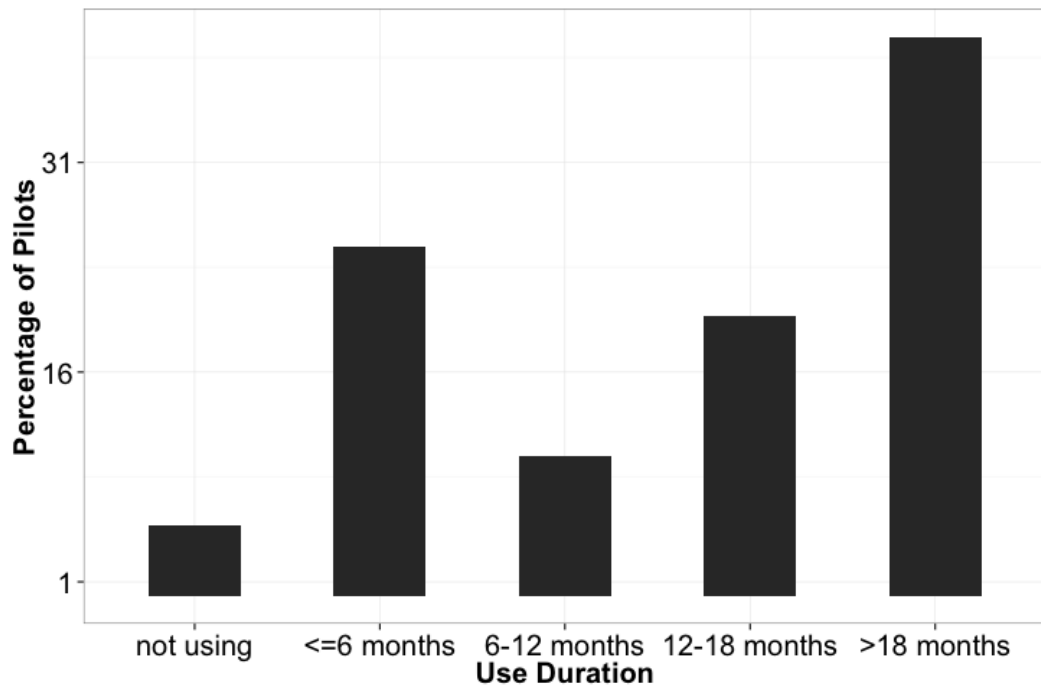
**Figure 42:** When the pilots have started to use them.
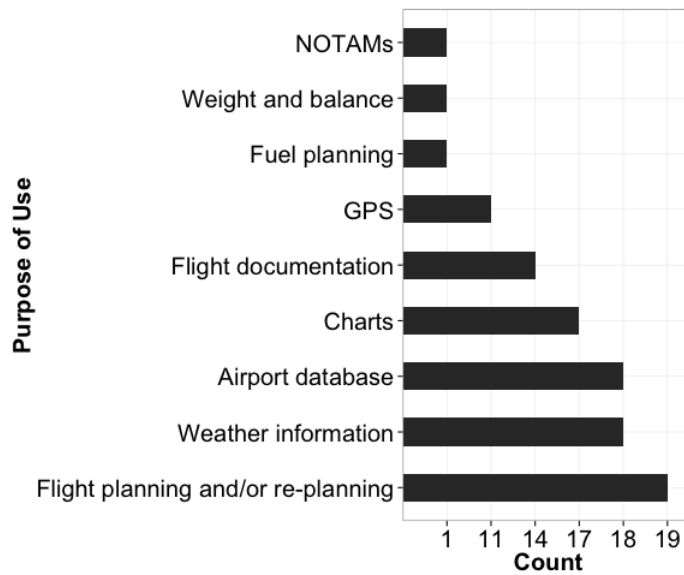


**Figure 43:** Purpose of flight software application use.

purpose is to represent the differences on workload between the Task with an existing application and the Task with the prototype application by flight scenarios.
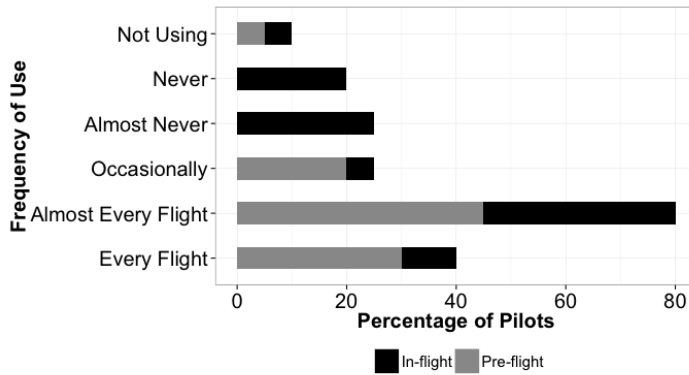
**Figure 44:** Frequency of flight planning application use for pre-flight and in-flight.
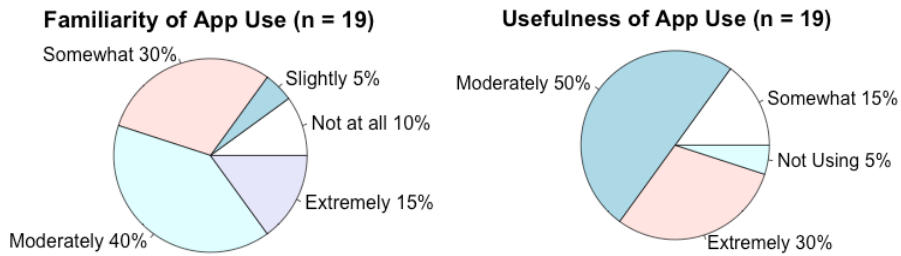


**Figure 45:** Familiarity of flight planning application use and usefulness rating.
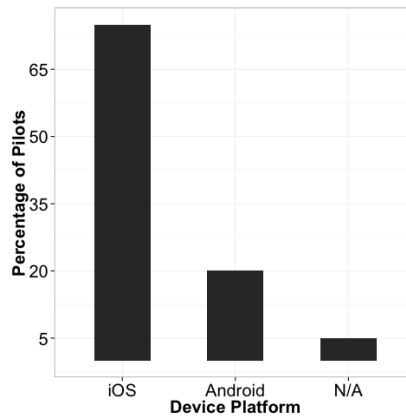


**Figure 46:** Platform type of flight software application.

Figure 48 shows that there is no outlier on workload assessment. Figure 49 provides how volunteer pilots performed and what the identified workload for each task were based on their self-reported NASA-TLX scores. This graphic represents that the use of prototype application at the experimental flights decreases the temporal, mental,
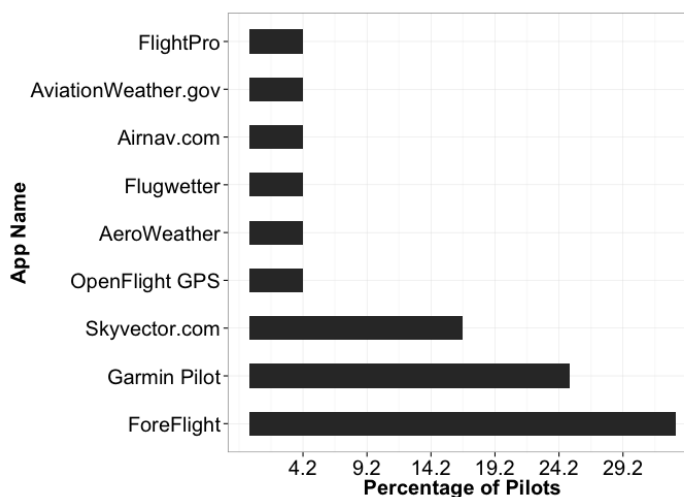
**Figure 47:** Name of flight software application which volunteer pilots use.

physical demands, and the volunteer pilots had lower effort while rerouting.

This graphic additionally represents that the workload does not significantly differ between daytime and night flights (A-B are daytime flights, and C-D are night flights). It means that the time of day does not affect the amount of time spent for the decision. Inspite of this finding, volunteer pilots stated that the weather change recognition depends on the time of day. Although the amount of time spent for the decision does not differ for the time of day, the only identified challenge of night flights is to distinguish the sudden weather changes.

Another workload and performance measurement was performed using time counter which measures when volunteer pilots realized weather impact zone and how much time volunteer pilots spent time to make a decision. The difference between the Task with an existing equipment and the Task with the prototype application was established to indicate whether the proposed system is useful for the decision-making process in flight.

As seen Figure 50, there are no significant difference on the timeline (time for the realization of weather condition change and time for the rerouting decision). However, volunteer pilots saved time to realize the weather condition change when they used the prototype application as seen in Figure 51. They spent that saved time for the
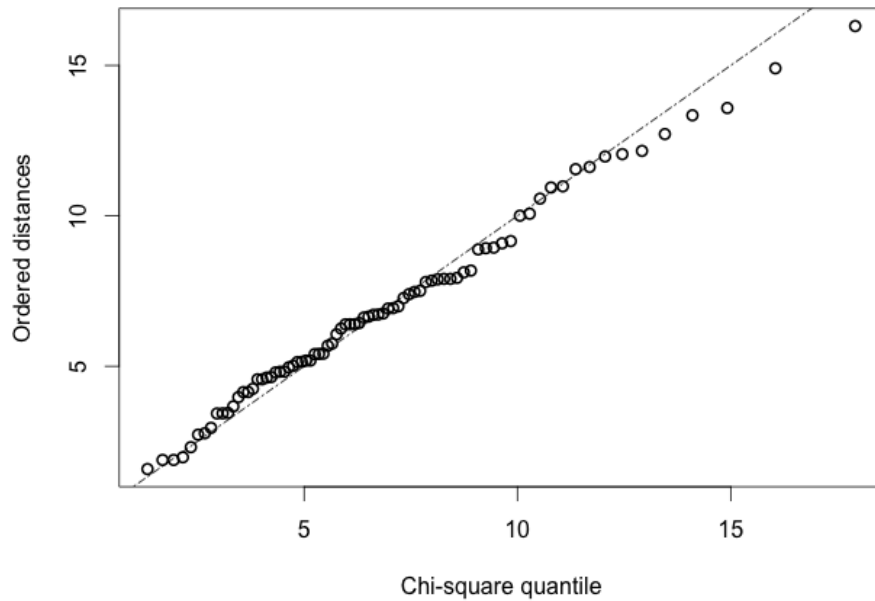
**Figure 48:** Checking outliers for workload measurement – NASA-TLX –.

decision process.

