IN-FLIGHT PLANNING AND INTELLIGENT PILOT AIDS FOR EMERGENCIES AND NON-NOMINAL FLIGHT CONDITIONS

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IN-FLIGHT PLANNING AND INTELLIGENT PILOT AIDS FOR EMERGENCIES AND NON-NOMINAL FLIGHT CONDITIONS

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LIST OF ABBREVIATIONS

ANOVA - Analysis of Variance

AOC - Airline Operations Center

ATC - Air Traffic Control

CDM - Collaborative Decision Making

CDU - Control Display Unit

CDU+ - Control Display Unit + (CDU variant where Autoplan can be selected)

CDU++ - Control Display Unit ++ (CDU variant where Autoplan is active at start of the run)

EFP - Emergency Flight Planner

EHSI - Electronic Horizontal Situation Indicator

EICAS - Engine Indicating and Crew Alerting System

ETA - Estimated Time to Arrival

F/D - Flight Directors

FAA - Federal Aviation Administration

FMA - Flight Mode Annunciator

FMS - Flight Management System

GPWS - Ground Proximity Warning System

IAS - Indicated Air Speed

MCP - Mode Control Panel

NASA - National Aeronautics and Space Administration

pFAST - passive Final Approach Spacing Tool

PFD - Primary Flight Display

PLI - Party Line Information

RFS - Reconfigurable Flight Simulator

STAR - Standard Terminal Arrival Route

TCAS - Traffic Collision and Avoidance System

TLX - Task Load Index

TOA - Type of Automation

URET - User Request Evaluation Tool

MODE CONTROL PANEL MODES

ALT HLD - Altitude Hold

FLCH - Flight Level Change

HDG HLD - Heading Hold

HDG SEL - Heading Select

LNAV - Horizontal Navigation

SPD - Speed

V/S - Vertical Speed

VNAV - Vertical Navigation

CONTROL DISPLAY UNIT TERMINOLOGY

ACT - Route status: Active

DIR/INTC - Direct/Intercept button

EXEC - Execute button

LEGS - CDU Legs Page

MOD - Route status: Modified

RTE - CDU Route Page

SUMMARY

A commercial flight plan comprises a series of turns and climbs or descents defined by headings or waypoints, and speed and altitude constraints at each. Situations do occur in-flight where the original plan must be altered. The objective of this research was to see how pilots perform in-flight planning by observing the planning behavior of pilots in non nominal and emergency conditions arising in the last 15-30 minutes of flight. The impact of autoflight systems on planning including notional systems with the capability of automatically generating a flight plan was also examined.

Results from the experiment showed that the autoflight systems did not have a significant impact on the replanning task. Instead, the specific scenario showed more of an effect on the primary performance measures of time of flight and distance flown. Interesting trends of lateral and vertical navigation were also seen, together with sometimes unconventional use of the autoflight systems. Pilots always tended to go for the most direct route possible when given discretion. Pilots did not verbally express any distinction between emergency and non-nominal flight conditions, however, the effect of these flight conditions was seen when the planning performance measures of time of flight and distance flown were analyzed. Most pilots were quite aggressive with their plans in terms of speeds and descents at higher altitudes but maintained shallow turns onto final approach.

Pilots favored the use of the automatically generated plan. From the experiment results it was determined that automatic flight path generation would be beneficial to the task of in flight replanning and would only serve to reduce the workload in high workload emergencies. However, it is imperative that, for such a system to be useful, it should have the ability of considering a number of factors simultaneously, including real time access to information about the immediate context, including traffic, weather and terrain.

CHAPTER 1

INTRODUCTION

Air transport pilots face situations at times that require them to re-route the aircraft. This calls for replanning the flight route either by modifying the existing plan or by creating a new plan by defining waypoints or headings, speeds and altitudes. However, this replanning in-flight can be a difficult task. From a pilot's point of view, any flight can be thought of as a plan of turns and descents, as well as changes in aircraft dynamics, such as extension of flaps and gear or the dumping of excess fuel. In addition to the causal effect of actions on the immediate trajectory, actions also change where and when subsequent actions need to be performed. Thus, in replanning, the pilot needs to account for all of these complex interactions in the trajectory to plan the flight-path of the aircraft. Unfortunately, it can be difficult for the pilot to predict all the interactions.

Research on planning has emphasized automation with a view to alleviating the workload on pilots and dispatchers either by automating planning processes or delegating decision-making away from the flight deck. However, few studies have examined the behavioral aspects of planning in general and the impact of automation in particular. This is especially true for "tactical planning", i.e., planning in a time horizon on the order of tens of minutes. Thus it is hypothesized that some automation in the flight deck should be available that could assist air transport pilots in tactical planning by considering many factors about the immediate and near-term situation.

For this thesis, a flight simulator experiment was conducted to study airline pilot performance in tactical replanning tasks using several different autoflight systems. Each pilot was placed into either a non nominal or an emergency situation which required replanning. All pertinent checklists were assumed to have been performed and the aircraft was currently in stable flight. His or her immediate task was to replan the current flight and fly down to the final approach using the available tools at hand. These tools always included the standard paper charts, such as the en-route chart, the STAR chart, and the approach plate. Depending on the scenario, they were given one of four types of automation, the MCP, the CDU and two variants of the CDU, the CDU+ and CDU++. All the types of automation were functionally similar to that of current aircraft. The latter two types had simulated automatic generation of plans called the Autoplan: in the CDU+ case, the automatically generated plan could be selected; and, in the CDU++ case, the Autoplan automatically became the active route. All the types allowed the pilot to modify the plan at any point during the flight.

The remainder of this thesis is organized as follows. To motivate this research Chapter 2 provides a background on tactical planning, cockpit automation and the benefits and problems associated with them. Chapter 3 provides the objectives of this research and details the experiment design including experimental apparatus, the independent variables to be studied, the experimental procedure, and the measures collected. Chapter 4 presents the results of the experiment. Chapter 5 provides a discussion of the results and the conclusions and recommendations from this study.

CHAPTER 2

BACKGROUND AND MOTIVATION

2.1 Flight Planning

Formally, a flight plan is a list of destinations or waypoints, their associated altitudes and speeds, and a destination which is to be filed with a legal authority before a flight. Functionally, the term "plan" can also refer to a succession of goals and actions that are designed and executed to fulfill the final objective.

In air transport, flight plans are typically created by the pilot and dispatcher, and approved (and potentially modified) by air traffic operators before take-off. In addition, a substantial amount of re-planning may need to be done on the fly during flight, where pilots have real time access to more current information sources.

Flight planning is essential as it is a process by which a suitable set of high level actions is created that will enable the flight to reach its destination. At a base level, flying an aircraft is essentially an exercise in managing available resources including time, fuel, energy, or a combination thereof. Management of these resources is crucial to an efficient flight and to do this the pilot must incorporate knowledge about the current environment. In higher workload situations, especially emergencies, pilots may face near impossible demands on their time. Flight planning offers a reduction of workload during later stages by enabling the pilot to follow a predetermined plan, and also can establish an efficient and safe trajectory throughout the flight.

In aviation, the terms time-critical, tactical and strategic are used quite often to describe behaviors and activities on the flight deck. Tactical behavior (and hence planning) is generally considered to be a near-term dynamic activity, whereas strategic planning behavior is generally considered to be a long term and big picture activity.

Using these three terms, Kuchar, Hyams and Fan (1998) defined a 'timeline' for planning. This classification is based on the time required or taken to arrive at a suitable course of action

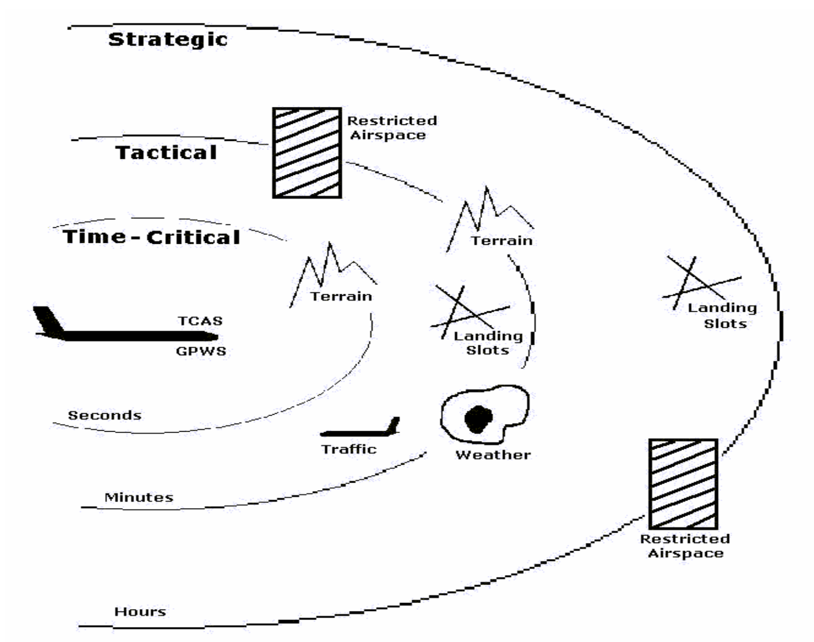


Figure 1 - Replanning Timeline (Adapted from Kuchar, Hyams and Fan, 1998)

The first type of planning is strategic planning. In airline operations this is usually done in an Airline Operations Center (AOC) by dedicated personnel who have access to current weather, air traffic, and airline specific information. These plans must also be cleared by air traffic control; they are usually made well in advance and require planning time of the order of hours. In most cases these are very detailed and provide a careful balance of business concerns (fuel costs, flight scheduling), environmental concerns, and aircraft performance.

The second type, tactical planning, is the focus of this research. During the flight unexpected situations may occur, requiring tactical replanning by the pilot. Tactical planning usually occurs on the order of minutes, and generally involves route modification designed to maintain safety and efficiency. Common tactical planning involves non-nominal situations like replanning the flight route to negotiate weather disturbances or changing the destination runway, and emergency situations like medical emergencies or cargo fires which require immediate landing. Although immediate safety is an important concern, other measures of efficiency (e.g. time to land, fuel burn, passenger comfort) may also be factored in to the extent a pilot can incorporate them in his or her plan.

The third and final type of planning is time-critical planning. Time-critical decisions usually require corrective action within a matter of seconds. The emphasis in these situations is on maintaining safety without regard for efficiency. Substantial research has been done on time critical events and a number of decision aids have been developed to assist pilots in decision making, including the Traffic Alert and Collision Avoidance System (TCAS) and Ground Proximity Warning System (GPWS).

2.2 Flight Deck Automation

Technological developments have made it possible to automate more and more functions in the flight deck and in other high workload and dynamic domains. Automation in the flight deck has evolved from the most basic autopilots to sophisticated systems such as flight management systems. Similarly, automation to maintain flight safety has also seen a sea change with the development of systems such as the Traffic Alert and Collision Avoidance System (TCAS) and the Ground Proximity Warning System (GPWS). The introduction of advanced technology on modern flight decks has succeeded in increasing the precision and efficiency of flight operations.

As part of this trend, systems have been developed that assist pilots with time-critical planning. For example, TCAS calculates an avoidance maneuver and displays it to the pilot, and the GPWS has a built-in aural alert which alerts the pilot to perform a standard avoidance maneuver. Due to their time critical nature, such re-planning tools have the characteristic of a forcing function on the pilot and are inherently automatic and assertive in nature. Another important element of modern flight deck automation is the Flight Management System (FMS).

"The FMS supports the pilots in a variety of tasks, such as flight planning, navigation and guidance, performance management and monitoring of flight progress." (Sarter and Woods, 1994). The major FMS interfaces for the pilot are the mode control panel (MCP) and the control display units (CDUs).The FMS is also intricately tied to many cockpit displays, including the primary flight displays (PFDs), and electronic horizontal situation indicators (EHSI), which display information about the autoflight modes and the current route of flight.

The CDUs consist of a keyboard and a data display screen. The keyboard is used by the pilots to enter data that define a flight path and to access flight related data available in the numerous display pages. The pilot-entered flight path is continuously updated to reflect current flight status and is presented on the EHSI when in map mode. This allows pilots to monitor progress along the path. In the EHSI plan mode, the pilot can visually check modifications to the active flight plan.

The MCP is used to activate different automatic flight modes such as: Vertical Navigation (VNAV), Lateral Navigation (LNAV), Heading Select (HDG SEL) and Flight Level Change (FLCH). The pilot can also use knobs on the MCP to dial in targets for individual parameters (airspeed, heading, altitude, and vertical speed), which are tracked when their corresponding automatic flight mode is activated. To find out which FMS modes are currently active, the pilot can monitor the flight mode annunciations on the PFD. These provide data on the active (or armed) pitch and roll modes and on the status of the autopilot(s). They also indicate the status and mode of the autothrottles, which can be set to either manual or automatic mode for speed and altitude control. The various FMS interfaces combine to provide the pilot with a high degree of flexibility in selecting and combining levels of automation to respond to different situations.

The FMS can also help with flight planning. When the authorized flight plan is being entered into the FMS while the aircraft is at the gate, it would be considered as being used for strategic planning purposes, and when a reroute is being planned in the air for the next few minutes of flight, it would be considered as being used for tactical planning. The FMS can also provide a "what-if" capability (Honeywell, 1996). For example, the pilot can query the FMS to determine how much extra fuel will be burned if he or she increases speed by Mach 0.02. This provides pilots the information needed to evaluate new plans.

Recent accidents and incidents involving glass aircraft suggests that the increase in automation in the flight deck also have a degree of operational burden associated with them. This can lead to various breakdowns in the overall human-machine system. This has been hypothesized to arise from the complexity of the FMS itself and/or poor portrayal to the pilot of its functioning. Studies exploring the pilots' mode awareness and understanding of the functional structure of automation are plentiful. However, less research has examined its utility for tactical planning.

2.3 Prior Research into Automated Tactical Planning Aids

Some studies have explored intelligent planning tools and their impact on tactical planning. Chen and Pritchett (2000) conducted a flight simulator experiment to investigate an in-flight computer based re-planner tool that could aid pilots in tactical planning, and to gain more information on how pilots planned in these situations and what factors were important to them. This system, called the Emergency Flight Planner (EFP), allowed the pilot to specify fixes, headings and distinct actions to be carried out at pilot defined waypoints or triggering conditions. Based on this information, the EFP then predicted the future flight path and displayed it to the pilot on vertical profile and horizontal moving map displays. The experiment also examined the utility of an automatically generated plan. From the experiment results, it was determined that, given the already high workload environment of the cockpit during an emergency, a planning tool in which the pilot had to manually enter a detailed plan would be detrimental to the safety of the flight. In addition to the evaluation of this tool, pilot planning was studied by breaking down a high level task into a series of low level actions and their triggers. The study showed that pilots preferred spatial representations of the plan as opposed to time-lines and time-based triggers. This study, however, studied only emergency flight conditions and did not explicitly study the behavior of pilots during planning when using current autoflight systems.

CHAPTER 3

DESIGN OF EXPERIMENT

3.1 Experiment Objectives

The main objectives of this experiment were to study:

- Pilot planning performance at in-flight re-planning in non-nominal and emergency flight conditions;
- Pilot planning behavior for in-flight re-planning in non-nominal and emergency flight conditions;
- The impact of cockpit automation on the planning process.

Additionally, this experiment was also a preliminary investigation of an intelligent cockpit aid capable of automatic flight plan generation. This investigation was preliminary in that only the concept of such a system was explored and the plans used for the experiment were preprogrammed into the planning interfaces.

3.2 Experiment Overview

In each experiment the pilots faced either a non nominal or an emergency situation about 30 minutes (85-90 miles) from landing. Before that start of each flight, pilots were given a scenario briefing (Appendix B.4) along with paper charts. They were given 25 seconds to go through the charts before the run was started. Their task was to replan the route while in flight, with the assumption that the all pertinent checklists had already been completed, the situation contained, and control of the aircraft had been regained just before the run started.

A confederate pilot was present in all runs. The main function of the confederate pilot was to get clearances from air traffic control, deploy the flaps and gear when asked by the test pilot, and to enforce the type of automation used for the run, i.e., in the CDU (and its variants) cases, pilots were not allowed to use the MCP and vice versa.

Sixteen pilots took part in the experiment. Each pilot ran nine flights for a total of 144 runs. The run order was determined by a test matrix which was a balanced combination of two independent variables: type of automation and scenario type, based on a Latin Square design. The types of automation tested were MCP, CDU, CDU+ and CDU++. The scenario types were classified into two types, non nominal and emergency.

The simulator logged important data including aircraft state variables (such as speed, distance, latitude and longitude) and identifiable actions in the autoflight systems (such as speed changes, altitude changes and heading changes). Additionally, pilots were also asked to fill a questionnaire at the end of each run and at the end of the experiment.

3.3 Scenario Design

To avoid pilot familiarity with a common arrival route, fictitious airports and arrival routes were used for the experiment. The airports were adapted from those previously utilized in two other experiments to study arrival procedures and cockpit display of traffic information (Yankosky and Pritchett, 1999) and the Emergency Flight Planner (EFP) (Chen and Pritchett, 2000). A new airport for the training runs and a number of waypoints, fixes and navigation aids were added to the existing charts. Terrain was not a consideration in the experiment.

A total of ten airports and their related charts were used for the experiment, one for each scenario. Four airports were reserved for non nominal scenarios, four for emergency scenarios, one for the faulty Autoplan scenario and one for the training scenario. The tenth airport reserved for the faulty Autoplan scenario and was used for both non nominal and emergency scenarios.

All the scenarios were designed to be of equal difficulty. The initial positions of the aircraft at the start of the scenarios were placed such that pilots could choose to approach the airport from either the left or the right of the runway. The run was terminated once pilots had intercepted the localizer at glideslope altitude at the outer marker. Before the start of each run, pilots were given a briefing sheet. Given below is a sample of a non-nominal scenario briefing and an emergency scenario briefing. The complete set of briefings is given in Appendix B.4.

Sample non-nominal briefing:

Atlantic Briefing

You are heading along the Townhouse One Arrival at Atlantic International Airport and are 13 miles past VOR CLR[114.0 CLR], when you receive word from ATC that there is severe turbulence directly in your path ahead and spanning the area shown in your en-route chart.

The destination is runway RW29L at Atlantic International. Your current state is:
- heading 347°
- 13000 ft altitude (-1200 fpm)
- 290 IAS

Start your replanning from this point.

Sample emergency briefing:

Bruin Briefing

You were heading along the Braddock Arrival, when your alarm systems detected a fire in the cargo hold. The fire has been put out by the flight attendants, but the extent of the damage is not clear. You are 52 miles past VOR BRN [114.0 BRN], by the time you decide to declare an emergency and all standard procedures and checklists have been completed.

The destination is runway RW18R at Bruin International Airport and your current state is:

- heading 34°
- 9000 ft altitude (-1200 fpm)
- 250 IAS

Start your replanning from this point.

Additionally, pilots were also provided paper charts for the area based on the current Jeppesen standard. The paper charts included an en-route chart, a Standard Terminal Arrival Route (STAR) chart and an approach plate. These charts are shown in Figure 2, Figure 3 and Figure 4.