*Assessment of Possible Design Requirements:* The Usability test was performed with criteria as learnability, usefulness, ease of use, flexibility, consistency and minimal action. These criteria with the details were shown in Table 14.

The assessment of user interface prototype was performed giving scale for each items on the list. The scale is 5-point scale, and each point was labeled based on descriptions. In Figure 52, these items were evaluated based on the mean values. The red bordered line is located on the point of 4; this line is a border. If any usability criteria is below than 4 point (if the criteria was scored 5 point at least 50% and 1 point no more than 5%, the mean value should be at least 4 point), it should be improved while iterating the design requirements and user interface prototype.

Each volunteer pilots scored each PDRs; the weighted priority for each design requirement are shown in Figure 53. 85% of design requirements have "High" priority besides 2 of them have same scored priority as "High" and "Medium". Those priorities
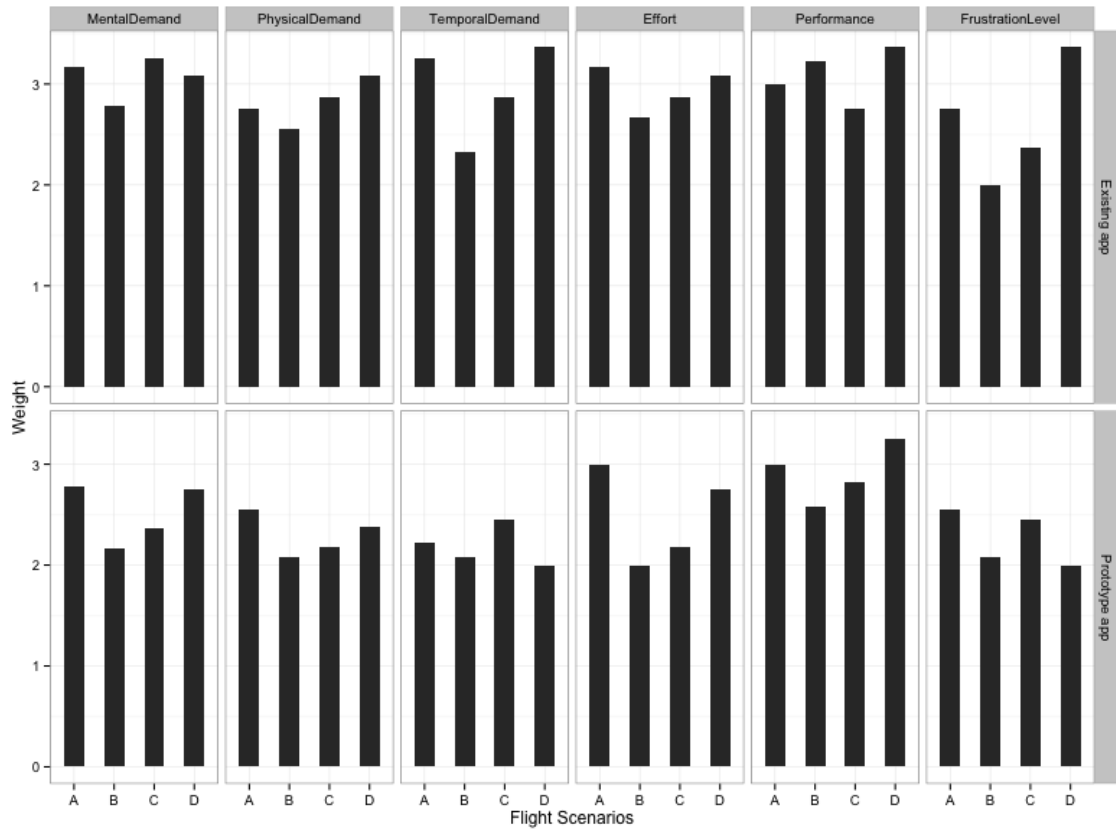
**Figure 49:** Average workload measurements – NASA-TLX –.
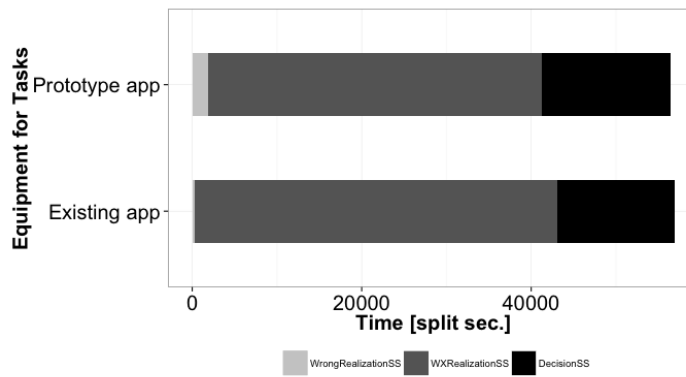


**Figure 50:** What the average timeline for decision-making to re-plan flight due to weather changes.

provide that how much important and necessary those Possible Design Requirements are for the flight re-planning decision process. These identified priorities support to
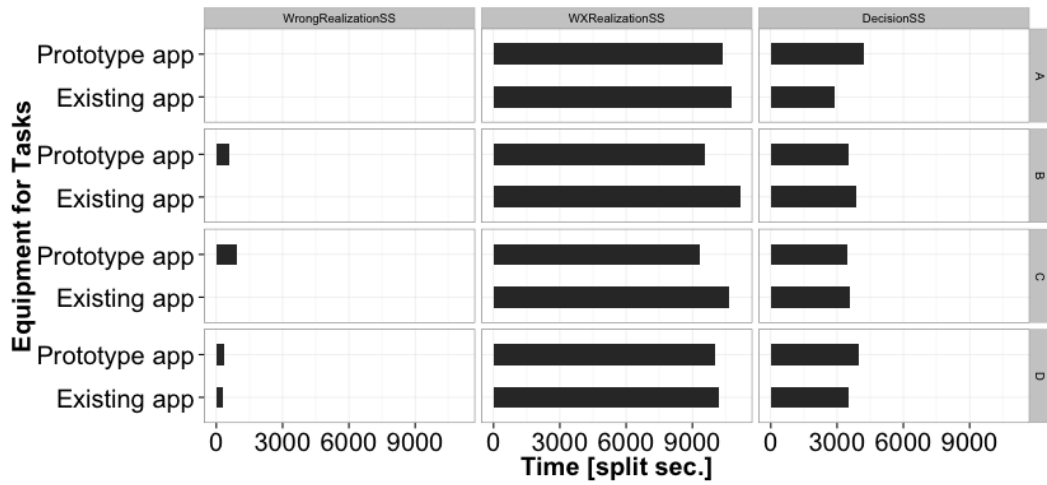
**Figure 51:** Average decision-making duration for flight re-planning due to weather changes.
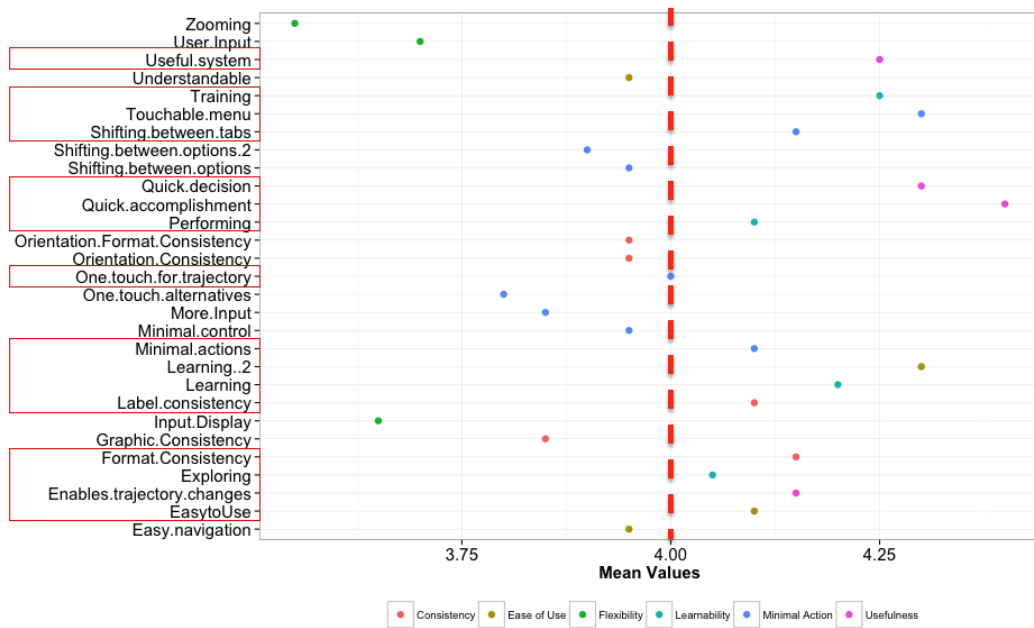


**Figure 52:** Assesment of user interface prototype.

iterate the description of design requirements.

**Table 14:** Usability criteria.

| Criteria | Factors |
|---|---|
| Learnability | Learning how to operate the system easily, Exploring which functions can be performed by trial-and-error, Performing given tasks straightforward, Training material should be sufficient and clear to use the system, |
| Usefulness | Using the system should improve the performance to make a quick decision, Using the system in flight should enable the pilot to accomplish rerouting task quickly, The system should provide useful evidence to perform tasks, The system should meet the needs of the pilots, |
| Ease of Use | Learning to operate the system for different tasks easily, The system should proceed the actions what the pilots request to do with it, The interaction with the system would be clear and understandable, |
| Flexibility | The pilot should be able to make zoom on the map and/or flight documents, The pilot should be able to enter and save the flight information, The system should provide options to the pilot, |
| Consistency | The graphics should use standard symbols, The label locations should be consistent for each tab, The information format should be consistent, The display orientation should be consistent for each tab, |
| Minimal Action | Easy shifting should be provided for menu options and flight path suggestions, The shifting between tabs and suggestions should be performed with one-touch tapping gesture, The selection action should be performed with double-finger touch gesture. |