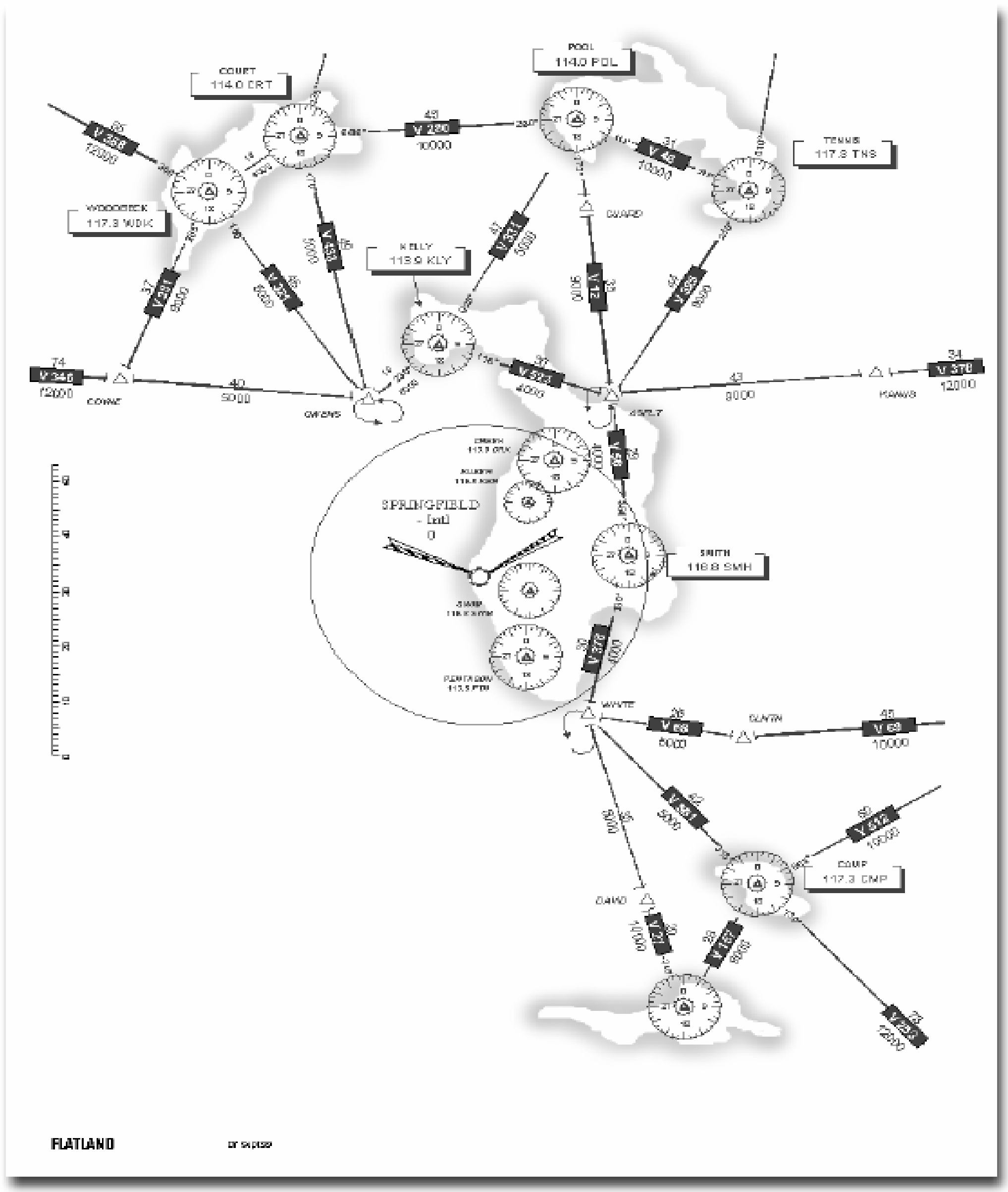


Figure 2 - Sample En-route Chart

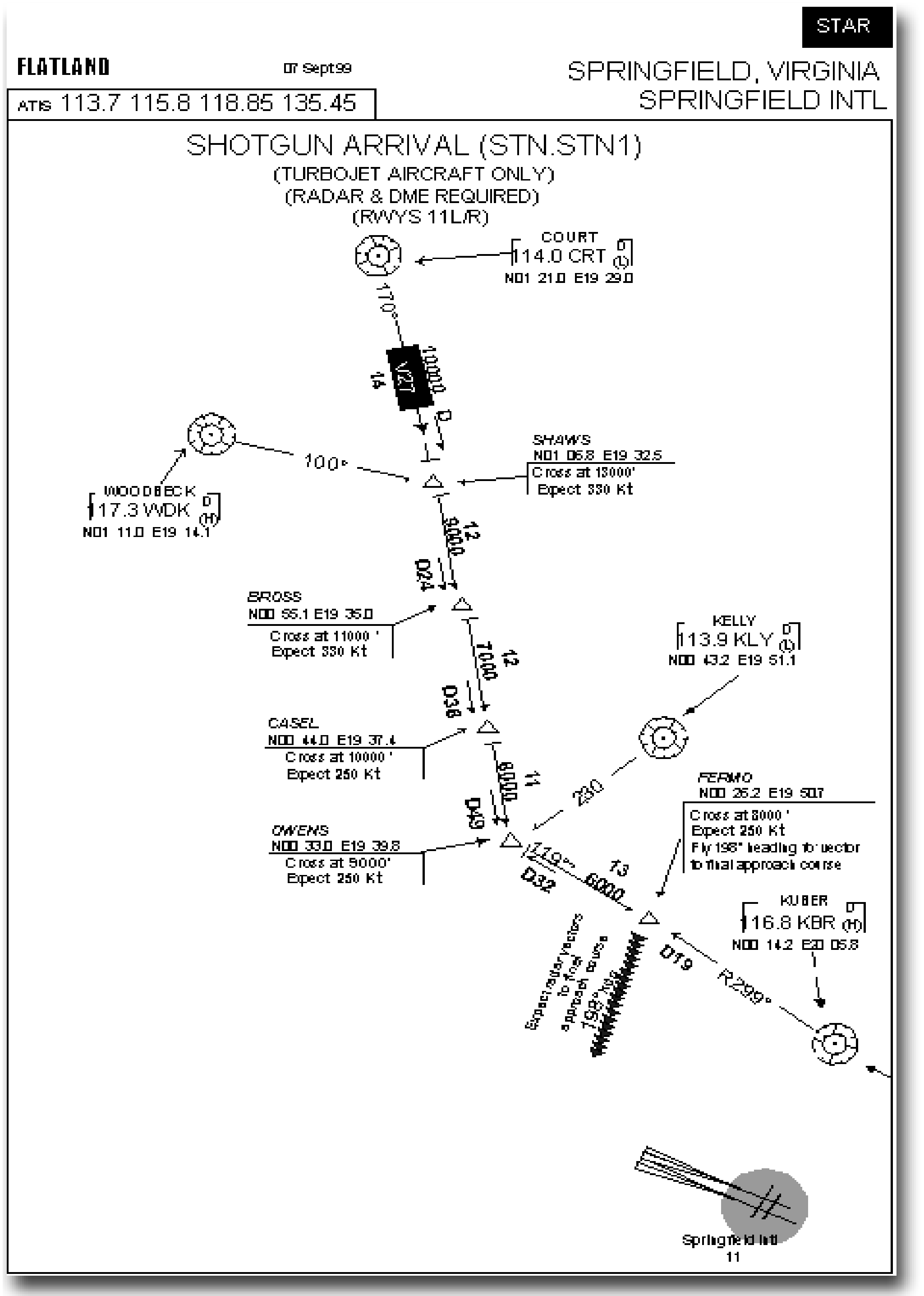


Figure 3 - Sample STAR Chart

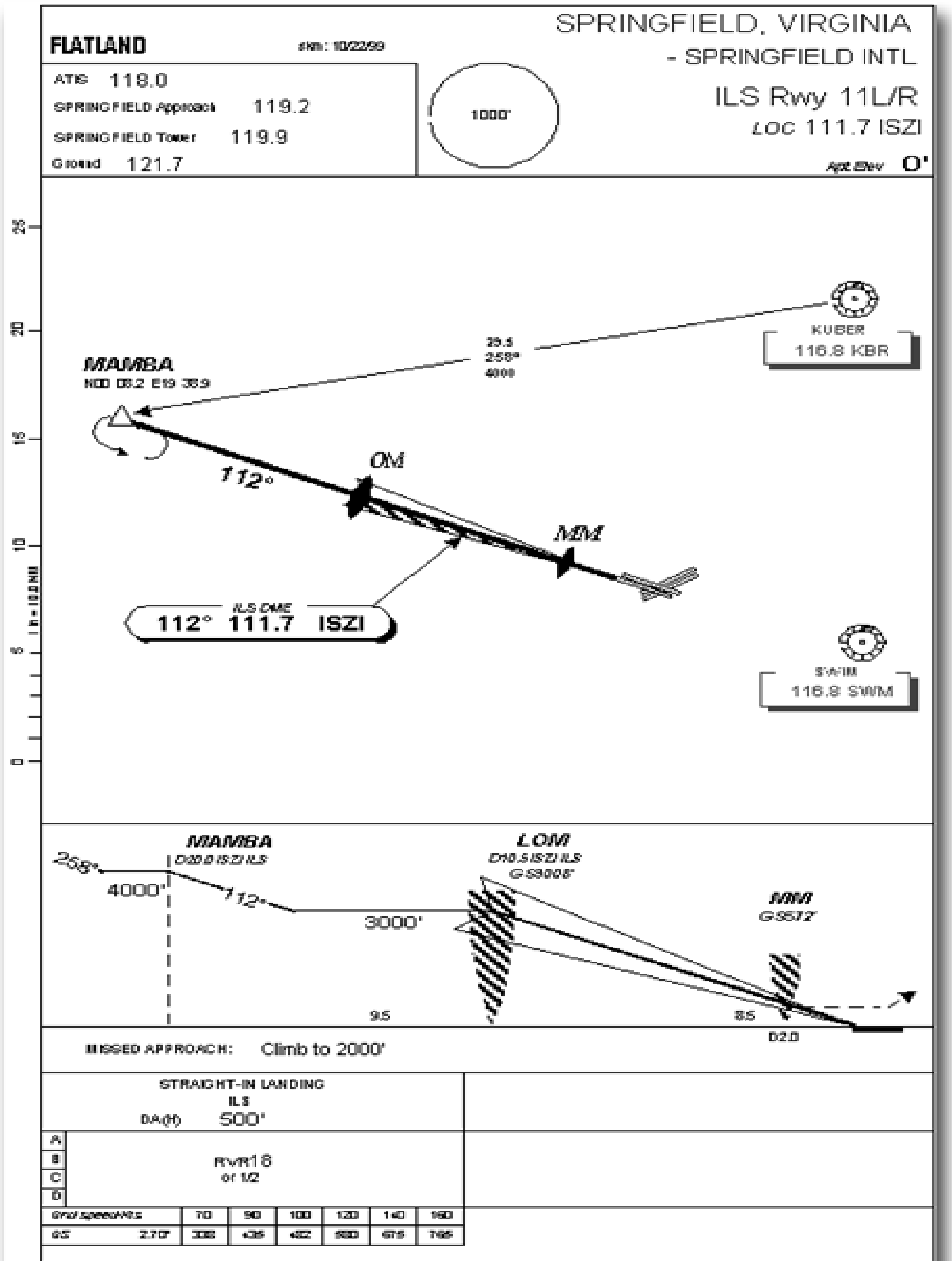


Figure 4 - Sample Approach Plate

3.4 Experiment Procedure

3.4.1 Briefing and Training

The experiment started by getting the informed consent of the participating pilot (Appendix B.3). This was followed by a briefing about the experiment and the simulator. Prior to the data runs, the pilots were put through training tutorials to acquaint them with the simulator and the experimental setup. This tutorial briefing is supplied in Appendix A. The two tutorials were separated into two phases, one to get acquainted with the various types of automation, and the other to experience a complete scenario. In the first phase of training, the pilot was asked to fly one run using only the MCP. When the pilot was comfortable using the MCP, the first tutorial was restarted and the pilot was exposed to the CDU type of automation and its variants. This phase of training was repeated till the pilot verbally expressed a satisfactory level of proficiency and comfort using all the types of automation. This was followed by the second phase of training, where the pilot was asked to fly a complete scenario using all the automation types to give him a better understanding of what to expect during the data runs. Following the completion of training, the pilots were shown the questionnaires that would follow all experimental runs. Upon completion of both tutorials, the pilots were then given the choice to review any of the previous tutorials or to continue on with the actual experimental runs.

3.4.2 Data Run Procedure

Following the tutorial session, a total of nine scenarios (including the faulty Autoplan scenario) were run for each pilot. For each of the scenarios, the pilot was given a description of the scenario in a briefing sheet and also told what type of automation they would be given. In addition, pilots were also told that all pertinent checklists had been completed and they had only to plan up to the termination point. A first officer was present during all the runs to start the runs, monitor aircraft systems, deploy the flaps and gears as requested and communicate ATC clearances to the test pilot. The first officer played no part in the planning task. In all the runs, the pilots were told the type of automation to use. In the CDU (and its variants) conditions, the pilot was not allowed to use the MCP except to make changes in the altitude window (this was needed since in typical MCP-FMS operation, the aircraft will not climb above or descend below the altitude specified in the MCP altitude window).

Following each scenario, the pilot was given a set of questions pertaining to that scenario (see Appendix B.1). At the conclusion of all the data runs, the pilot was given a brief set of questions pertaining to their background, the experiment as a whole, in-flight replanning and planning tools (see Appendix B.2).

3.5 Experiment Participants

A total of sixteen pilots participated in the experiment. Fifteen pilots were from a major airline carrier and one from a major charter service with experience in a major airline service. One pilot was recently retired. All the subjects were male. All the subjects were either captains or first officers.

Total piloting hours ranged from 5000 to 16,000. Eight of the test subjects were captains with experience ranging from 12,000 to 16,000 hours and an average of 12,250 hours of flying experience. The other eight were first officers with experience ranging from 5000 to 10,500 hours and an average of 7400 hours of flying experience. Table 1 shows a summary of the pilots' experience and backgrounds. Eleven pilots were initially military trained before becoming civilian pilots and 5 pilots were initially trained in civil aviation. The subjects had flown or were current in a range of glass-cockpit aircraft, including the Boeing 737-800, 737-300NG, 757, 767, and MD-88. Of the 16 pilots, 6 had previous experience with flight planning software of some sort before (other than the FMS), with all six being exposed to ground based planning software and one pilot with experience in ground based (B.A.R.T) and in-flight replanning software (Global Data Systems). All subjects were compensated for their time.

Table 1 - Summary of Pilot Background and Experience

Rank	
Captain	8
First Officer	8
Initial Training	
Military	11
Civilian	4
Both	1
Total Hours	
>= 5000 and < 10000	8
>= 10000 and < 12000	3
>= 12000 and < 15000	3
>= 15000	2
Hours in Glass	
>= 2000 and < 4000	9
>= 4000 and < 6000	5
>= 6000	2
Current Aircraft	
B737-NG	4
B757	1
B767	5
B777	2 (1 retired)
MD-88	4
Hawker	1

3.6 Experiment Apparatus

The experiment was conducted on a fixed-base desktop flight simulator based on the Boeing 747-400. The flight simulator has been developed using the Reconfigurable Flight Simulator (RFS) software (Ippolito and Pritchett, 2000). The simulator runs on two networked desktops PCs. One screen shows the flight instruments, namely, the Primary Flight Display (PFD), Electronic Horizontal Situation Indicator (EHSI) (also known as the Navigation Display [ND]), and controls for the flaps and gears. The second screen displays the Mode Control Panel (MCP), the Control Display Unit (CDU) and navigation display controls (ND controls). Both the desktops PCs were equipped with a mouse as an input device. The setup was distributed over four flat panel LCD screens with two screens - one displaying the PFD, EHSI and flaps and gears, and the other displaying the CDU, MCP and ND controls - for the captain and two screens showing the same displays for the first officer. Figure 5 shows the experiment setup.

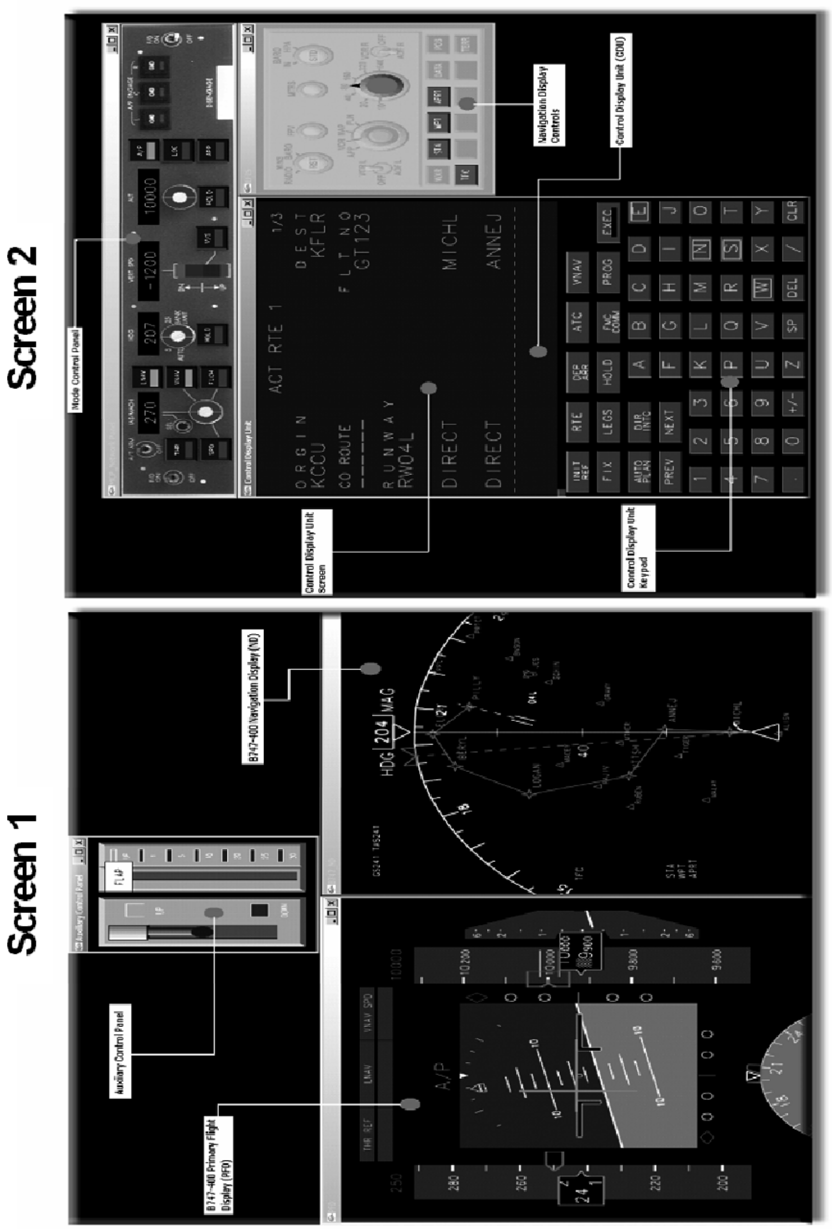


Figure 5 - Experiment Setup for Each Pilot

3.6.1 Flight Instruments

The flight instruments included the primary flight display (PFD), electronic horizontal situation indicator (EHSI), the Mode Control Panel (MCP) and Control Display Unit (CDU), all of which are based on the Boeing 747-400 glass cockpit.

The PFD (Figure 6) shows the current aircraft state such as the current airspeed and altitude. At the top center of the PFD are the Flight Mode Annunciators (FMAs) which display which mode of flight the autopilot is in. The magenta figures above the altitude and speed tapes show the MCP target altitude and target speed respectively. The vertical speed indicator beside the altitude tape shows the rate of climb or descent. The two magenta bars in the middle of the display are the Flight Directors (F/D) which show the pitch and roll of the aircraft. The arrow indicator at the top of the calibrated scale on the artificial horizon indicates the bank angle.

Figure 6 - Primary Flight Display (PFD)

The EHSI (Figure 7) used in this experiment is based on that used in the B747-400. The EHSI is comprised mainly of a track up moving map display. The display shows the current flight path as a solid magenta line. Any lateral modification to the current active flight path is shown by a white stippled line. The current position of the aircraft is shown as a solid white triangle. The green arc shows the point where the aircraft will reach its MCP target altitude. The map also shows the various navigation aids (with their identifiers) in the vicinity of the aircraft in blue. The destination runway is shown in white with its 3-letter identifier, with the approach line extending 14 miles.

The Autoplan shows up on the EHSI as a stippled orange line which turns solid magenta when executed.

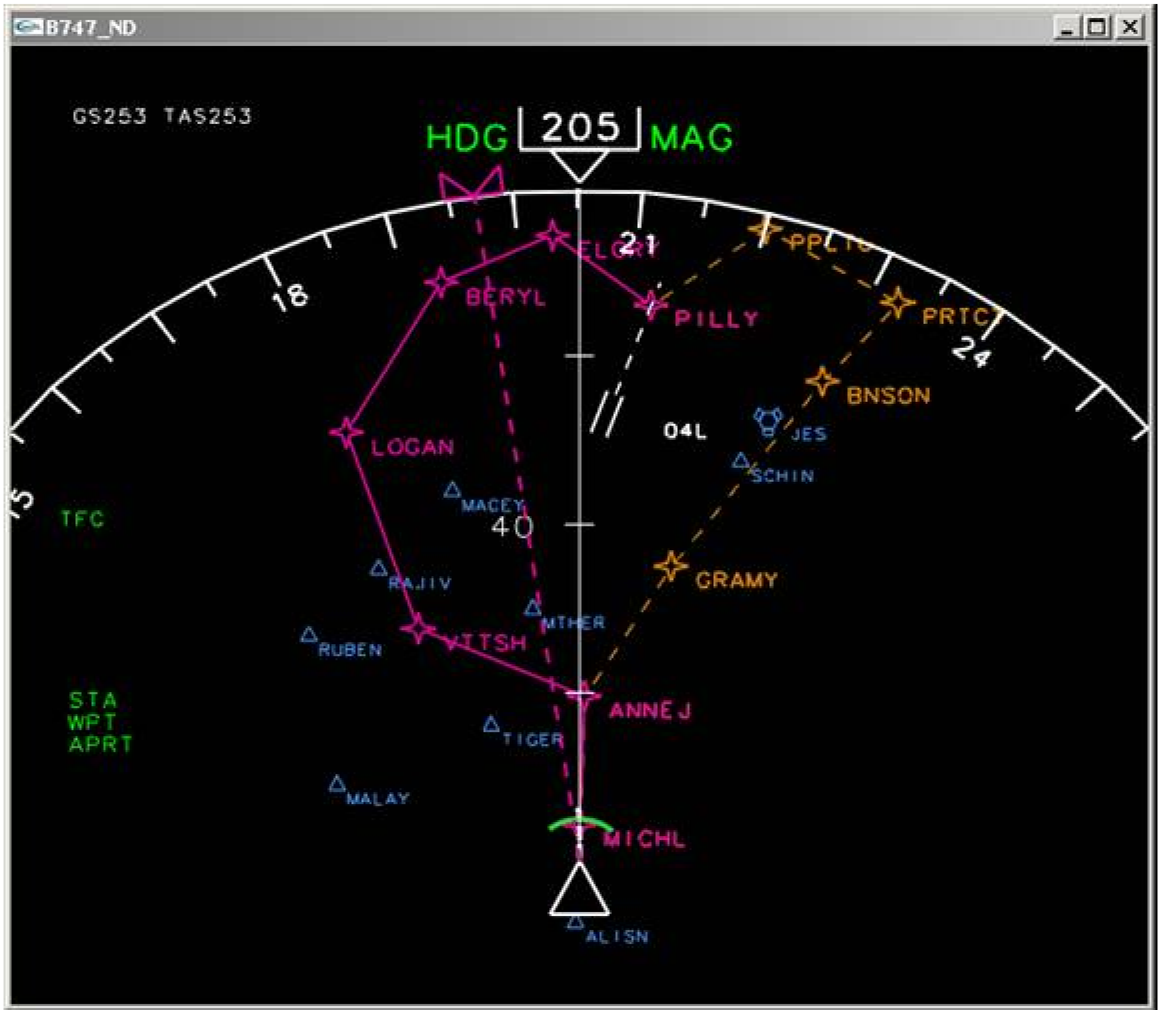


Figure 7 - Electronic Horizontal Situation Indicator (EHSI)

The MCP is an autoflight system through which the pilot can change heading, altitude, speed and rate of descent. The flight mode (i.e., HDG, FLCH, VS, ALT, LNAV, VNAV, and SPD) selected in the MCP is displayed on the FMA on the PFD. The MCP used in this experiment (Figure 8) is modeled on the B747-400 MCP, and the pilot used a mouse as an input device to enter values into the MCP. The target values for speed, heading, vertical speed and altitude could be entered by the pilots by clicking on the dials below the display window. For example, to change heading, clicking on the right half of the circular dial will increase the heading angle and clicking on the left half will decrease the heading angle, and similarly for the Indicated Air Speed (IAS) and altitude. The vertical speed (V/S) is usually controlled by a roller dial which in this MCP is the pink and indigo dial just below the V/S target window.

Figure 8 – RFS Mode Control Panel

The CDU is an autoflight system which, among other things, pilots use to plan/replan flight routes. This experiment used a graphical interface CDU (Figure 9) modeled on the B747-400 CDU, where the pilot used a mouse as an input device to enter data into the CDU. For this experiment, the pilot had only the RTE and LEGS pages available to them. Pilots could enter data into the scratchpad and insert it wherever desired. (Detailed working of this CDU is documented in the section titled “The RFS Control Display Unit (v1.0) Made Easy” in the pilot briefing Appendix A).

Figure 9 - RFS Control Display Unit

3.7 Independent Variables

3.7.1 Scenario Types

Two scenario types were tested, namely, emergency and non-nominal situations. Both of these required the pilot to perform tactical planning.

3.7.1.1 Non-Nominal Scenarios

These are situations where there is no unusual urgency to land the airplane. These are not very important in terms of the time taken to land. All of these cases can be resolved with a simple detour from the original flight plan. The non-nominal scenarios used in this experiment were:

Runway Closure: Required the pilot to reroute to a nearby alternative.

Runway Change: Required the pilot to change the destination runway.

Weather Disturbance: Required a pilot to navigate around a weather disturbance i.e., a storm cell.

Opening up/closing of restricted airspace: Required a pilot to navigate around restricted airspace.

Common to these scenarios is the fact that they envision landing in the order of tens of minutes, i.e., immediate landing is not an overwhelming concern. Other factors such as aircraft stability, fuel economy, standard operating procedures, etc. are important factors when deciding on the rerouting. None of these conditions alter the performance of the aircraft in any way and fuel was not a concern.

3.7.1.2 Emergency Scenarios

These are situations where there is an urgency to land the aircraft as soon as possible. Thus, in the event of emergencies, the pilots are given a free hand in deciding the route to be taken which may involve violating any altitude and speed constraints or procedures. Emergency situations can have a number of causes. The emergency scenarios used in this experiment were:

Cargo Fire: This is an emergency wherein a fire in the cargo hold had just been extinguished at the start of the run. The extent of damage was not known and the pilot was required to land the aircraft as soon as possible.

Medical Emergency: This emergency required the pilot to replan, reroute and land as soon as possible.

Fuel Filter Emergency: This is an emergency wherein the fuel filter can get blocked by debris thereby inhibiting the intake of fuel into the engines. Landing immediately is imperative.

Loss of Hydraulic Pressure in One of the Hydraulic Systems: This is an emergency wherein the EICAS shows a loss of hydraulic pressure in one of the hydraulic systems. Landing immediately is imperative.

All of the emergencies were predicted to be of equal severity. However, they are similar in that the replanning process still has to be executed and the new route implemented, and they do not alter the performance of the aircraft in any way. Emergency scenarios differ from non-nominal scenarios in that they envision the time to landing to be less, i.e., on the order of a few minutes.

3.7.2 Type of Automation

In each run, the pilot was asked to use a particular type of automation. Specifically, the four types of automation tested are detailed in the following sub-sections.

3.7.2.1 Mode Control Panel (MCP)

Pilots were only allowed to command the following autoflight modes through the MCP using heading select and heading hold (HDG), vertical speed (V/S), altitude hold (ALT), flight level change (FLCH) and speed (SPD).

3.7.2.2 Control Display Unit (CDU)

In this condition, pilots were asked to use a conventional CDU based on a Honeywell 747-400 CDU. Only pages that assist in planning (RTE and LEGS) were made available to them.

3.7.2.3 Control Display Unit + (CDU+)

With this type of automation, pilots had the CDU available to them as in the previous case. This automation had an added functionality called the Autoplan. This is a computer generated flight path that can assist pilots in planning. Pilots could access these plans whenever they like and use it as the active route, or plan so that their route can intersect parts of the Autoplan, or disregard it totally. The Autoplan feature does not exist in current cockpits.

3.7.2.4 Control Display Unit ++ (CDU++)

This automation works the same as the CDU+ with the difference that, when the simulation run starts, the Autoplan is implemented as the active flight route. Pilots have the option of overriding this plan or modifying as in the previous automation.

In the CDU+ and CDU++, the Autoplan was designed to be the best plan for the given scenario type. For example, in the emergency scenarios, the Autoplan was designed to get the aircraft down as soon as possible, keeping in mind standard airspace regulations and following/intersecting standard airways as depicted in the charts. In the non-nominal scenarios, the Autoplan placed stress on other factors such as negotiating the cause of re-route and minimizing the distance flown.

3.8 Experiment Design

The experiment was divided into two parts run sequentially in one session. The first experiment tested all eight combinations of automation and scenario types. In the second experiment, pilots were asked to fly only one run, the ninth run, using the CDU++ type of automation only. The experiment condition in this run was based on the same automation-scenario combination for all the pilots. The second experiment was included in the tests to explore the effect of an erroneous automatically generated plan on pilot performance. This faulty Autoplan scenario followed completion of the primary scenarios.

The first experiment consisted of a 4x2 test matrix as shown in Table 2, and was made up of a combination two independent factors, type of automation and scenario type. The test matrix was arrived at by first blocking by type of automation. Then, within each block of type of automation, the two scenarios types were run in random order. The order of the automation block was based on a fully balanced Latin squared design to mitigate order effects. Specific scenarios were assigned randomly and care taken that the same number of pilots flew the same scenario with the same automation.

The four types of automation were the Mode Control Panel (MCP), Control Display Unit (CDU), and two variants of the CDU namely, CDU+ and CDU++. Additionally, two scenario types were examined, non-nominal and emergency.

Table 2 - Experiment Test Matrix

Type of Automation	Scenario Type: Non Nominal	Scenario Type: Emergency	
MCP	16 Pilots x 1 run	16 Pilots x 1 run	Expt. #1
CDU	16 Pilots x 1 run	16 Pilots x 1 run	Expt. #1
CDU+	16 Pilots x 1 run	16 Pilots x 1 run	Expt. #1
CDU++	16 Pilots x 1 run	16 Pilots x 1 run	Expt. #1
Faulty Autoplan	All runs using CDU++		Expt. #2

Expt. #1:

- 8 runs per pilot
  - – 4 runs non-nominal
  - – 4 runs emergency
- Run order blocked by automation and balanced using Latin Square Design

Expt. #2:

- 1 run per pilot
  - – ½ pilots had non-nominal scenarios
  - – ½ pilots had emergency scenarios

The second experiment consisted of a 1x2 matrix, and was made up of a combination of one type of automation, the CDU++, and the two scenario types. It consisted of only one run per pilot, and used a between subjects design, where the scenario types were randomly assigned. This experiment used the faulty Autoplan scenario where an error in the automation provided the pilot with an inappropriate Autoplan. The plan lacked context sensitivity to the situation and thus did not provide the best plan for the current situation, i.e., in the non nominal flight condition the Autoplan generated an overly aggressive route fit only for emergencies and, in the emergency flight condition, provided a gently paced route that increased time of flight beyond what the emergency called for.

3.9 Dependent Measures

3.9.1 Data Collection

Three types of data were collected:

1. The graphical interface of the CDU recorded important events in the flight replanning task. The final mouse click triggering an event was recorded as an identifiable action. These events included switching between RTE and LEGS pages, making changes to an existing RTE page or a LEGS page, going through the route programmed in by clicking the PREV and NEXT buttons (in the case of the CDU-based autoflight conditions), making altitude, speed and heading changes (in the case of the MCP), creating/deleting a fix/waypoint from the flight plan, changing altitude and speed parameters of existing waypoints, resolving

route discontinuities, looking at alternative routes, activating an inactive route, and executing a change in the flight plan.

2. Aircraft state data, including airspeed, current heading and current altitude, was logged every second by the simulator.
3. At the end of each run and at the end of the experiment, pilots were asked to answer a questionnaire. The end of run questionnaire included questions about the factors considered during planning, the strategies used, and effectiveness of the autoflight system used, a rating of the ease of planning using that autoflight system compared with currently available type of automation they would have used and a NASA TLX workload rating sheet. The end of experiment questionnaire included questions on pilot background, in-flight replanning in the two scenario types, flight replanning systems and tools, performance of the Autoplan and the NASA TLX pair-wise comparisons of sources of load. The complete end of run questionnaire and end of experiment questionnaire are given in Appendix B.

3.9.2 Data Analysis

Two different factors were expected to influence the performance of the pilot in the first experiment runs. The first factor was the scenario type, with the categorization of either non-nominal or emergency scenarios. The specific non nominal scenarios used are described in section 3.7.1. The type of automation available to the pilots was the second factor. The four different autoflight systems are described in section 3.7.2.

Analysis of the aircraft state data, event logs during the flight, performance logs during the flight, measures such as duration and the length of the run, modifications to the Autoplan and pilots' responses to the questionnaires included:

- Ability to diagnose/recognize errors in automation;
- Pilot dependency on automation;
- Time and distance saved for that run compared with the original plan;
- Pilot's choice of route implemented and the apparent reasons behind the choice. This could indicate the correlation (if any) between type of automation, type of scenario and in-flight replanning behavior;
- Deviation from the existing preprogrammed route to indicate the amount of time saved compared with the time taken if the original path was followed;
- Time taken to start modifying the existing plan or entering a new plan;
- Regularity with which they tend to update the plan versus leaving it once it has been created;
- Apparent strategies and factors considered during planning;
- Pilot preferences of certain autoflight systems for in-flight replanning tasks;
- Comparison of ease of planning using different autoflight systems;
- Performance of the Autoplan; and
- Workload assessment of the replanning task.

The data analysis was divided into three categories: pilot performance, pilot planning behavior, and workload assessment.

Performance was measured in the first experiment by time to landing and distance to landing. In the ninth run, pilot performance was also measured by whether pilots recognized the Autoplan was faulty.

Planning behavior can be manifested in a number of ways. Apparent strategies were analyzed for planning with the MCP and the CDU such as establishing one-dimension of path first followed by the other. For example, some pilots may prefer to plan for the lateral path first and then the vertical path. Others may plan for the vertical path first and then the lateral path so that they don't need to descend at a high rate, yet others may do it as a series of heading changes followed by descents. In some cases, some pilots may start planning immediately and bring out a rough plan and then keep refining that plan over time, whereas others may take some more time and come up with an almost concrete plan which requires few adjustments.

A workload assessment based on pilot responses to the NASA TLX Workload sheet was also performed to examine which source of workload was felt the most during the scenarios.

CHAPTER 4

EXPERIMENT RESULTS

In total, 144 runs were performed: 128 under the first experiment comparing the different autoflight systems and 16 runs for the second experiment's faulty Autoplan case. The 16 faulty Autoplan runs will be discussed separately from the regular 128 runs.

Unless otherwise specified, the data obtained were analyzed for type of automation, scenario type, specific scenario and run order effects by fitting to a general linear model. If the residuals of the fit met the requirements for Analysis of Variance (ANOVA), an ANOVA was conducted. The type of automation, scenario type and specific scenario were analyzed as fixed effects. Pilots, however, were analyzed as a random factor, allowing generalization of the observations to a major portion of the pilot population. In addition, interactions between the factors were examined.

Where significant results were found for one or more of the factors, a one-way (ANOVA), along with a pair-wise comparison using a 95% confidence level Tukey test, was performed strictly on those factors to confirm the results. A non parametric Kruskal-Wallis test was also performed to test the null hypothesis that there are no differences among the factors.

4.1 Pilot Performance

The primary measures of pilot performance in the first experiment were the distance flown and the duration of the run. In emergency situations, such as a medical emergency or cargo fire, these measures directly reflect the safety of the aircraft. In non nominal situations, such as weather or airport closures, these measures reflect airline operation considerations such as flight time, flight schedules and fuel burn. As can be seen in Figure 10 and Figure 11, in both scenario types, the type of automation used was not a significant factor. No significant order effects were seen on these measures either. The scenario type and the specific scenario, however, did show a significant effect on these measures. To confirm the scenario and scenario type effects, an ANOVA was performed, showing a significant scenario effect ($F = 33.92$, $p < 0.001$) and an effect from the scenario type ($F = 69.46$, $p < 0.001$).