## 5.3   Results and Iterations

According to data analysis, the results provide useful evidences about the development of the Design Requirements and the iteration on the prototype application. Using observations and comments of volunteer pilots about PDRs, Decision Action Diagram
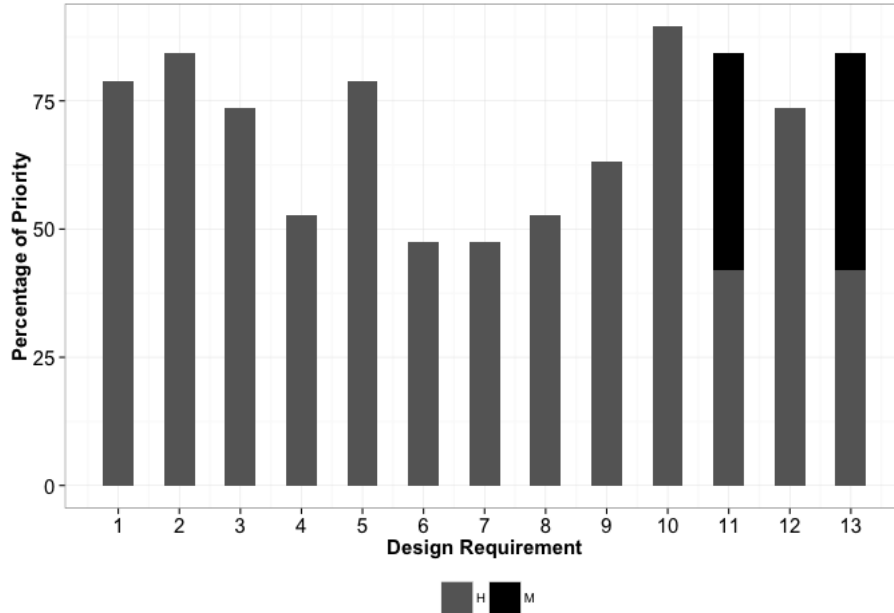
**Figure 53:** Given priority by volunteer pilots (H: High and M: Medium).

and Hierarchical Task Analysis are generated to adapt the flight planning and in-flight re-planning process regarding to the use of the prototype application while experiemental flights. The most important point for HTA does not aim to change the rerouting procedure defined by FAA. However, how to integrate the use of software application to help the decision is aimed to demonstrate by using this task analysis.

In Tables 15 and 16, the list of developed design requirements were provided. As explained on Section 4.1.1, the design requirements were prioritized as DR and Sub-DR; those main and sub design requirements were categorized according to DR priorities which were labeled by volunteer pilots.

### 5.3.1 Hierarchical Task Analysis

The design iteration criteria of HTA includes continuing the re-description to the point at which [3]:

- The main interfaces or functional elements within an interface can be identified.

- The tasks have sufficient detail to enable a workload assessment to be undertaken.

- Underlying knowledge and skills can be defined in sufficient detail. Thus for selection and manpower planning less detail is required than for developing a training program.

According to the utterance of volunteer pilots during experimental flights, the two separate HTAs, are shown in Figures 54 and 55, were generated to demonstrate how the flight planning and rerouting/re-planning software application can be used to support the pilots.

Once the pilot saves necessary flight plan information into tablet-based flight planning software application (see Figure 54), the pilot must notice the sudden weather changes on flight path by visual confirmation as seen in Figure 55 which demonstrate how general aviation pilots demand to use. If the pilot notices any sign about the change on weather condition, he/she must check the weather forecast from the software application and must confirm what he/she notices by visual. When the pilot confirms the occurrence of bad weather condition on the recent flight path, he/she immediately reports this condition to ATC.

When the pilot starts to communicate with ATC, he/she must report what the visual cues about the weather condition and also must request the updated weather forecast on the recent flight path for double checking. The pilot has two options:

1. If flying on the recent flight path is not safe based on the updated weather forecast, the pilot has to request rerouting through the alternative flight path. Since the pilot requests the rerouting, he/she must provide the alternative flight path directions to ATC and must get confirmation before changing the direction of the aircraft.

2. If flying on the recent flight path is safe, the pilot must maintain aircraft control to fly safely on the recent flight path.

**Table 15:** Iterated design requirement descriptions.

| DR # | Design Requirements (DRs) |
|---|---|
| **DR 1** | Design the flight planning software application by adding a new tab as "Flight Plan". The user should be able to enter and save the flight plan data including alternative flight path info. |
| **Sub-DR 1.1** | "Flight Plan" tab enables the pilot to tap on way-points and select them to create flight plan. |
| **Sub-DR 1.2** | Design the "Flight Plan" tab including: (1) Destination, (2) Origin, and (3) Alternate airports, (4) Flight date & time, (5) Options as weather, air-traffic, and fuel amount. |
| **Sub-DR 1.3** | Options on "Flight Plan" tab should be activated or deactivated in flight. |
| **DR 2** | Design the flight planning software application by adding a new tab as "Rerouting". The user should be able to compare the possible flight paths to reroute or change the trajectory of the flight vertically or horizontally. |
| **Sub-DR 2.1** | "Rerouting" tab must include the options as vertical trajectory possibility, horizontal trajectory suggestion, alternative flight path. |
| **Sub-DR 2.2** | The display screen must demonstrate two different suggestions to decide how to divert the aircraft. The pilot should be able to see the comparison between (1) Alternative Flight Path (AFP) & Vertical Trajectory of the flight path, (2) AFP & Horizontal trajectory of the flight path, (3) Vertical & Horizontal trajectory of the flight path. |
| **Sub-DR 2.3** | "Rerouting" tab demonstrate the comparison between flight reroute options, and provide relevant flight path information (such as estimated fuel amount, estimated heading and speed changes, weather forecast, predicted flight time change). |
| **Sub-DR 2.4** | "Rerouting" tab must provide the information of weather radar overlayed with map, and predicted fuel amount to arrive the destination. In addition to these, the user must be able to receive the location of the aircraft close to the flight path. |
| **DR 3** | The weather impact zone, which causes the rerouting decision, must be demonstrated with the appropriate geometrical shape. It provides that the pilot can recognize the weather zone impact to avoid the aircraft from that area to fly in safe. This requirement is currently applied for other applications; therefore, it is not special for this study. |
| **Sub-DR 3.1** | This weather impact zone shape provides the boundaries as estimated radius, top and bottom altitude levels that the pilot cannot approach, descend or climb. |
| **Sub-DR 3.2** | Vertical trajectory of the flight path is not a defined flight path. The system should be able to provide the altitude difference between top and the bottom of the weather impact zone. This support the pilot to decide to descent or climb to pass the weather impact zone. |

**Table 16:** Cont. of Table 15: Iterated design requirement descriptions.

| | |
|---|---|
| **DR 4** | Design the flight planning software application by adding a new tab as "Flight Track". |
| **DR 5** | When the pilot taps on one of these flight path suggestions at the "Rerouting" tab, the "Flight Track" tab must be updated with the selected flight path. |
| **DR 6** | The pilot should be able to get weather forecast overlayed on the map. |
| **DR 7** | If the weather information is updated in flight that it might affect the safe of flight, the system must suggest warning message on the screen. |
| **DR 8** | The pilot is able to ignore the warning message and keep flying on the current flight path. Or the pilot is able to tap on "Rerouting" to see suggestions. |
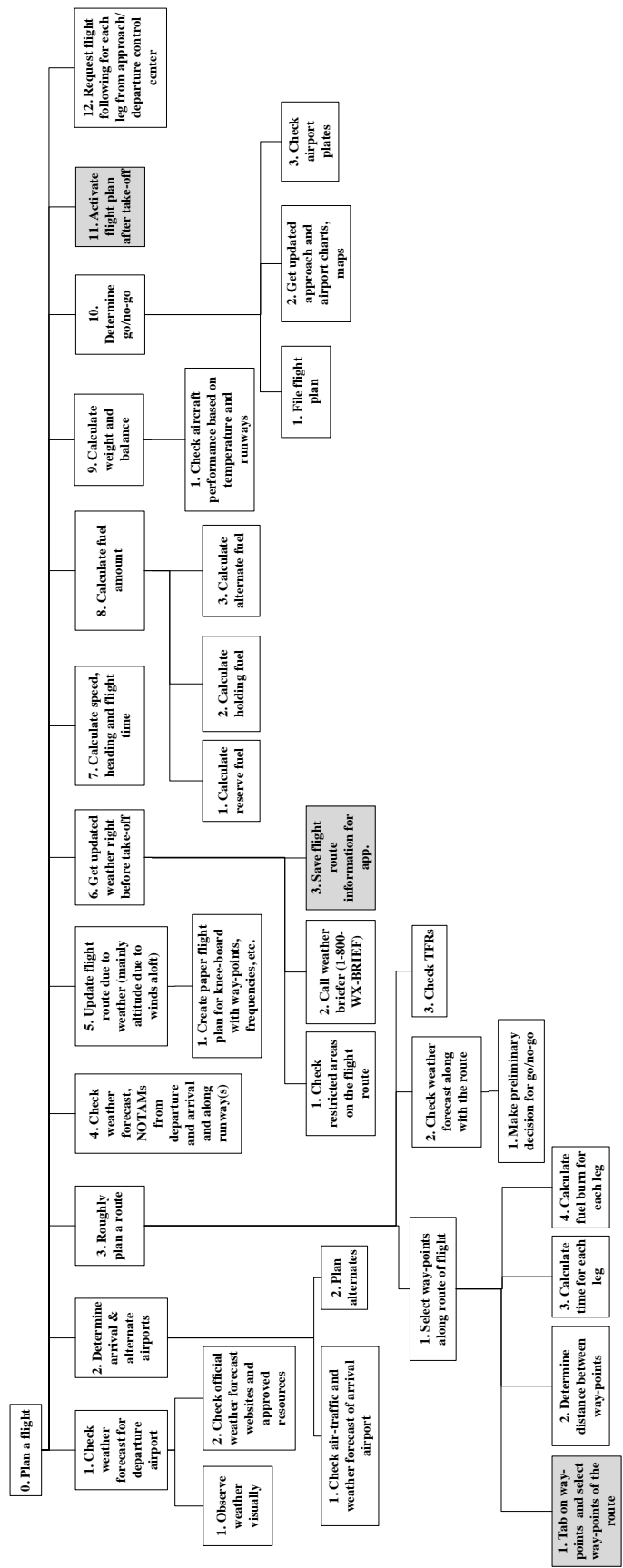
**Figure 54:** Adapted HTA for flight planning based on the design requirements.
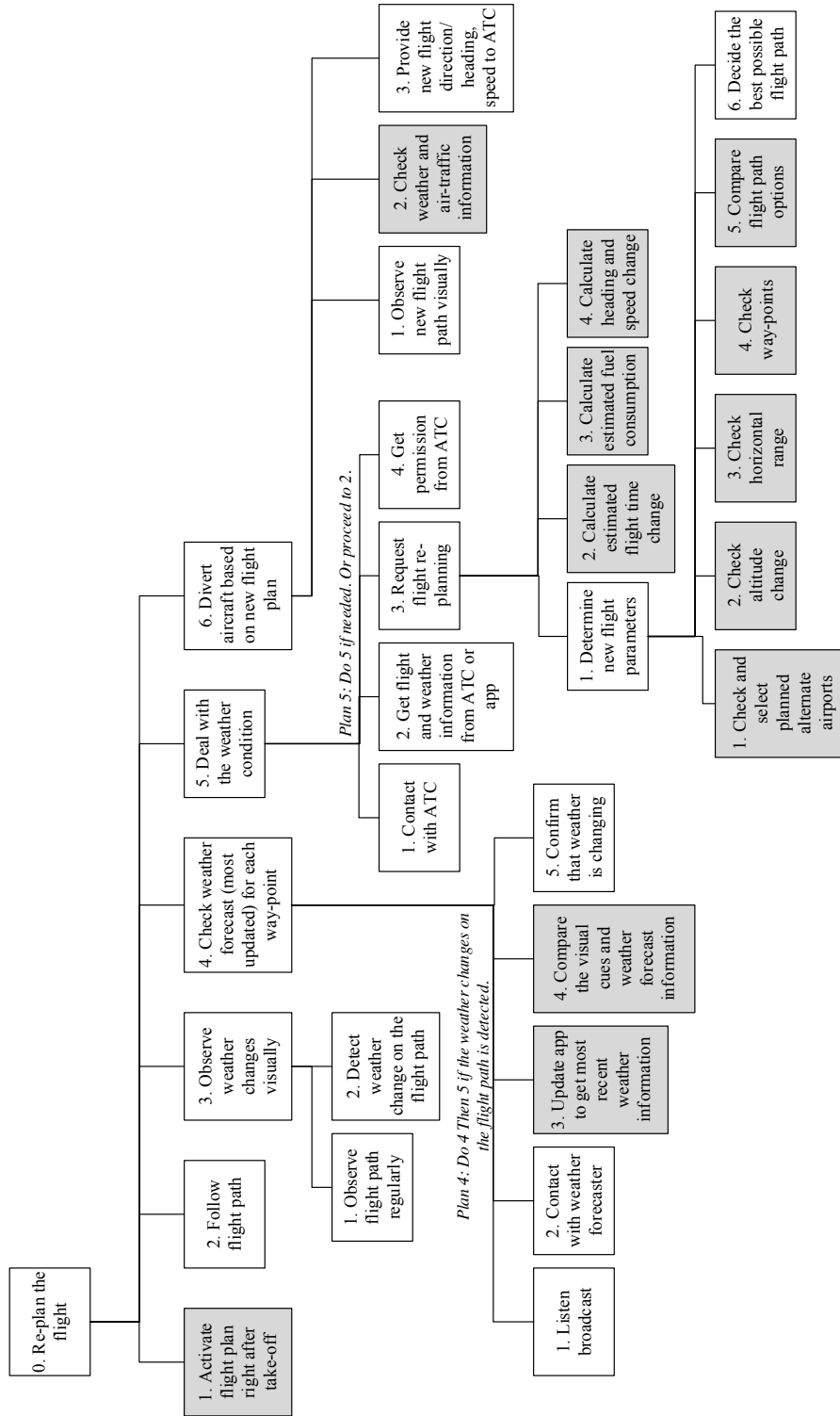
**Figure 55:** Adapted HTA for flight re-planning based on the design requirements.