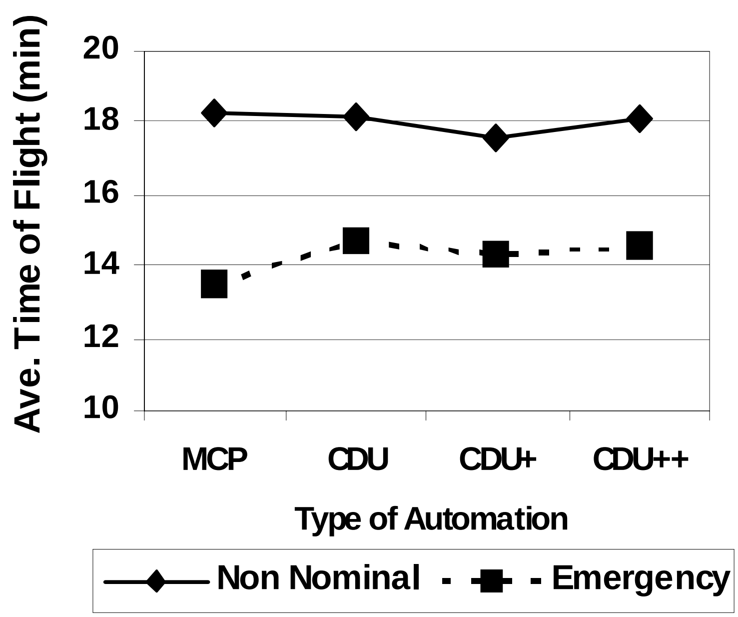


Figure 10 - Average Time of Flight

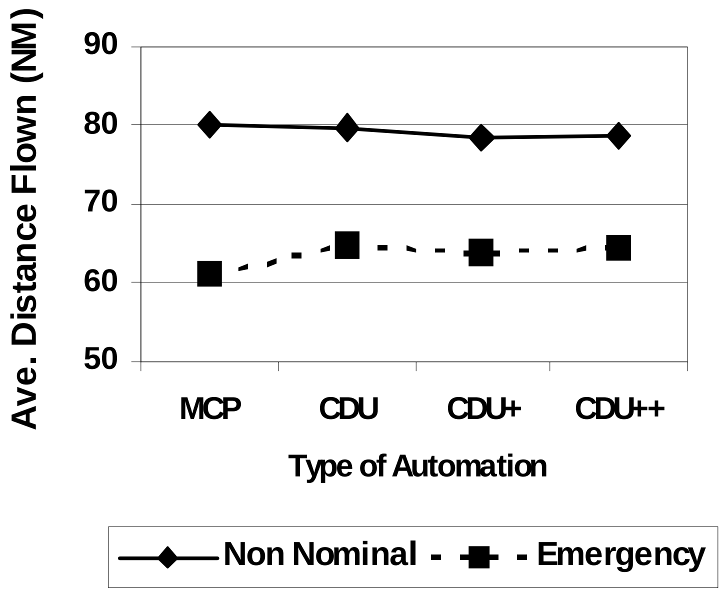


Figure 11 - Average Distance Flown

Since the type of automation did not have any significant effect on the performance measures of time and distance, these measures were also looked at by specific scenario across all types of automation. As seen in Figure 12 and Figure 13, in the non nominal scenarios, the average time of flight and distance flown were distinctly higher for the first two scenarios: weather disturbance and restricted airspace. A certain degree of variability in flight path was seen as evidenced by the flight paths in Appendix D. In the emergency scenarios, time of flight and distance flown was higher for the second two: the hydraulic systems failure and fuel filter emergencies.

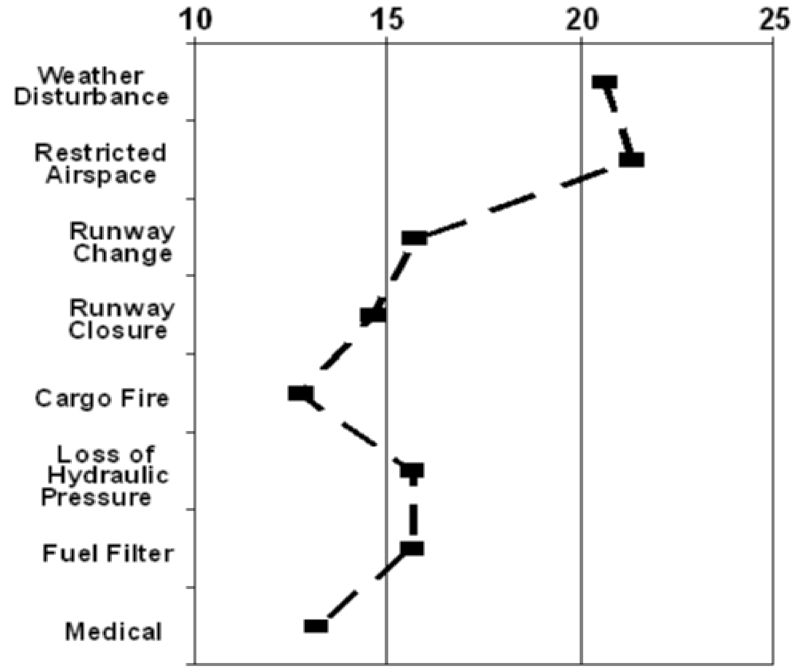


Figure 12 - Average Time of Flight per Scenario

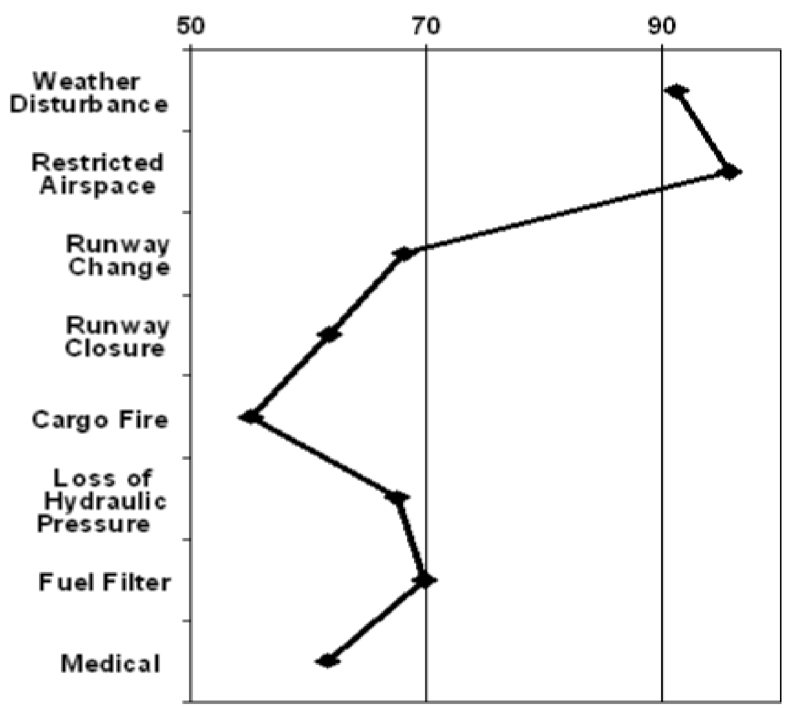


Figure 13 - Average Distance Flown per Scenario

Although the scenarios were intended to have similar travel times, to account for any intended differences between scenarios, another measure was the deviation in time of flight and distance flown from the baseline plans for each scenario. The baseline plans used were the original routes in the CDU at the start of the run. As can be seen in Figure 14 and Figure 15, the main effects here were also the scenario type ($F = 66.43$, $p < 0.001$) and the scenario ($F = 14.72$, $p < 0.001$). Additionally, no run order effects were seen with the time of flight measure, but the distance flown showed significant run order effects ($F = 9.66$, $p=0.003$) (Figure 16).

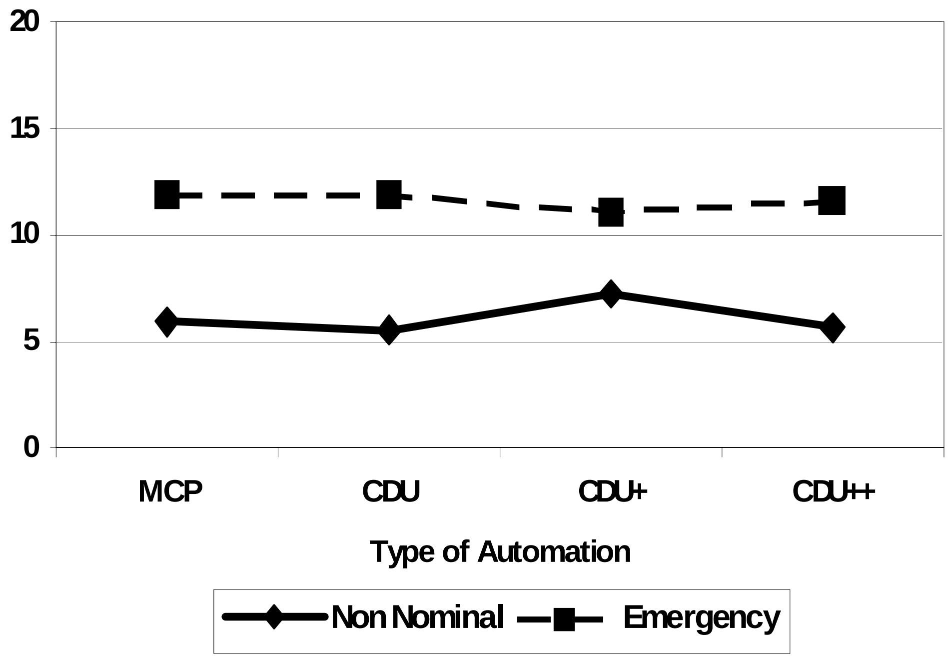


Figure 14 - Average Deviation in Time of Flight

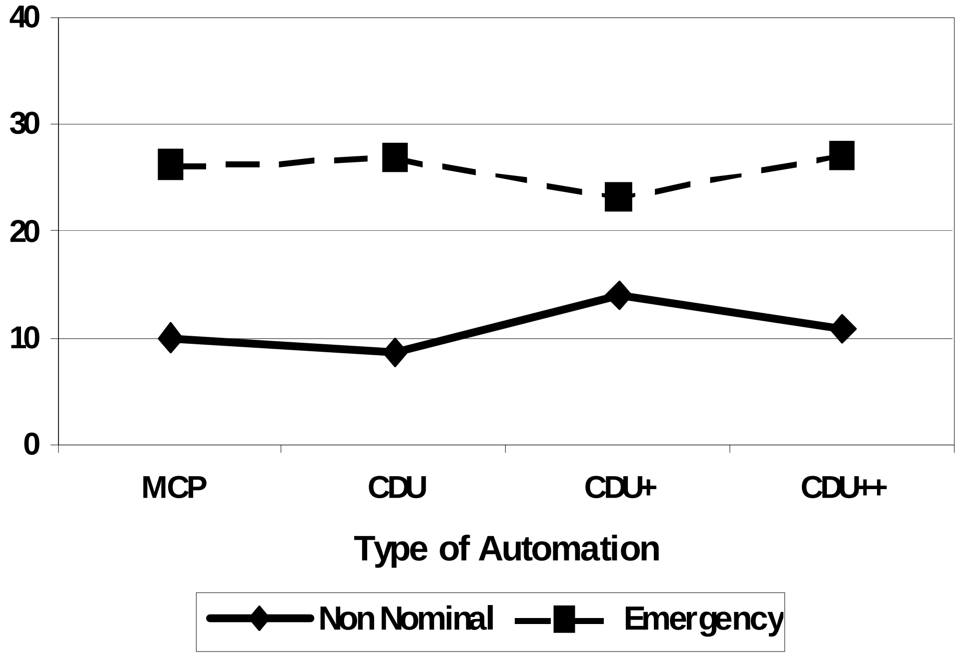


Figure 15 - Average Deviation in Distance Flown

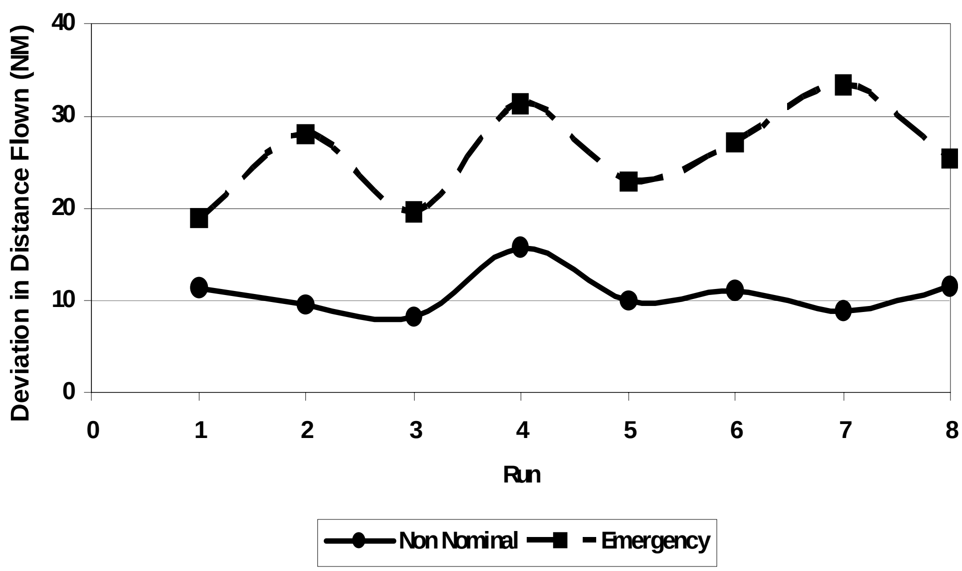


Figure 16 - Run Order Effect on Deviation in Distance Flown

Another measure looked at pertaining to pilot planning performance were the speed violations. According to Federal Aviation Administration (FAA) regulations, aircraft flying below 10000 feet must remain at a speed of 250 knots or below, except when given discretion by a controller or in an emergency. Figure 17 shows the total number of speed violation in all 128 runs in the first experiment. Figure 18 breaks this measure down by the scenario type. The scenario, scenario type and run order showed significant effects on this measure as did the pilot-scenario interaction. However, all these effects failed normality tests and an ANOVA could not be conducted. Order effects were also seen (Figure 19) but also failed subsequent normality tests. However, the non-parametric Kruskal-Wallis test showed that the medical emergency (emergency) had the highest number of speed violations and the weather disturbance (non-nominal) had the lowest number of speed violations.