### 5.3.2   Decision Action Diagram

Decision Action Diagram has been created according to the comments of volunteer pilots and the information provided by the pilots which were collected based on think-aloud method during experimental flights. These diagrams provide an indication of the information requirements and the focus attention upon decision-making process [3]. Thus, two DADs were created separately for flight planning and in-flight re-planning using tablet-based prototype application.

As seen in Figure 56, how a pilot is able to use tablet-based flight planning software application when he/she has a flight plan and/or also he/she can use it to get necessary flight path information for the decision on flight planning. Although, this part of design cannot be evaluated as activity, volunteer pilots provided their feedback about how they can use the system while preparing the system for in-flight use.

Those DADs indicate that how the prototype application can be adapted to the current flight planning and in-flight re-planning procedures. Specifically, DADs provide the evidence for what the impact of the prototype application on the decision of pilots is.
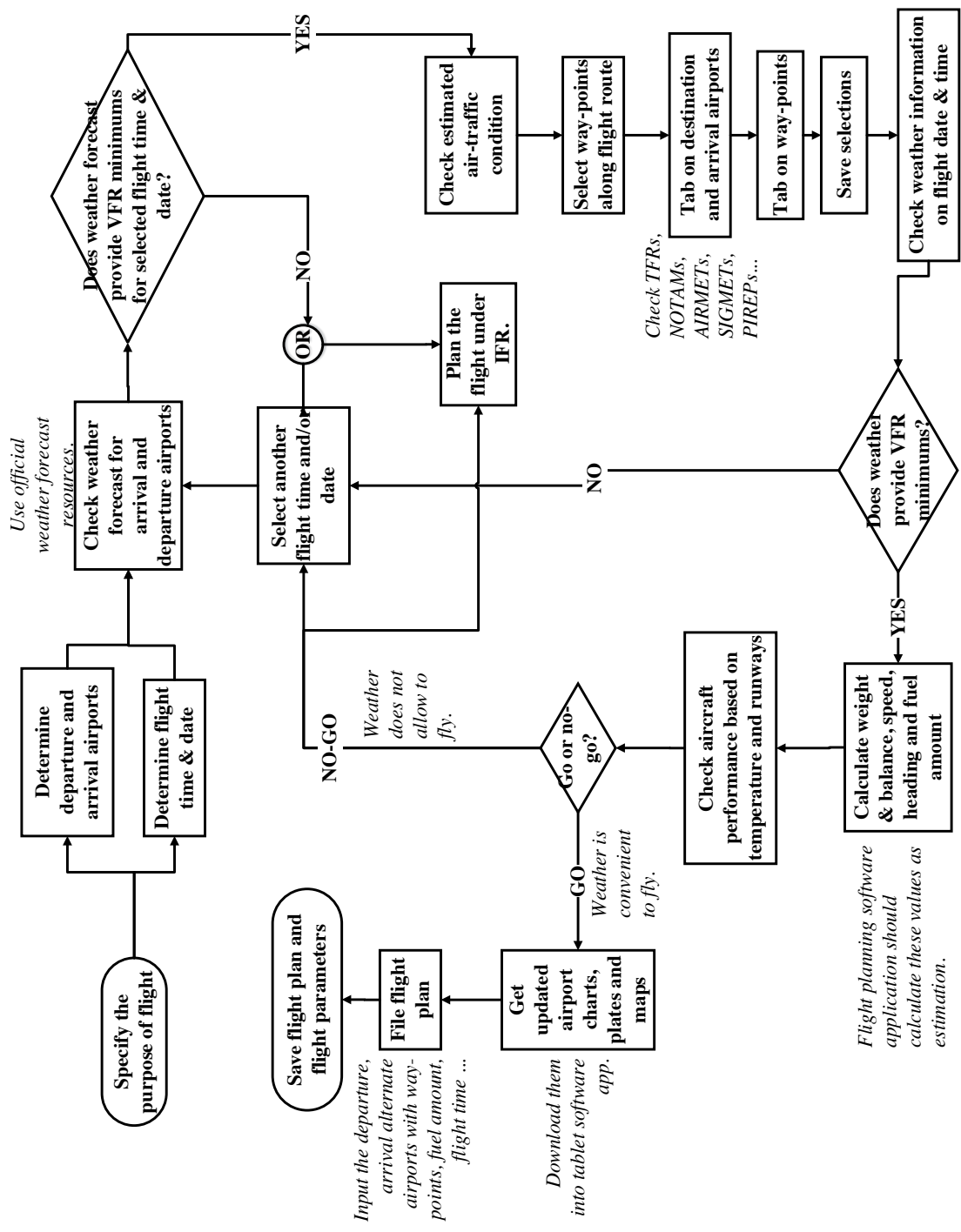
**Figure 56:** How a pilot make a decision to plan a flight.
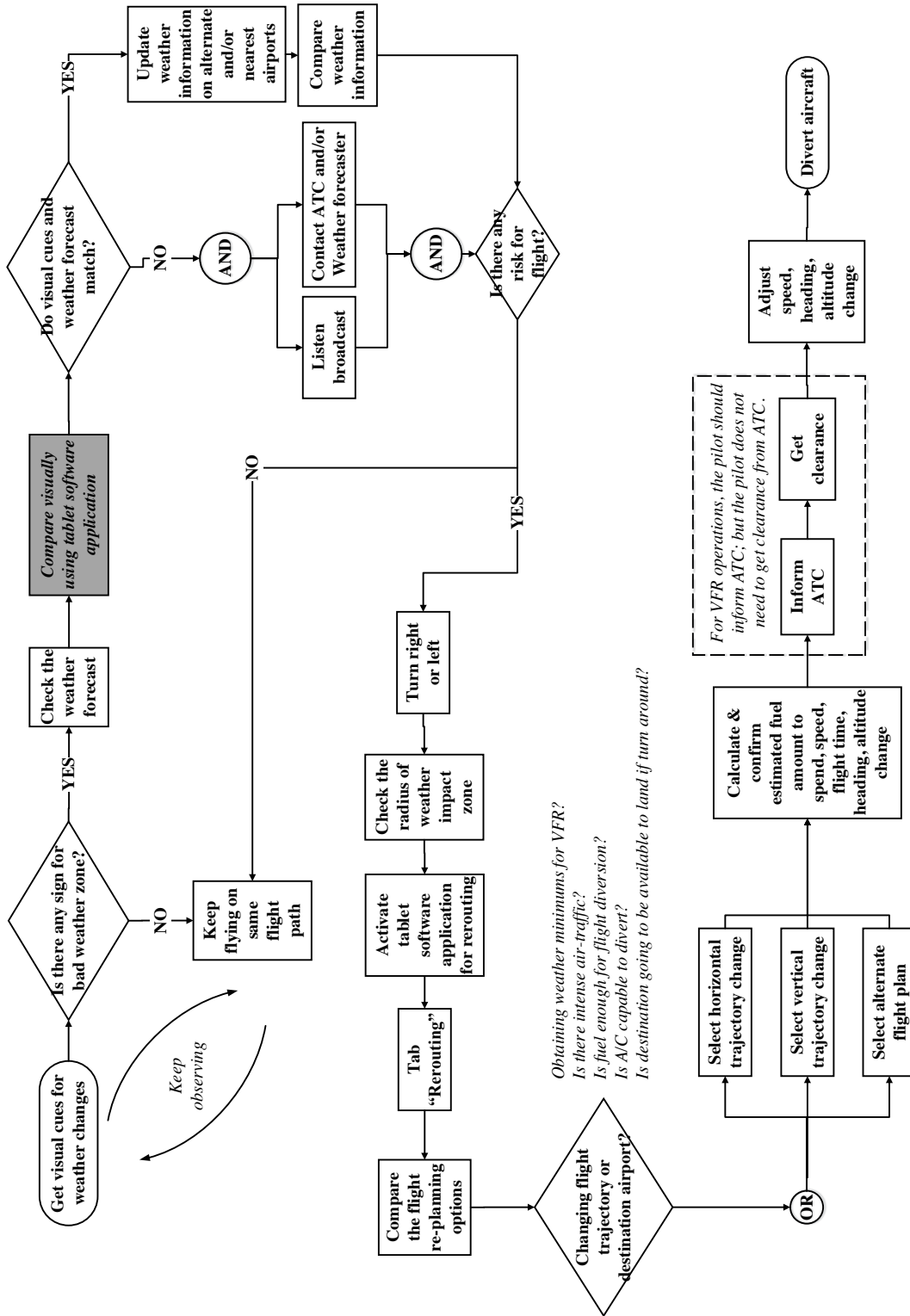
**Figure 57:** How a pilot make a decision to re-plan recent flight.

# CHAPTER VI

# CONCLUSION

This thesis was conducted to examine how general aviation pilots perform a flight planning and in-flight re-planning process using recent technology. Ultimately, the DRs for tablet-based flight planning software application were developed while the flight planning and in-flight re-planning procedures were adapted using task models. For this thesis, the research questions were:

1. How does the use of flight planning software applications on an electronic tablet affect the decisions of general aviation pilots for rerouting in response to sudden weather changes?

2. What are the design requirements that aid General Aviation pilots with safely rerouting due to weather changes?

Examining how general aviation pilots perform a flight planning and in-flight re-planning helps to understand the environmental characteristics and factors which have negative impact on their in-flight re-planning decisions. Then, Possible Design Requirements were described using the results of document analysis and interviews. According to identified scope of thesis,

- The prospective user should be single general aviation pilot who flies with single engine aircraft under VFR,

- The restrictions on work domain are: (1) for "Single Pilot Operations", the pilot enhances all flight workload during the flight; (2) the pilot has been trained to fly with the basic six electromechanical, round dial formatted instrumental, requiring minimal "heads-down" time.

**Table 17:** Summary of the thesis method.

| Research Question | Methodology | Outcome |
|---|---|---|
| **RQ # 1** | Interviews, Document analysis | (1) The flight planning and in-flight re-planning processes were examined. (2) The generation of HTA and DAD summarizes how the current flight planning and in-flight re-planning are performed. (3) IFM (in Chapter 3) represents the needs and demands of a general aviation pilots as a tablet-based flight planning software application, and how the proposed system can be inserted. |
| **RQ # 2** | HITL experiments, Iteration on Design & DRs | (1) The PDRs were identified using the interpretation of task models. (2) A mobile interface prototype was designed for pilot interaction for evaluation of the system. (3) DADs and HTAs were generated to demonstrate how the flight planning and in-flight re-planning process should be updated. (4) The PDRs were iterated based on the feedback of volunteer pilots as DRs. |

**How to Plan and Re-plan a Flight:** Document analysis and interviews provided the fundamental information about the recent flight planning and in-flight re-planning process. The outcomes of both interview and document analysis were used to create HTA, DAD and AH with Information Flow Model. Hierarchical Task Analysis and Decision Action Diagram (shown in Figures 23 & 24 and 25 & 26) provide how a pilot performs flight planning and in-flight re-planning using existing tablet-based applications and devices. Besides those analyses, Information Flow Model (shown in Figure 27) was created to identify the work domain and the need of information model under the tasks.

**Proposing and Validating Design Requirements:** Since volunteer pilots and document analysis provide evidences about how the system and the recent technology are demanded for the update of the flight re-planning process. Using HTA and DAD methods, the tasks and the decision model of a pilot were discussed to describe Possible Design Requirements.

Then, the PDRs and the prototype application were evaluated with HITL experiments. Those experiements showed that the use of prototype application saved time to decide about the rerouting options. And the comments from volunteer pilots proved that this type of development on tablet-based application can help general aviation pilots such that they may have more detailed information about the impact of weather change, and may prevent the possible airplane crashes.

In Chapter 5, the adapted flight planning and in-flight re-planning procedures were described using HTAs and DADs. Those models were created based the tasks in the order of how volunteer pilots performed during rerouting decision process.

The Design Requirements were idetified under the assumption that there are no the technological problems in a general aviation cockpit such as lack of datalink service. If the cockpit is not equipped with portable or installed datalink device, the pilot is not able to get real-time weather forecast using this tablet-based application. But this application can still support the pilot to suggest a flight reroute option as alternate flight plan which uses the selected alternate airport.

Ultimately, this thesis represents that the proposed system must support pilots using a tablet-based software application. This application aims to provide graphical information for in-flight rerouting options that the system must calculate the estimated changes of flight time, heading, speed, fuel amount to spend and other parameters relevant to new flight path.

## 6.1   Contributions

This thesis work contributions are described below:

1. Provide the information needs and major user (general aviation pilot) needs for flight software application on an electronic tablet.

2. Describe and provide the design requirements for a flight software application interface dedicated to the weather forecast in rerouted/re-planned flight path.

3. Validate the design requirements and develop the design requirements.

This thesis is concluded with the improvement and update of weather related flight plan application interface and the assessment of design requirements for general aviation pilots. While updating design requirements and the design iteration process of the thesis, the results of the HITL provide the necessary information about the usability of tool and the performance changes for effective decision.

## *6.2 Future Research*

Since the process of designing a software application on an electronic tablet, this thesis was concluded with the validation and iteration of design requirements for a tablet-based flight planning software application. For this thesis, the desires of pilots and the proposed in-flight re-planning process should be improved or updated in compliance with technological development.

This study would be extended with the development of a dynamic system model with different flight scenarios to examine and validate the proposed tablet-based flight planning software application. This would be provide more evidence to learn about the impact of system on the pilots' decision.

Although the design requirements were intended to develop for VFR environment, they would be improved and updated for in-flight re-planning under IFR environment if weather conditions are unavailable to re-plan flight under VFR.

# APPENDIX A

# FLIGHT PLAN DOCUMENT

Description of the flight plan form [33] (Figure 3):

1. Type: Flights may be Visual Flight Rules, Instrument Flight Rules and DVFR, or a combination of types, termed composite.

2. Aircraft Identification: The registration of the aircraft, usually the flight number or tail number.

3. Aircraft Type/Special Equipment: The type of aircraft and how it is equipped. Equipment codes may be found in the FAA Airmen's Information Manual.

4. True Airspeed: The planned cruise true airspeed of the aircraft in terms of knots.

5. Departure Point: Usually the identifier of the airport from which the aircraft is departing.

6. Departure Time: Proposed and Actual times of departure.

7. Cruising Altitude: the planned cruising altitude or flight level.

8. Route of Flight: Proposed route of flight can be made up of airways, intersections, navaids, or possibly direct.

9. Destination: Point of intended landing, the destination airport.

10. Estimated Time En-route: Planned elapsed time between departure and arrival at the destination.

11. Remarks: Any information the PIC believes is necessary to be provided to ATC.

12. Fuel on Board: The amount of fuel on board the aircraft, in hours and minutes of flight time.

13. Alternate Airports: Airports of intended landing as an alternate of the destination airport. May be required for an IFR flight plan if poor weather is forecast at the planned destination.

14. Pilot's Information: Contact information of the pilot for search and rescue purposes.

15. Number On-board: Total number of people on board the aircraft.

16. Color of Aircraft: The color helps identify the aircraft to search and rescue personnel.

17. Contact Information at Destination: Having a means of contacting the pilot is useful for tracking down an aircraft that has failed to close its flight plan and is possibly overdue or in distress.

# APPENDIX B

# INTERVIEW

## *B.1   Demographic Questionnaire*

## Examination Interview

Participant Number

> Type here

Demographic Information

What is your age?

   ○ <= 20

   ○ 21-25

   ○ 26-30

   ○ 31-35

   ○ > 35

What is your gender?

   ○ Male

○ Female

○ Prefer Not to Answer

Pilot Information & Flight Experience

Are you a member of Yellow Jacket Flying Club?

Yes                    No

What is your pilot certification?

○ Student

○ Sport

○ Recreational

○ Private

○ Commercial

○ Airline Transport Pilot

○ Other, please     Type here
  specify...

What ratings do you hold?

108

Select all that apply.

☐ Airplane Single Engine Land

☐ Airline Single Engine Sea

☐ Airline Multi Engine Land

☐ Airline Multi Engine Sea

☐ Rotorcraft Helicopter

☐ Instrument Airplane

☐ Instrument Rotorcraft

☐ Other, please specify...     | Type here |

## Flight Hours

| Total flight hours | Type here |
| Day-time flight hours | Type here |
| Night flight hours | Type here |
| VFR - flight hours | Type here |
| IFR - flight hours | Type here |

## In what region(s) do you fly?

Please list all.

109

> Type here

What model aircraft do you fly?

> Type here

Flight Planning Software Applications on the Electronic Tablet

Electronic Tablet: iPad, Windows tablet, Android tablet...

Have you ever used any flight planning software application on the electronic tablet?

Yes                    No

Submit

110

## B.2 Examination Questionnaire Part 2

# Examination Interview - Part 2

When you complete the questionnaire, I will next ask you to demonstrate how you would use the flight planning software application and what the features of it are useful for your flights.

## Participant Number

Type here

## Flight Planning Software Application

### When did you start to use a flight planning software application?

○ <= 6 months

○ 6 - 12 months

○ 12 - 18 months

○ > 18 months

### What is the type of electronic tablet?

Select all that apply.

111

☐ iPad

☐ Windows

☐ Android

☐ Other, please
  specify...                    | Type here |

## Which software application do you use?

Select all that apply.

☐ ForeFlight

☐ Garmin

☐ WingX

☐ FlightAware

☐ QRouting

☐ Other, please
  specify...                    | Type here |

## How familiar are you with the flight planning software application?

| Extremely familiar | Moderately familiar | Somewhat familiar | Slightly familiar | Not at all familiar |
|:---:|:---:|:---:|:---:|:---:|
| ○ | ○ | ○ | ○ | ○ |

112

## How useful do you find the flight planning software application?

| Extremely useful | Moderately useful | Somewhat useful | Slightly useful | Not at all useful |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

## When do you use the flight software application?

Select all that apply.