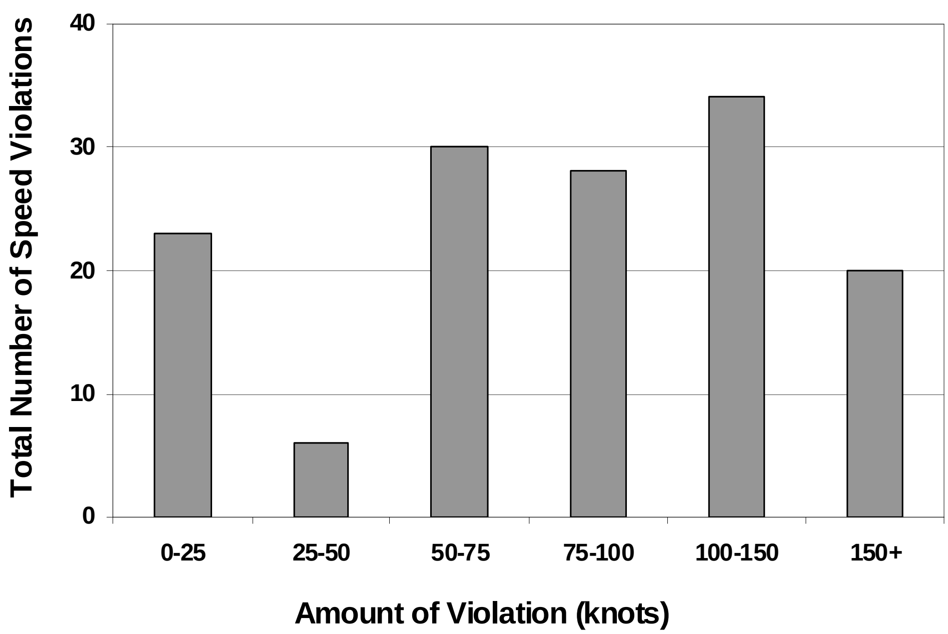


Figure 17 - Number of Speed Violations in 128 runs

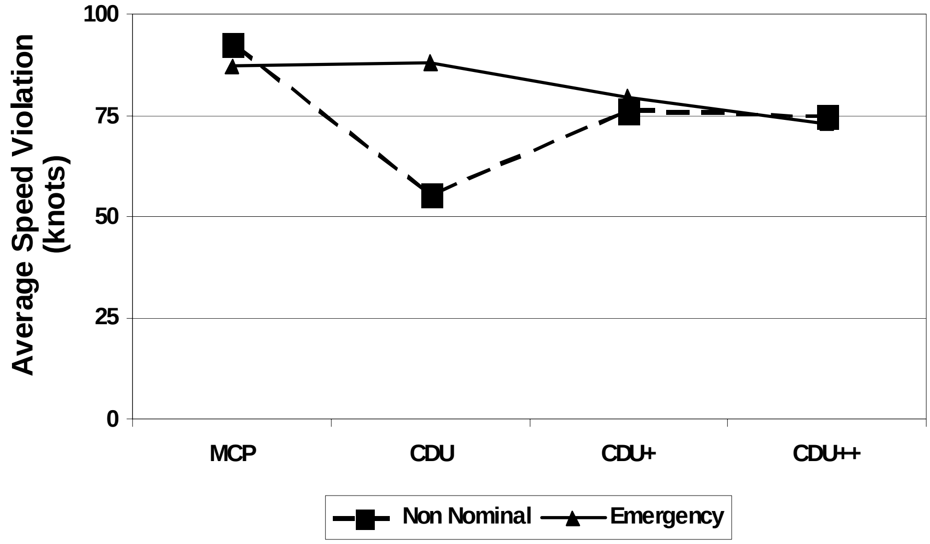


Figure 18 - Average Speed Violations per Scenario Type

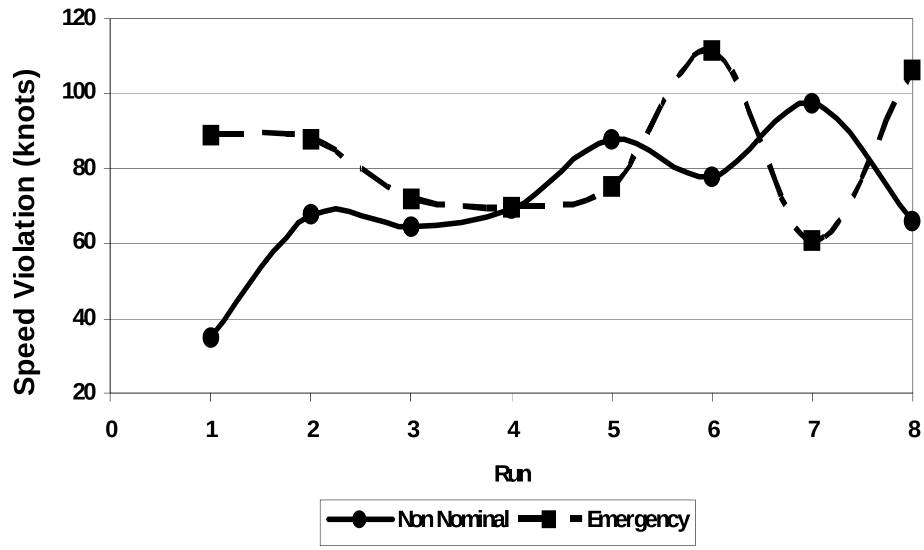


Figure 19 - Run Order Effects in Speed Violations

4.2 Pilot Planning Behavior

A number of measures examined pilot planning behavior. First the flight paths were looked at for any trends in planning behavior. As an example, the flight paths are shown in Figure 20 for the medical emergency scenario. The flight paths for all scenarios are shown in Appendix D.1. During the experiment it was observed that the type of automation and scenario had an effect on pilots' course of action. For this reason, to describe the effect of the automation on planning behavior, the measures were also analyzed by the type of automation. The specific scenario effect was also considered to explain specific behaviors.

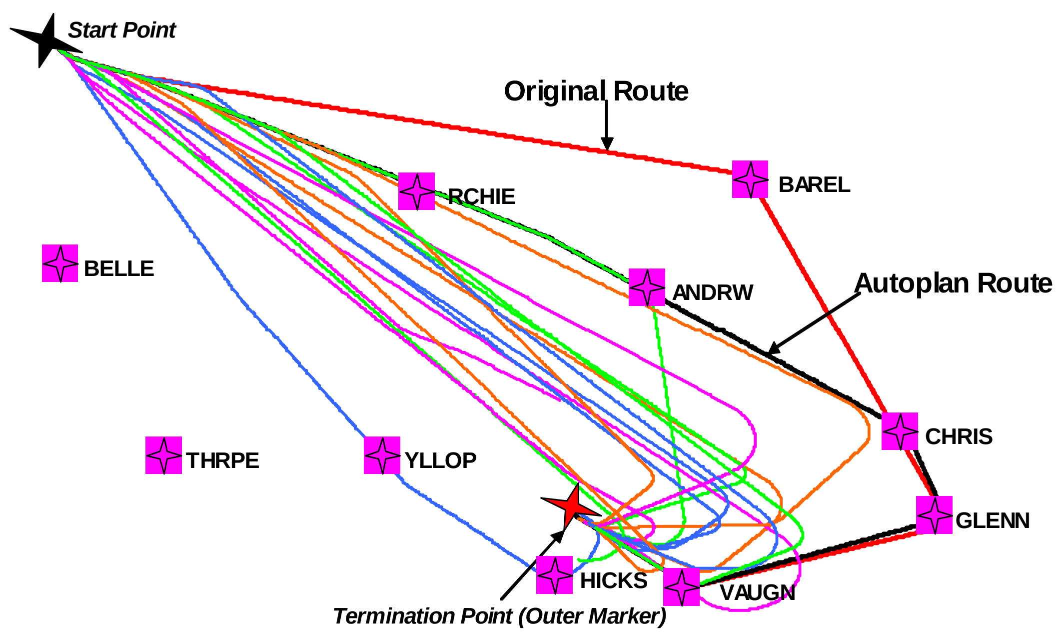


Figure 20 - Flight Paths for the Medical Emergency Scenario

4.2.1 General Observations on Planning Behavior

In general, in each scenario type, the primary objectives were to minimize distance to go and to create an expeditious route to the approach. The timing and ordering of fixes did not show any specific pattern by which a pilot tended to plan. The usage of the type of automation also showed very specific personal choice traits. For example, 10 of 16 pilots, with all types of automation, immediately increased speed and kept a high altitude to get abeam of the outer marker as fast possible. All pilots except one created an along track waypoint ahead of the waypoint being flown direct to, at which point they started reducing speed. In 58.3% of the runs where pilots could create along track waypoints (CDU, CDU+ and CDU++ types of automation = 96 runs), this point was abeam of the outer marker, which would give them a much smoother turn onto the final approach leg. When using the MCP, this point was visually marked out (as verbally reported by pilots during the experiment) and then HDG SEL was used to turn onto final. When using the CDU and its variants, all pilots used the only the LEGS page during planning as this provided the necessary information of heading, distance, and speed and altitude constraints at waypoints. In general, 14 pilots agreed with the routing the Autoplan provided; however, they did not agree with the speed and altitude profile in the Autoplan and proceeded to make subsequent changes. Most pilots used the Autoplan to orient themselves in the desired direction and then modified the waypoints to create a more direct route to the runway.

In terms of dimensional planning, in all cases, pilots first got themselves oriented in the desired direction. This was then followed by a 'cleaning up' of the route, where some waypoints were deleted or added to provide a more direct route. This was then followed by a series of speed and altitude changes until the termination point. Speed and altitude changes did not follow any specific pattern.

Some interesting observations in usage of the type of automation were made during the experiment. Some of the pilots, in order to reduce workload, would simply ‘trick’ the CDU into behaving like an MCP. For example, in a long stretch, the pilot would put in a very low altitude constraint at the active waypoint, which in turn would provide a high rate of descent, and then change the altitude constraints back to specified limits when at a suitable distance from the waypoint. Only two pilots resorted to this technique as they did remember that they would not be allowed to use the MCP when using the CDU or its variants.

Another technique commonly used by the pilots was the DIRECT-TO function. In some cases, instead of creating a waypoint abeam or a little ahead of the marker, pilots would wait till the aircraft was abeam or a little ahead of the marker and then initiate a DIRECT-TO to the outer marker after accounting for the distance required for a turn. This proved extremely effective, and had a result similar to that of creating a waypoint, albeit the turn required was sharper. This behavior was exhibited in five runs spread among two pilots. In all scenarios, the pilots were cleared to the glideslope altitude. Thus, when using the CDU and its variants, in most cases, pilots would enter the clearance altitude into the altitude window in the MCP and then adjust the vertical profile by altitude changes in the CDU LEGS pages. This was done to eliminate the altitude intervention by the MCP.

4.2.2 Pilot Planning Across Automation Types

In the MCP cases, whenever a new speed or altitude target was entered and kept constant for at least fifteen seconds, it was counted as a speed or altitude change. For the CDU cases, the change in a future speed or altitude or both was identified as an event and logged in the simulator. It was observed that the average number of speed and altitude changes when using the MCP was distinctly lower than for the other types of automation which is evidenced by Figure 21 and Figure 22 but did not show any statistical significance. This suggests that with the MCP, pilots did not have the hindrance of forcibly changing speed and altitude constraints at waypoints as was required with the other TOAs. Among all the types of automation, the CDU+ was found to have the highest average number of speed and altitude changes. This suggests that these measures are more a function of pilot choice than scenario or automation effects.

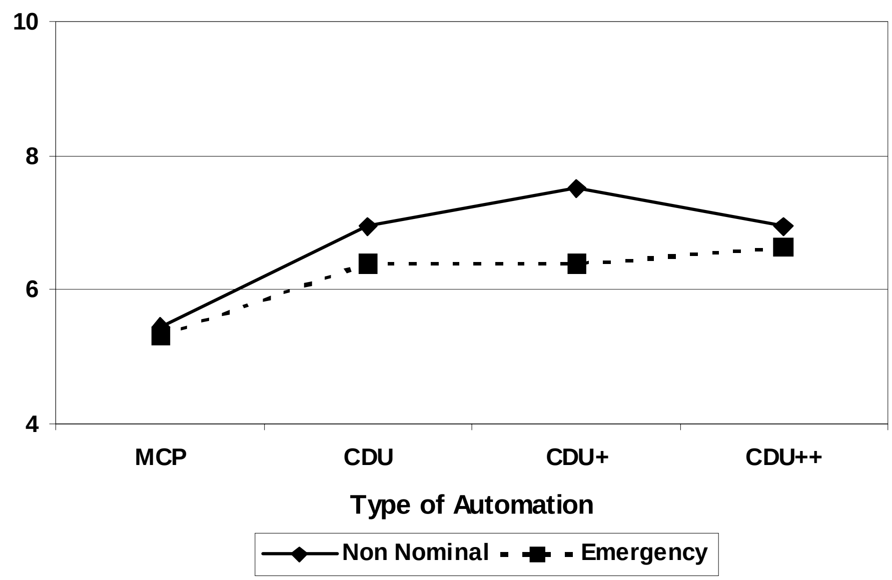


Figure 21 - Average Number of Speed Changes

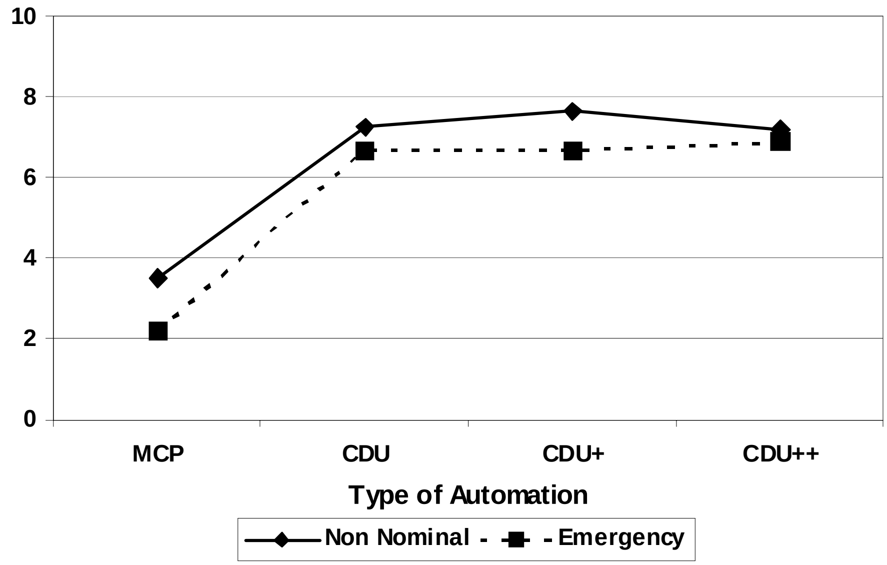


Figure 22 - Average Number of Altitude Changes

Two more measures examined pilot behavior with the CDU (and its variants). These were the time taken to the first modification and the time taken for the first execution of a change to the route in the CDU from the start of the run. The time taken to first modification was defined as the time difference between the start of the run and the first instance when the page status (either the RTE or LEGS page) changes from active (ACT) to modified (MOD), and the time taken for the first execution was defined as the time difference between the start of the run and the first instance of the EXEC button being pressed to confirm an action. These measures were indicative of the time the pilot takes to start planning and implement a change to the plan. A combination of these two measures showed that on an average, pilots took a shorter time to start re-planning using the CDU+ type of automation than with CDU or CDU++.