☐ Pre-flight

☐ In-flight

## What is the flight planning software application use of frequency?

|  | Every flight | Almost every flight | Occasionally/Sometimes | Almost never | Never |
|---|---|---|---|---|---|
| Pre-flight | ○ | ○ | ○ | ○ | ○ |
| In-flight | ○ | ○ | ○ | ○ | ○ |

## What is your purpose(s) in using the software application?

Select all that apply.

☐ Weather information

☐ Flight documentation

113

☐ Airport database

☐ GPS

☐ Flight planning and/or re-planning

☐ Other, please specify...        | Type here |

## What would you like to develop the flight planning software application's feature?

| Type here |

## Flight Planning & Weather Information

## Describe your flight planning process before flight.

Please specify if you use flight plan software application.

VFR        | Type here |

IFR        | Type here |

114

Which sources do you use for weather information when you plan your flight?

Select all that apply.

☐ METAR

☐ TAFs

☐ SIGMETs

☐ AIRMETs

☐ PIREPs

☐ Other, please specify...            | Type here |

What equipment is on your aircraft relevant to flight planning, IMC, weather, sensing?

| Type here |

Flight Re-planning or Trajectory Changes due to Weather Changes

Have you ever had to re-plan your flight or alter your trajectory?

If you select "No", you can submit your questionnaire.

Yes                    No

If you have selected "Yes" for previous question, please describe such a situation:

Type here

Which information sources did you use to handle with the situation?

Select all that apply.

☐ Communication with ATC

☐ Communication with other closest aircraft

☐ Listening radio

☐ Using flight plan software application

☐ Other, please       Type here
   specify...

What would you expect from a software application for re-planning?

116

Type here

Submit

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Administrator
▲

This toolbar is
only visible to
administrators.

Page 1 ▼

## B.3   Examination Questionnaire Part 3

# Examination Interview - Part 3

Participant Number

> Type here

What is the reason(s) you prefer not to use a flight planning software application on the electronic tablet?

Select all that apply.

☐ High cost for software application

☐ High cost for tablet

☐ Not necessary to use it.

☐ Other, please specify...        Type here

Flight Planning & Weather Information

Describe your flight planning process before flight.

118

VFR

> Type here

IFR

> Type here

## Which sources do you use for weather information when you plan your flight?

Select all that apply.

- ☐ METAR

- ☐ SIGMETs

- ☐ AIRMETs

- ☐ TAFs

- ☐ PIREPs

- ☐ Other, please specify...
          | Type here |

What equipment is on your aircraft relevant to flight planning, IMC, weather, sensing?

Please list all, especially for weather information and flight path trajectory.

Type here

Have you experienced any flight re-planning or trajectory changes due to weather changes?

If you select "No", you can submit your questionnaire.

Yes            No

May you tell the situation you experienced about flight re-planning/trajectory changes due to weather changes?

Type here

Which information sources did you use to handle with the situation?

☐ Communication with ATC

☐ Communication with other closest aircraft

☐ Listening radio

☐ Checking the weather monitor (if it is installed)

☐ Other, please specify...

> Type here

### Which steps have you followed for re-routing/trajectory changing procedure?

> Type here

### Have there been situations where you had difficulty about re-planning because you didn't have the right information or equipment?

Describe the situation.

> Type here

Submit

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## Supporting General Aviation Pilots During Rerouting Due to Sudden Weather Changes

As a graduate student at Georgia Institute of Technology, I am researching how a flight plan software application on an electronic tablet impacts General Aviation pilot's decision for rerouting/re-planning the flight due to weather changes in flight. The purpose of this study is to understand how and why the pilot reroutes/re-plans the flight in flight when the weather changes suddenly.

I am interested in understanding the flight experiences and opinions of pilots. Your participation as a pilot will support the understanding of the flight plan and re-plan using different information resources. Ultimately, this study will enlighten the design requirement descriptions of decision support system.

• 	PARTICIPATION AND WITHDRAWAL

Your participation in this study is completely voluntary, and you may subsequently withdraw from this study at any time without penalty or consequences of any kind.

• 	CONFIDENTIALLY

Any information that is obtained in connection with this study and that can be directly or indirectly identified with you will remain confidential.

The results of the questionnaire will not be linked to you. Any demographic information and your pilot certification information that is collected is for this study purposes only and will not be used to identify you.

• 	CONTACT

If you have any questions or concerns about the study, please email Dr. Karen M. Feigh or Guliz Tokadli at karen.feigh@gatech.edu and glztokadli@gatech.edu at any time.

*Required*

1. **Agreement** *
   *Mark only one oval.*

   ( ) 	I agree with these terms

   ( ) 	I disagree (Submit form) 	*After the last question in this section, stop filling out this form.*

## Demographic Information

2. **What is your age?** *

*Mark only one oval.*

- ◯ <= 18
- ◯ 18-20
- ◯ 21-25
- ◯ 26-30
- ◯ 31-35
- ◯ >35

3. **What is your gender?** *

*Mark only one oval.*

- ◯ Female
- ◯ Male
- ◯ Do not prefer to answer

# Pilot Certification & Flight Experience

4. **What is your pilot certification?** *

*Mark only one oval.*

- ◯ Student
- ◯ Sport
- ◯ Recreational
- ◯ Private
- ◯ Commercial
- ◯ Airline Transport Pilot
- ◯ Other: .................................................................

5. **What rating do you hold?** *

Please select all that apply
*Check all that apply.*

- ☐ Airplane Single Engine Land
- ☐ Airline Multi Engine Land
- ☐ Airline Single Engine Sea
- ☐ Airline Multi Engine Sea
- ☐ Rotorcraft Helicopter
- ☐ Instrument Airplane
- ☐ Instrument Rotorcraft
- ☐ Other: .................................................................

6. **Total Flight Hours** *

........................................................................................

7. **Day-time Flight Hours** *

........................................................................................

8. **Night Flight Hours** *

........................................................................................

9. **VFR Flight Hours** *

........................................................................................

10. **IFR Flight Hours** *

........................................................................................

11. **In what region(s) do you fly?** *
    Please list all.

........................................................................................

........................................................................................

........................................................................................

........................................................................................

........................................................................................

12. **What aircraft model do you fly?** *

........................................................................................

## Flight Software Application on an Electronic Tablet

Electronic Tablet including iPad, android tablet, android phone, iPhone, smartphone, so on.
Flight Software Application: App is mostly used for the flight planning, navigation, flight filing, etc.

13. **Have you ever used any flight software application on the electronic tablet?** *
    *Mark only one oval.*

    ( ) Yes      *Skip to question 14.*

    ( ) No       *Skip to question 30.*

## Flight Plan Software Application on an Electronic Tablet

14. **When did you start to use a flight planning software application?** *
   *Mark only one oval.*

   ( ) <=6 months

   ( ) 6-12 months

   ( ) 12-18 months

   ( ) >18 monts

15. **What is the type of electronic devices?** *
   Please select all that apply.
   *Check all that apply.*

   [ ] iPad

   [ ] Android tablet

   [ ] Windows tablet

   [ ] iPhone

   [ ] Smartphone (Windows)

   [ ] Smartphone (Android)

   [ ] Other: .......................................................................

16. **Which software application do you use?** *
   *Mark only one oval.*

   ( ) ForeFlight

   ( ) WingX

   ( ) Garmin

   ( ) FlightAware

   ( ) QRouting

   ( ) Other: .......................................................................

17. **How familiar are you with the flight planning software application?** *
   *Mark only one oval per row.*

   | | Extremely familiar | Moderately familiar | Somewhat familiar | Slightly familiar | Not at all familiar |
   |---|---|---|---|---|---|
   | | ( ) | ( ) | ( ) | ( ) | ( ) |

18. **How useful do you find the flight planning software application?** *
   *Mark only one oval per row.*

   | | Extremely useful | Moderately useful | Somewhat useful | Slightly useful | Not at all useful |
   |---|---|---|---|---|---|
   | | ( ) | ( ) | ( ) | ( ) | ( ) |

19. **When do you use the flight software application?** *

    Please select all that apply.
    *Check all that apply.*

    ☐ Pre-flight

    ☐ In-flight

20. **What is the flight planning software application use of frequency?**

    *Mark only one oval per row.*

    |  | Every flight | Almost every flight | Occasionally/Sometimes | Almost never | Never |
    |---|---|---|---|---|---|
    | Pre-flight | ◯ | ◯ | ◯ | ◯ | ◯ |
    | In-flight | ◯ | ◯ | ◯ | ◯ | ◯ |

21. **What is your purpose(s) in using the software application?** *

    Please select all that apply.
    *Check all that apply.*

    ☐ Weather information

    ☐ Flight documentation

    ☐ Airport database

    ☐ GPS

    ☐ Flight planning and/or re-planning

    ☐ Other: ........................................................................................

22. **What would you like to develop as one of the flight software application's features?** *

    ....................................................................................................

## Flight Planning and Weather Information

23. **Describe your flight planning process before flight. Please specify the flight planning under VFR or IFR.** *

    Please specify the steps which includes the use of flight software application if you use any flight plan software on an electronic tablet.

    ....................................................................................................
    ....................................................................................................
    ....................................................................................................
    ....................................................................................................
    ....................................................................................................

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24. **Which sources do you use for weather information when you plan your flight?** *

Please select all that apply.
*Check all that apply.*

- [ ] METAR
- [ ] TAFs
- [ ] SIGMETs
- [ ] AIRMETs
- [ ] PIREPs
- [ ] Other: ......................................................................

25. **What equipment is on your aircraft relevant to flight planning, IMC, weather, sensing?** *

Please list all, especially for weather information and flight path trajectory.

.................................................................................

.................................................................................

.................................................................................

.................................................................................

.................................................................................

## Flight Re-planning or Trajectory Changes due to Weather Changes

26. **Have you ever had to re-plan your flight or alter your trajectory?** *

*Mark only one oval.*

- ( ) Yes
- ( ) No (Submit form)    *After the last question in this section, stop filling out this form.*

27. **Please describe such a situation:**

.................................................................................

.................................................................................

.................................................................................

.................................................................................

.................................................................................

28. **Which information sources did you use to handle with the situation?**
Please select all that apply.
*Check all that apply.*

☐ Communication with ATC

☐ Communication with other closest aircraft

☐ Listening radio

☐ Using flight plan software application

☐ Other:

29. **What would you expect from a software application for re-planning?** *

30. **What is the reason(s) you prefer not to use a flight planning software application on the electronic tablet?** *
Please select all that apply.
*Check all that apply.*

☐ High cost for software application

☐ High cost for electronic device

☐ Not necessary to use it

☐ Other:

## Flight Planning & Weather Information

31. **Describe your flight planning process before flight. Please specify the flight planning under VFR or IFR.** *
Please specify the steps which includes the use of flight software application if you use any flight plan software on an electronic tablet.

32. **Which sources do you use for weather information when you plan your flight?** *
Please select all that apply.
*Check all that apply.*

- [ ] METAR
- [ ] TAFs
- [ ] SIGMETs
- [ ] AIRMETs
- [ ] PIREPs
- [ ] Other: ...........................................................................................

33. **What equipment is on your aircraft relevant to flight planning, IMC, weather, sensing?** *
Please list all, especially for weather information and flight path trajectory.

...................................................................................................

...................................................................................................

...................................................................................................

...................................................................................................

...................................................................................................

34. **Have you experienced any flight re-planning or trajectory changes due to weather changes?** *
*Mark only one oval.*

( ) Yes

( ) No (Summit form)    *After the last question in this section, stop filling out this form.*

35. **May you tell the situation you experienced about flight re-planning/trajectory changes due to weather changes?**

...................................................................................................

...................................................................................................

...................................................................................................

...................................................................................................

...................................................................................................

36. **Which information sources did you use to handle with the situation?**
Please select all that apply.
*Check all that apply.*

- [ ] Communication with ATC
- [ ] Communication with other closest aircraft
- [ ] Listenning radio
- [ ] Checking the weather monitor (if it is installed)
- [ ] Other: ................................................................................

37. **Which steps have you followed for re-routing/trajectory changing procedure? ***

................................................................................
................................................................................
................................................................................
................................................................................
................................................................................

38. **Have there been situations where you had difficulty about re-planning because you didn't have the right information or equipment? ***
Describe the situation.

................................................................................
................................................................................
................................................................................
................................................................................
................................................................................

## INTERVIEWS: ADDITIONAL GRAPHICS

*Flight Hours:* VFR and IFR flight hours were compared to examine whether there is any difference about decision-making process of flight rerouting/re-planning. Besides VFR and IFR flight hours, the comparison between Daytime and Night flight hours were represented.
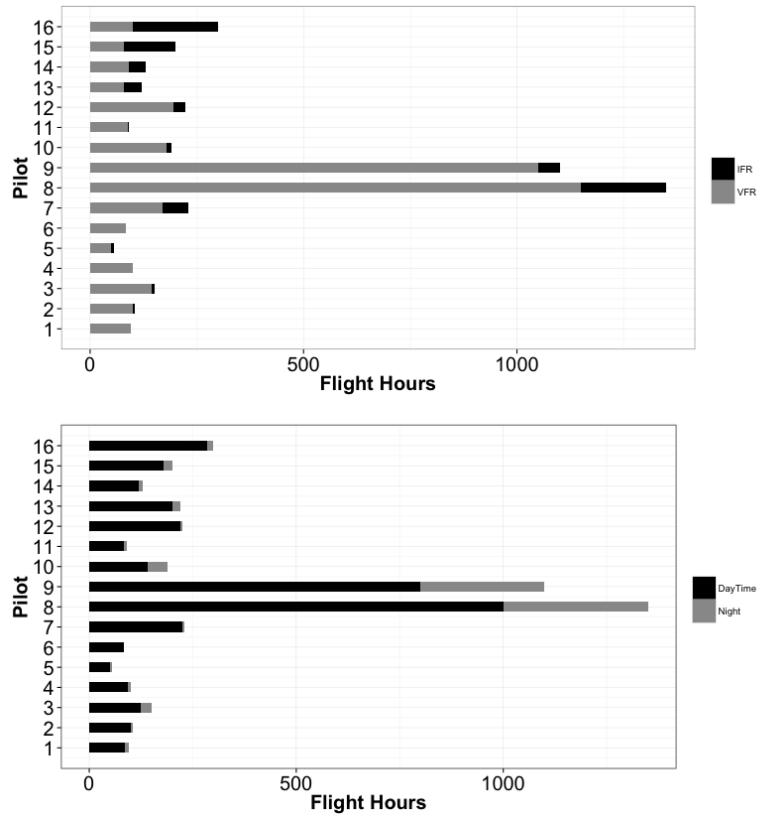


**Figure 58:** The comparison between flight hours (VFR vs. IFR (on the left hand side) and Day-time vs Night flights (on the right hand side))

*Aircraft Types:* 41% of the pilots fly with C172 Skyhawk. Thus, they listed same information sources to fly in safe. Although, if the pilot flies not only with C172, he/she compared the information sources he/she has on the other aircraft type.
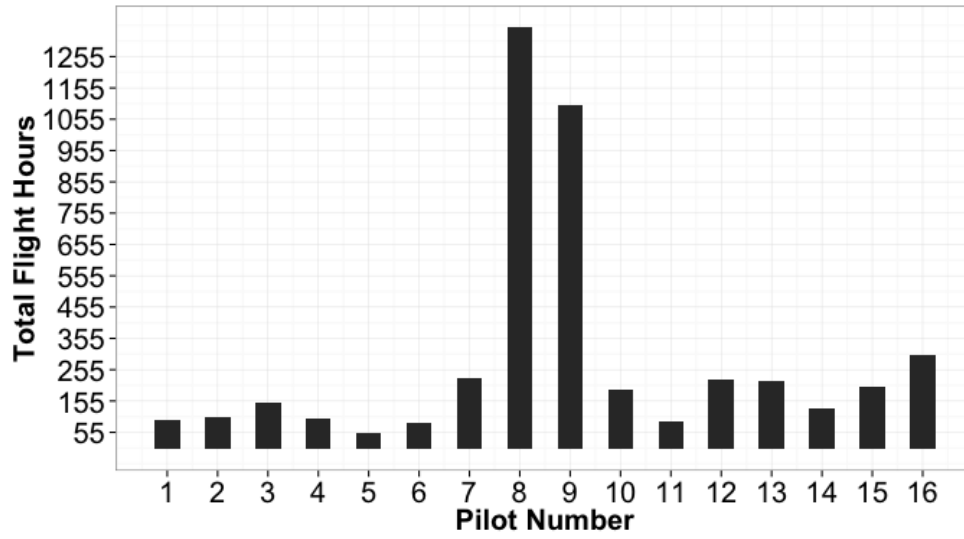
**Figure 59:** Total flight hours.
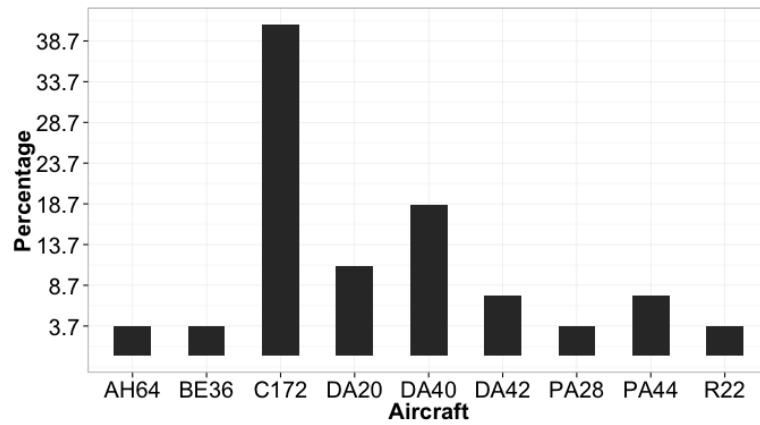


**Figure 60:** Aircraft types.

**Table 18:** Having weather caused flight re-planning ratio.

| Application use | Number of Pilot | Having Situation (Yes) |
|:---:|:---:|:---:|
| Yes | 13 | 10 |
| No | 3 | 2 |

*Flight Planning Software Application Users:* Number of how many volunteer pilots who have experienced weather caused flight re-planning is represented in Table 18.

*Weather-Caused Flight Re-planning Experience:* When the verbal responses (qualitative data) were explored, the keywords were picked using Atlas.ti software to find a relationship between the decisions of pilots. In Figure 61, the the code cooccurence tables show the comparison between the selection of landing airport and flight diversion or trajectory change.
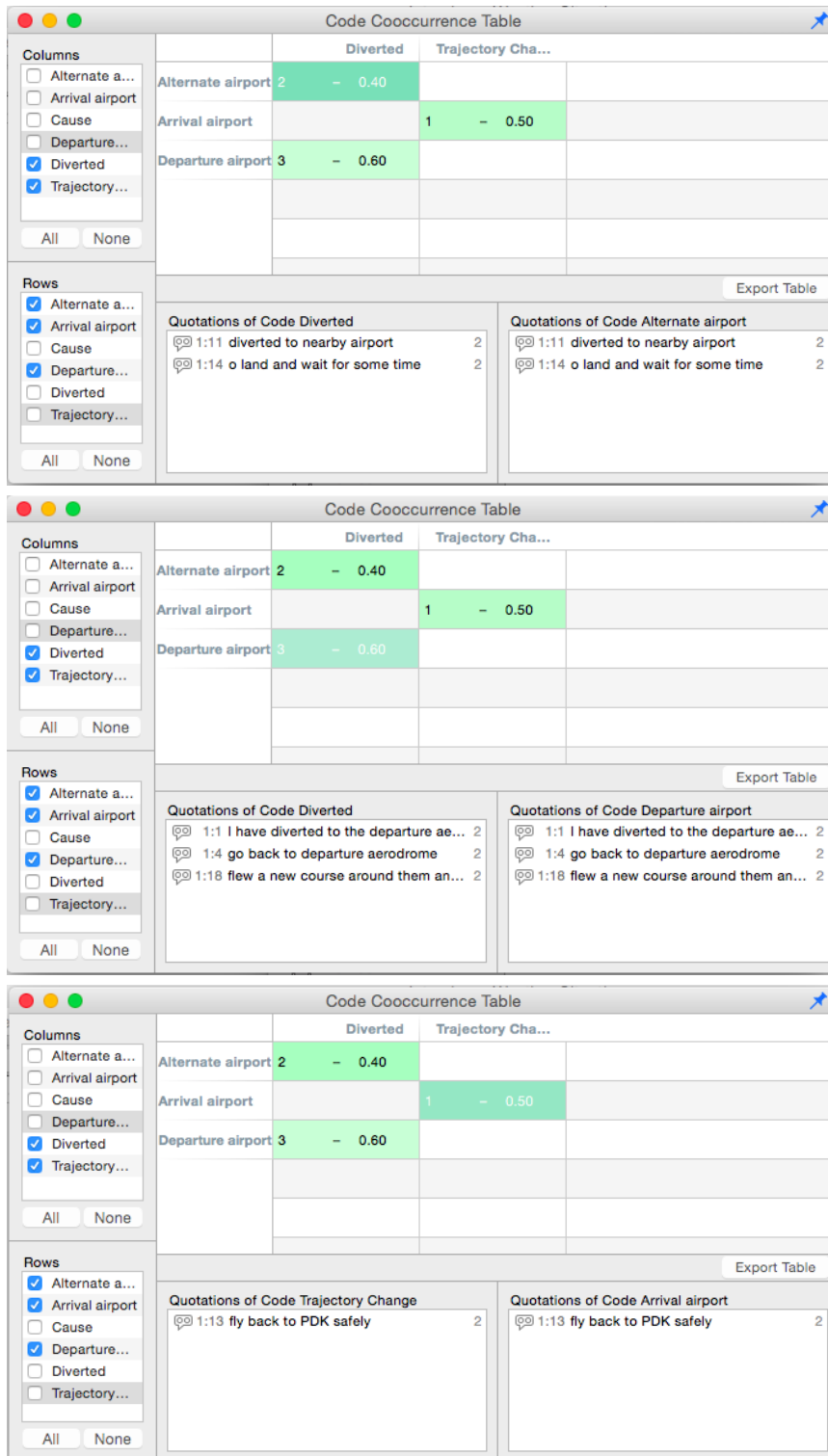
**Figure 61:** Flight re-planning decisions.