In addition to the above, apparent strategies in planning were also examined. A general pattern that did emerge was that pilots oriented themselves in the desired direction first (mostly direct to a point abeam the marker) by either using HDG SEL in MCP cases or initiating a DIRECT-TO in the CDU (and its variants) cases. This was followed by vertical profile management via speed and altitude changes to get to that point, followed by a turn to base leg to line up for approach fully configured. Figure 23 and Figure 24 shows the real paths and planning pattern for a non-nominal scenario (weather disturbance) and an emergency scenario (loss of hydraulic pressure) respectively.

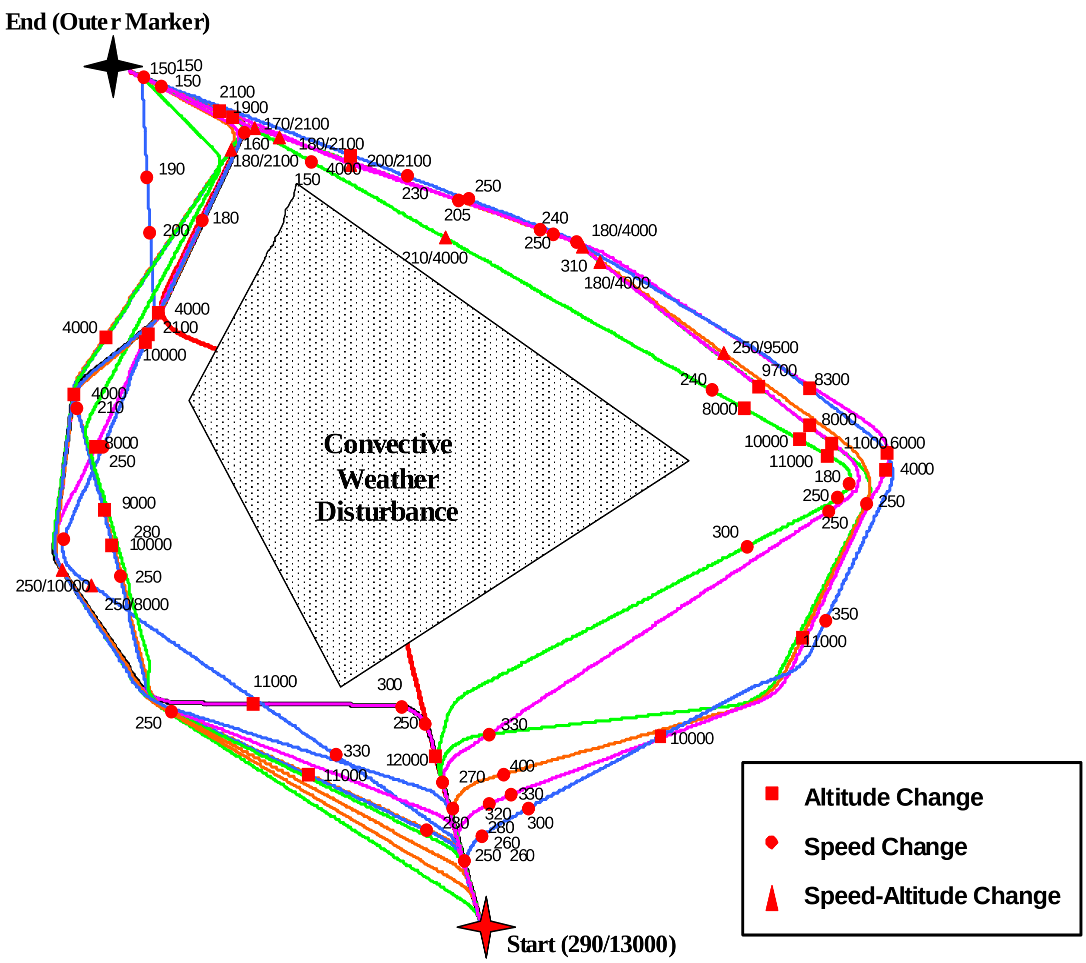


Figure 23 – Flight Paths and Altitude and Speed Changes in the Weather Disturbance Scenario

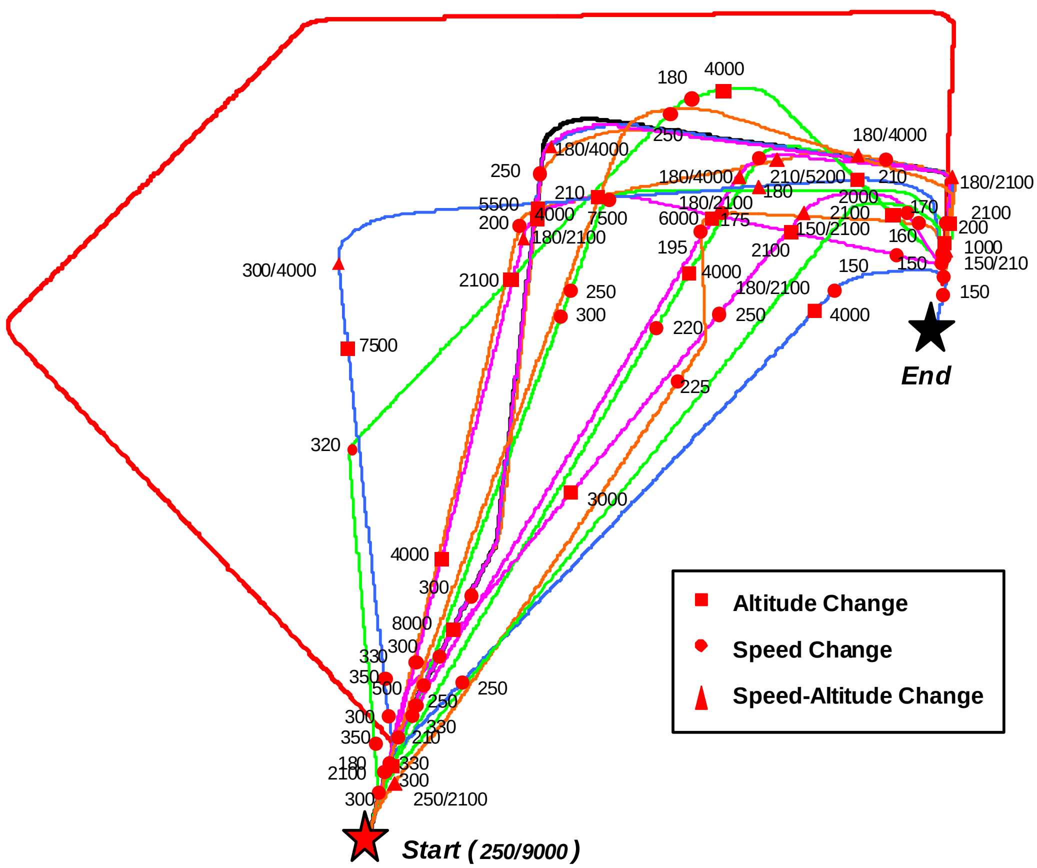


Figure 24 – Flight Paths and Altitude and Speed Changes in the Hydraulic Pressure Loss Scenario

Twelve of 16 pilots were at a point abeam the marker at the landing speed and glideslope altitude from where they started their turn onto final approach. The remaining four gave themselves a little more time by taking a turn further out from the marker and descending during the turn. This, however, resulted in three of the pilots reaching the outer marker (termination point) at an altitude higher than glideslope intercept altitude. The fourth pilot, due to high speed at the turn, did not have sufficient time and distance to slow down to the outer marker speed constraint. He did make the altitude constraint but could not line up for approach and was a little offset from the course. It was also observed that speed and altitude changes were made in no particular order, except that one was made only after the other was established. It was also seen that, in almost all the cases where a turn onto the base leg was required, pilots maintained a high speed up to a point abeam the marker and had shallow turns onto final approach.

An analysis of the subjective questionnaires revealed that the most common factors considered during re-planning were the distance to go, weather, time, and aircraft safety (Figure 25). In general, all pilots said that the first priority was to minimize the time of flight and the distance to go, irrespective of the situation. Other considerations included factors such as aircraft performance, safety of the maneuver and efficiency (Figure 26).

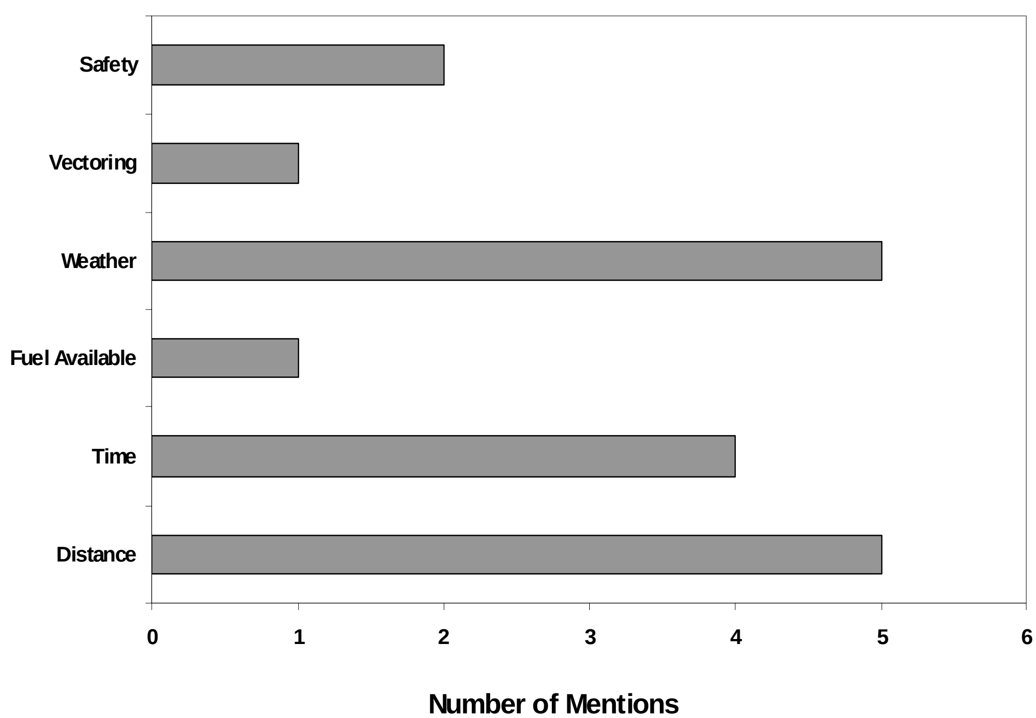


Figure 25 - Factors Considered During Planning

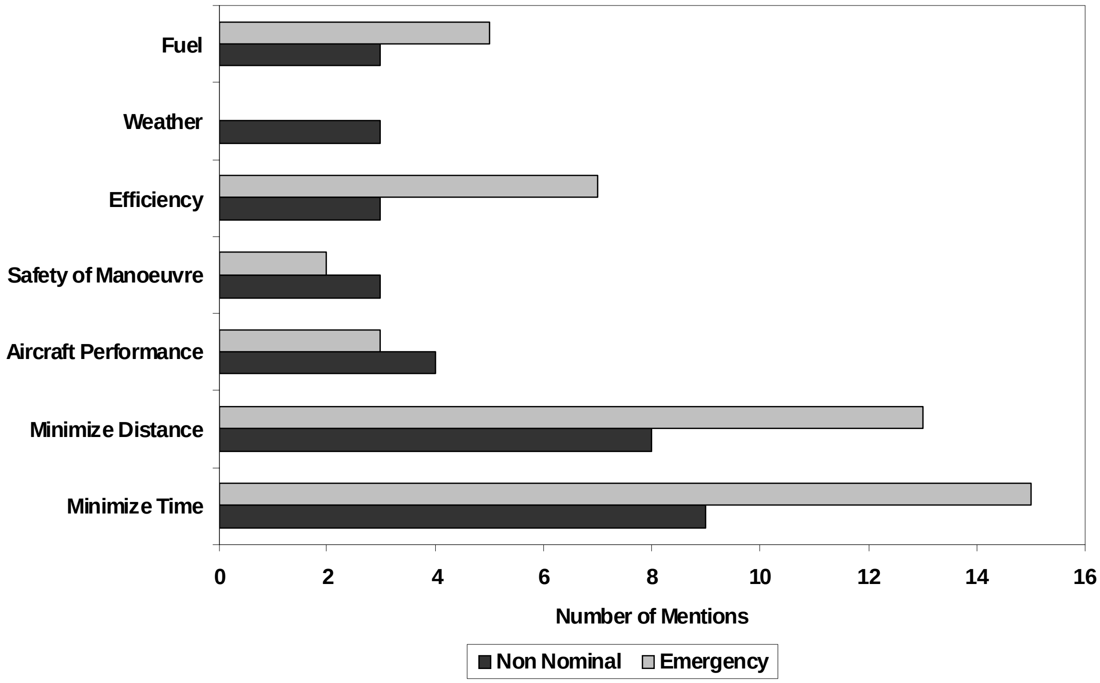


Figure 26 - Strategies in Choosing the Route Planned and Implemented

4.2.3 Pilot Planning Using the Mode Control Panel

When comparing the flight paths for the scenarios types (Appendix D.1), it was seen that, when using the MCP for the weather disturbance, two pilots went right of the weather and two pilots went left of the weather. Pilots who went right of the weather said it was easier to line up for approach and did not require any adverse maneuvering. In the restricted airspace scenario, it was seen that three pilots went right of the restricted areas and one went left. In the remaining non nominal scenarios, all the pilots followed similar right downwind paths. For the emergency scenarios, all pilots took the same right downwind and base leg paths. However, average speeds for the emergency scenarios were distinctly higher than for the non nominal scenarios, with two pilots flying a substantial length of the run at 400 knots in the medical emergency scenario.

Figure 27 shows a brief snapshot of the mode usage of the MCP. These were measured by the number of times the mode in question was physically engaged by the pilot. Mode switching internally by the autopilot was not taken into account for these measures. It should be noted that SPD mode was always enabled, unless the pilots switched to FLCH mode, and would automatically revert from FLCH to SPD mode when the target altitude was reached, unless SPD was physically engaged during FLCH mode. Thus, the SPD mode usage in the figure below shows the physical engagement of this mode by the pilot when in FLCH mode.