# APPENDIX D

# VALIDATION EXPERIMENT

## *D.1   Demographic Questionnaire*

## Validation Experiment

Pilot Number

> Type here

Demographic Information

What is your age?

- ○ <= 20
- ○ 21-25
- ○ 26-30
- ○ 31-35
- ○ > 35

What is your gender?

- ○ Male

◯ Female

◯ Prefer Not to Answer

## Pilot Information & Flight Experience

### Are you a member of Yellow Jacket Flying Club?

Yes             No

### What is your pilot certification?

◯ Student

◯ Sport

◯ Recreational

◯ Private

◯ Commercial

◯ Airline Transport Pilot

◯ Other, please specify...      Type here

### What ratings do you hold?

Select all that apply.

☐ Airplane Single Engine Land

☐ Airline Single Engine Sea

☐ Airline Multi Engine Land

☐ Airline Multi Engine Sea

☐ Rotorcraft Helicopter

☐ Instrument Airplane

☐ Instrument Rotorcraft

☐ Other, please specify...     Type here

## Flight Hours

| Total flight hours | Type here |
| --- | --- |
| Day-time flight hours | Type here |
| Night flight hours | Type here |
| VFR - flight hours | Type here |
| IFR - flight hours | Type here |

## In what region(s) do you fly?

Please list all.

> Type here

## What model aircraft do you fly?

> Type here

## Flight Planning Software Applications on the Electronic Tablet

Electronic Tablet: iPad, Windows tablet, Android tablet...

## When did you start to use a flight planning software application?

- ◯ <= 6 months
- ◯ 6 - 12 months
- ◯ 12 - 18 months
- ◯ > 18 months

## What is the type of electronic tablet?

Please explain why you prefer to use it.

○ iPad

Type here

○ Windows tablet

Type here

○ Android tablet

Type here

○ Other, please specify...

Type here

## Which software application do you use?

Please explain why you prefer to use it.

○ ForeFlight

Type here

○ FlightAware

Type here

○ WingX

Type here

○ Garmin

Type here

○ QRouting

Type here

○ Other, please specify...

Type here

## How familiar are you with the flight planning software application?

| Extremely familiar | Moderately familiar | Somewhat familiar | Slightly familiar | Not at all familiar |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

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## How useful do you find the flight planning software application?

| Extremely useful | Moderately useful | Somewhat useful | Slightly useful | Not at all useful |
|:---:|:---:|:---:|:---:|:---:|
| ○ | ○ | ○ | ○ | ○ |

## When do you use the flight software application?

Select all that apply.

☐ Pre-flight

☐ In-flight

## What is the flight planning software application use of frequency for pre- and in-flight phases?

|  | Every flight | Almost every flight | Occasionally | Almost never | Never |
|---|:---:|:---:|:---:|:---:|:---:|
| Pre-flight | ○ | ○ | ○ | ○ | ○ |
| In-flight | ○ | ○ | ○ | ○ | ○ |

## What is your purpose(s) in using the software application?

Select all that apply.

☐ Weather information

☐ Flight documentation

☐ Airport database

☐ GPS

☐ Flight planning and/or re-planning

☐ Charts

☐ Other, please specify...   [ Type here ]

[ Submit ]

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Administrator

[ Page 1 ▼ ]

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## D.2 Post-Flight Questionnaire

# Post-Flight Questionnaire

### Participant Number

Type here

### Task Number

Type here

### Scenario Number

Type here

### Mental Demand

How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, communicating, listening, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Low                                               High

### Physical Demand

How much physical activity was required (e.g., tabbing, activating, updating, etc.)?
Was the task easy or demanding, slow or brisk?

Low                                                                                    High

## Temporal Demand

How much time pressure did you feel due to the rate or pace at which the tasks or task
elements occurred?

Low                                                                                    High

## Effort

How hard did you have to work (mentally and physically) to accomplish your level of
performance?

Low                                                                                    High

## Performance

How successful do you think you were in accomplishing the goals of the task set by
the experimenter (or yourself)? How satisfied were you with your performance in
accomplishing these goals?

High                                                                                    Low

## Frustration Level

How insecure, discourage, irritated, stressed and annoyed versus secure, gratified,

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content, relaxed and complacent did you feel during the task?

Low       (                       )       High

May you describe your flight experience? Is there any differences you feel during your flight? If yes, please describe.

Type here

Submit

Administrator

Page 1 ▾

## D.3 Assessment of Design Requirements

| DR # | Design Requirements (DR) | Priority | Comments |
|------|--------------------------|----------|----------|
| DR1 | Design the flight planning software application by adding a new tab as "Flight Plan". The user should be able to enter and save the flight plan data including alternative flight path info. | | |
| DR2 | Design the "Flight Plan" tab including: (1) Destination, (2) Origin, and (3) Alternate airports, (4) Flight date & time, (5) Options as weather, air-traffic, and fuel amount. | | |
| DR3 | Design the flight planning software application by adding a new tab as "Rerouting". The user should be able to compare the possible flight paths to reroute or change the trajectory of the flight vertically or horizontally. | | |
| DR4 | "Rerouting" tab must include the options as vertical trajectory possibility, horizontal trajectory suggestion, alternative flight path. | | |
| DR5 | "Rerouting" tab must provide the information of weather radar overlayed with map, and predicted fuel amount to arrive the destination. In addition to these, the user must be able to receive the location of the aircraft close to the flight path. | | |
| DR6 | The weather zone, which causes the rerouting decision, must be demonstrated with the appropriate geometrical shape. It provides that the pilot can recognize the weather zone impact to avoid the aircraft from that area to fly in safe. This requirement is currently applied for other applications; therefore, it is not special for this study. | | |
| DR7 | The screen must demonstrate two different options to decide how to change the flight path. The user should be able to see the comparison between (1) Alternative Flight Path (AFP) & Vertical Trajectory of the flight path, (2) AFP & Horizontal trajectory of the flight path, (3) Vertical & Horizontal trajectory of the flight path. | | |
| DR8 | Design the flight planning software application by adding a new tab as "Flight Track". | | |
| DR9 | When the user tabs one of these flight path demonstrations on the "Rerouting" tab, the "Flight Track" tab must be updated with the selected flight path. | | |
| DR10 | The user should be able to get weather forecast overlayed on the map. | | |
| DR11 | Vertical trajectory of the flight path is not a defined flight path. The system should be able to provide the altitude difference between top and the bottom of the weather zone. This support the pilot to decide to descent or climb to pass the weather impact zone. | | |
| DR12 | If the weather information is changed in a way that it might affect the safe of flight, the system must suggest warning message on the screen. | | |
| DR13 | The user is able to ignore the warning message and keep flying on the current flight path. Or the user is able to go "Rerouting" tab to see options. | | |

## D.4  Post-Experiment Questionnaire: Usability

# Post-Experiment Questionnaire - Page 1

Pilot Number

Type here

Learning

Learning how to operate the system

difficult                                                                        easy

Exploring features by trial and error

difficult                                                                        easy

Performing tasks is straightforward

never                                                                           always

## Training materials

confusing    [                    ]    clear

## Usefulness

### Using the system would improve my performance to make a quick decision

strongly
disagree    [                    ]    strongly agree

### Using the system in the flight would enable me to accomplish rerouting task more quickly

strongly
disagree    [                    ]    strongly agree

### I would find the system useful in the flight

strongly
disagree    [                    ]    strongly agree

### It meets my need for flight rerouting and trajectory changing

strongly
disagree    [                    ]    strongly agree

Ease of Use

Learning to operate the system would be easy for me

strongly disagree        strongly agree

I would find it easy to get the system to do what I want it to do

strongly disagree        strongly agree

My interaction with the system would be clear and understandable

strongly disagree        strongly agree

The system would be easy to use

strongly disagree        strongly agree

Flexibility

Does it provide zooming for display expansion?

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bad                                                                                     good

## Does it provide user selection of data entry?

bad                                                                                     good

## Does it provide user selection of data display?

bad                                                                                     good

Consistency

## Are consistent, standard symbols used for graphic data?

bad                                                                                     good

## Is the label location consistent?

bad                                                                                     good

## Is the label format consistent?

bad                                                                                     good

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Is the display orientation consistent?

bad                                                  good

Is the display format consistent?

bad                                                  good

Minimal Action

Does required data need to be entered more than once?

bad                                                  good

Is it easy to shift among the menu options?

bad                                                  good

Is it easy to shift among the alternative flight paths?

bad                                                  good

Is it easy to shift among different trajectories?

bad                                                                                            good

Is the shifting among different trajectories required only one-touch action?

bad                                                                                            good

Is the shifting among the alternative flight paths required only one-touch action?

bad                                                                                            good

Can the menu and options be selected by touching?

bad                                                                                            good

Does it require minimal steps in sequential menu selection?

bad                                                                                            good

Does it require minimal user control actions?

bad                                                                                            good

Aspects

List the negative
aspect(s):

Type here

List the positive
aspect(s):

Type here

Other comments about functions and features that would improve the
system:

Type here

Submit

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