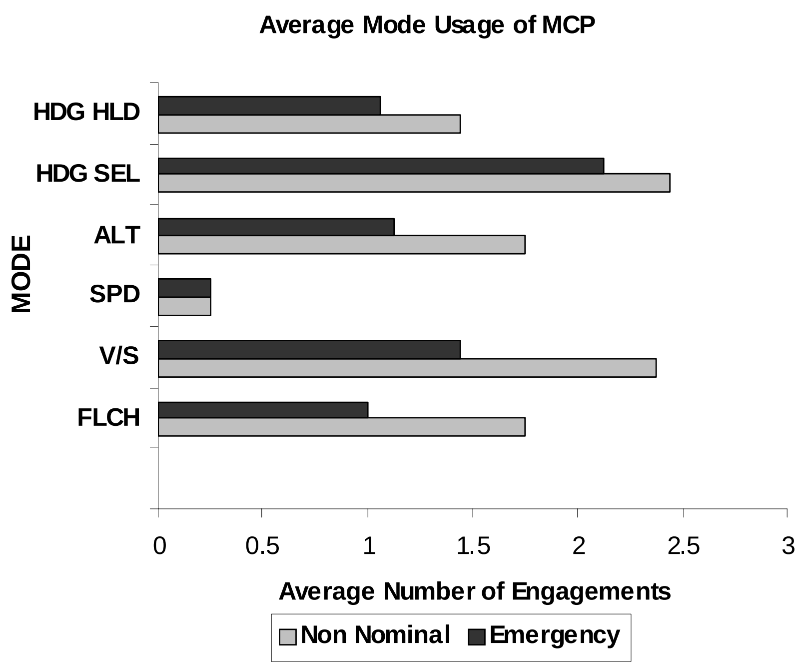


Figure 27 - Mode Usage in the MCP per Run

As can be seen from the figure above, heading select (HDG SEL) was the most frequently used mode. HDG SEL was engaged from 1 to 5 times per run. Related to the usage of HDG SEL was the usage of the heading hold (HDG HLD) mode. This measure showed that pilots engaged this mode once on average for emergency (ranging from 0 to

4) and non nominal scenarios (also ranging from 0 to 4). Though the scenario did not show any significant effect on the usage of this mode, the average mode engagement for these two modes was higher for the emergency scenarios. The only significant factor here was the pilot, which suggests that the use of these modes for lateral navigation is more a personal choice.

A comparison of flight level change (FLCH) and vertical speed (V/S) modes showed that V/S mode proved to be a preferred mode for vertical navigation. It was observed that 2 of 16 pilots did not engage the FLCH mode in either of the scenarios in which they use the MCP. The specific scenario also did not affect their choice as was revealed in discussions during the experiment. The reason given was that they like to have control over the descent rates which can be defined in the V/S mode, but is internally calculated by the autopilot in the FLCH mode. None of the main effects had any significant effect on these two modes, which suggests that usage of these modes is a personal choice of pilots. Six pilots said that for emergencies, they preferred to use the more aggressive FLCH for climb and descent maneuvers. Seven pilots said they preferred V/S as it allowed them to control their own rate of descent/climb, though it did increase workload and monitoring activities slightly. The remaining three pilots did not give any preference in using these modes for vertical navigation.

4.2.4 Pilot Planning Using the Control Display Unit (CDU)

In the CDU (and its variants) cases, each click of the EXEC button was logged. The EXEC button was required to be pressed every time a change to the route was to be entered as the active route to be followed by the FMS. Specifically, these changes included adding/deleting a waypoint, erasing the previous action, resolving a route discontinuity, and making a speed or altitude modification. This was useful in analyzing the number of times that the plan was updated, and how thoroughly the pilots planned their task, i.e., whether they formed a skeletal plan and refined it along the way or took a little more time and proceed to implement a more concrete plan with fewer modifications.

When the timing of the EXEC button hits was looked at, it was seen that pilots who took longer to start and execute their plans had a spate of modifications and executions in the initial part of their plan and consequently fewer modifications along the way. This did reinforce the inference that the pilots who took longer to start planning had a more concrete idea of their planned route than other pilots. In addition to the above, it was observed that 10 of 16 pilots updated their plans more frequently in the non nominal scenarios than the emergency, five pilots updated their emergency plans more frequently and one showed no difference.

4.2.5 Pilot Planning Using the CDU with Autoplan Available (CDU+)

From a comparison of the flight paths for both scenario types, it was seen that, for the weather disturbance, only one pilot intentionally decided against the Autoplan and went to the right of the weather. The reasons given were the ease of lining up for approach and that it was a non nominal scenario. In the runway change scenario only one pilot followed the Autoplan route (with a few modifications) on its right downwind path, simply agreeing with the route in general and assuming that Autoplan gave the best route.

The frequency of update measure (Figure 28) showed a consistent spread across the scenario types. It was observed that 11 of 16 pilots updated their plan more frequently in the non nominal scenarios than the emergency scenarios, four pilots updated their emergency plans more frequently and one pilot showed no difference.

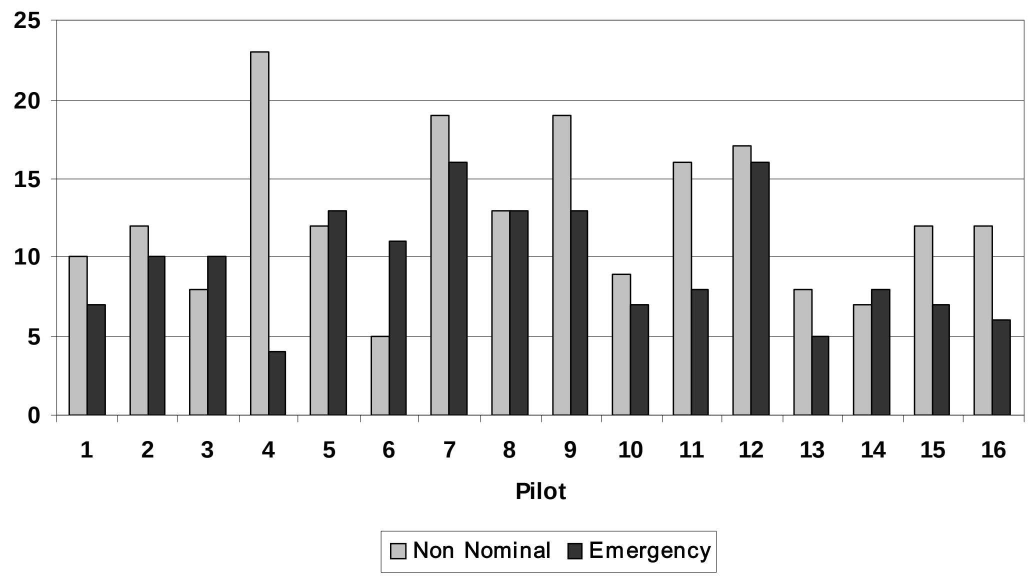


Figure 28 - Frequency of Update of Plan in CDU+ Cases

Pilots' reliance on the Autoplan was examined by the number of runs in which the Autoplan was the active route at the point when the run was terminated. When using the CDU+, one pilot did not use the Autoplan at all. Additionally, 7 of 16 pilots were seen to have used the Autoplan for both scenarios. From the remaining eight pilots, four used the Autoplan only for the emergency scenarios and four others used it only for the non nominal scenarios. In all runs where the Autoplan was used, modifications were made for a more direct route and to the speeds and altitudes in no particular order.

4.2.6 Pilot Planning Using the CDU with Autoplan Active at Start (CDU++)

From a comparison of the flight paths for the non nominal and emergency scenario types, it was observed that, for the non nominal scenarios, only one pilot (runway change scenario) chose to follow a route different to the others. In this case, however, the pilot simply followed the Autoplan route assuming it was the best route. From discussions and responses, it emerged that only distance and time were the important factors taken into account. In the remaining three non nominal scenarios, all the pilots followed similar downwind patterns with the corresponding turns to base leg. In the emergency scenarios, only one pilot followed a different route (fuel filter scenario).

In all runs using CDU++, the Autoplan was maintained as the active route up to the end of the run. However, changes were made to get a more direct routing, and also to speeds and altitudes to ensure a safe and expeditious flight. Another observation made here was that 9 of 16 pilots made substantial modifications to the Autoplan to the extent that they followed a different downwind path compared to the Autoplan.

4.3 Pilot Interaction with Automation

4.3.1 Use of Autoplan

Pilot responses and simulator log files also gave us insight into the reliance of the pilots on the Autoplan. In general, all pilots with the exception of two agreed with the general routing that the Autoplan provided, but also concurred that they required speed and altitude changes and, in some emergency cases, quite extensive changes. However, they did approve of the Autoplan feature. The sole pilot who did not like the Autoplan feature did categorically state that he was not a big fan of automation as he did not agree with the extent to which it delegates control of the aircraft away from him. Figure 29 shows the number of runs each pilot had with the Autoplan as the active route.

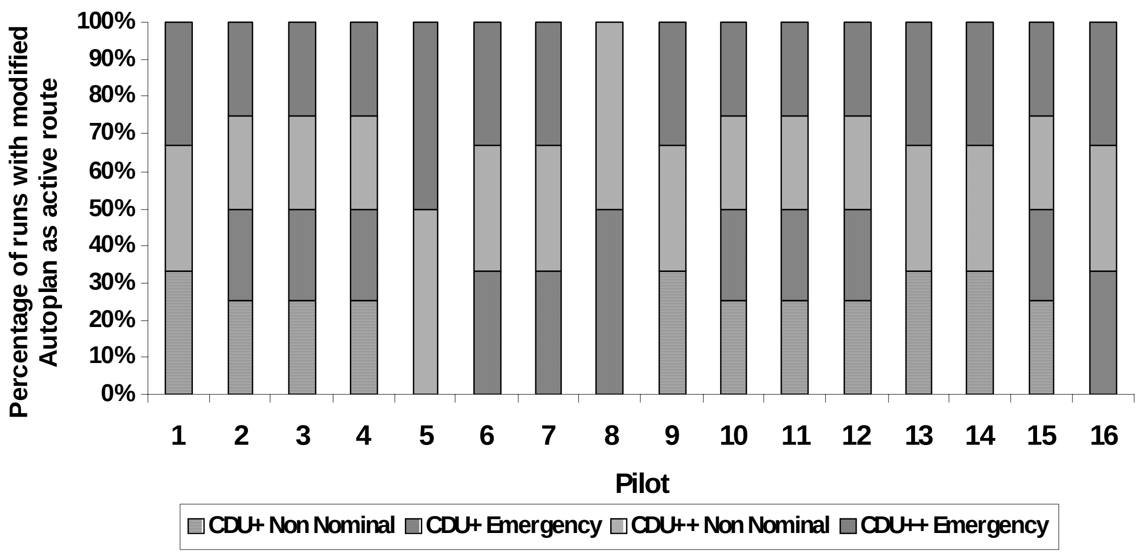


Figure 29 - Number of Runs with Modified Autoplan Active until End of Run

4.3.2 Pilot Comments on Automation

On the completion of each scenario, pilots were asked a series of questions pertaining to replanning in that scenario using the type of automation they used. Among the questions asked was a comparative evaluation of the automation used to what they would have preferred to use for that scenario on a Likert scale from ‘Easier’ to ‘More Difficult’ (Figure 30). It should be noted that, in each type of automation, there are a total of 32 runs with 16 pilots undergoing 2 runs each, one for each scenario type. These include cases where in a pilot may have preferred a different type of automation for each scenario type. The complete response to the end of run questionnaire for each pilot is given in Appendix C.2.

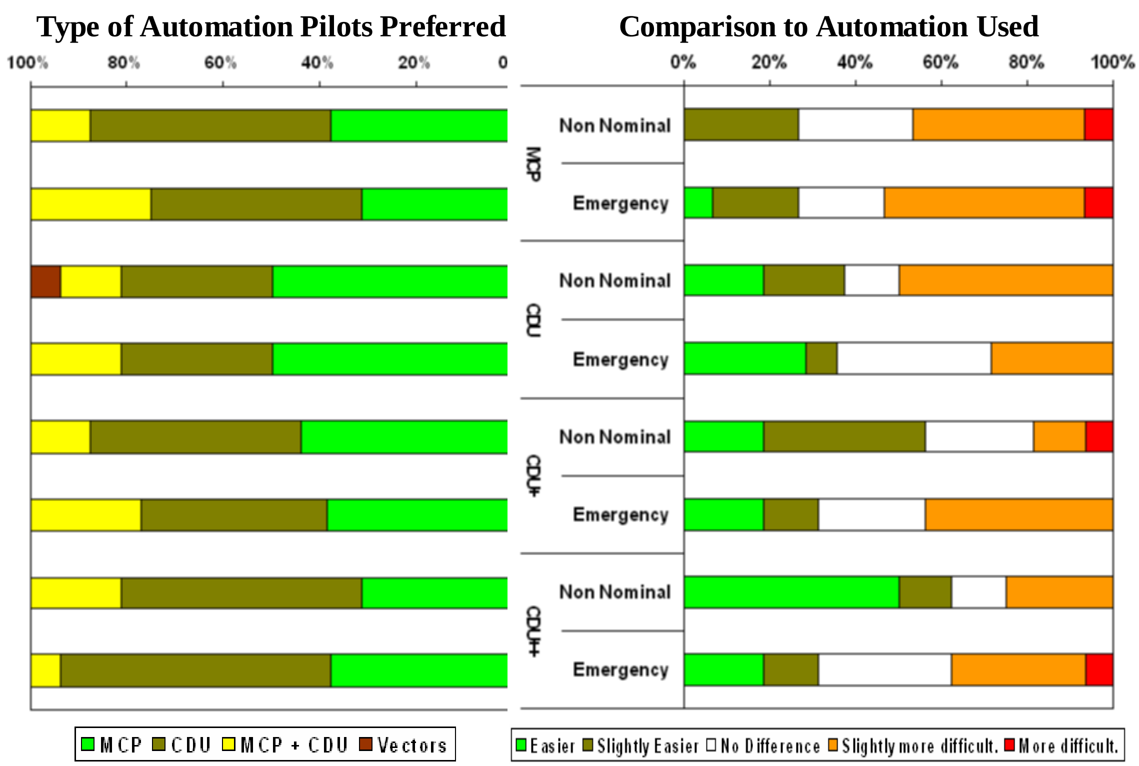


Figure 30 - Pilot Comparison of Automation Used with Preferred Automation

An interesting read from the above figure is that some pilots preferred to use a particular type of automation even though it resulted in more work for them and planning was more difficult. This could arise out of familiarity with the system currently being used and how often pilots use these in real world situations.

At the end of the experiment, the pilots were asked to rank the planning tools available to them; from best (1) to worst (4), according to which one was they felt was more useful for each scenario type. Figure 31 summarizes the rankings.

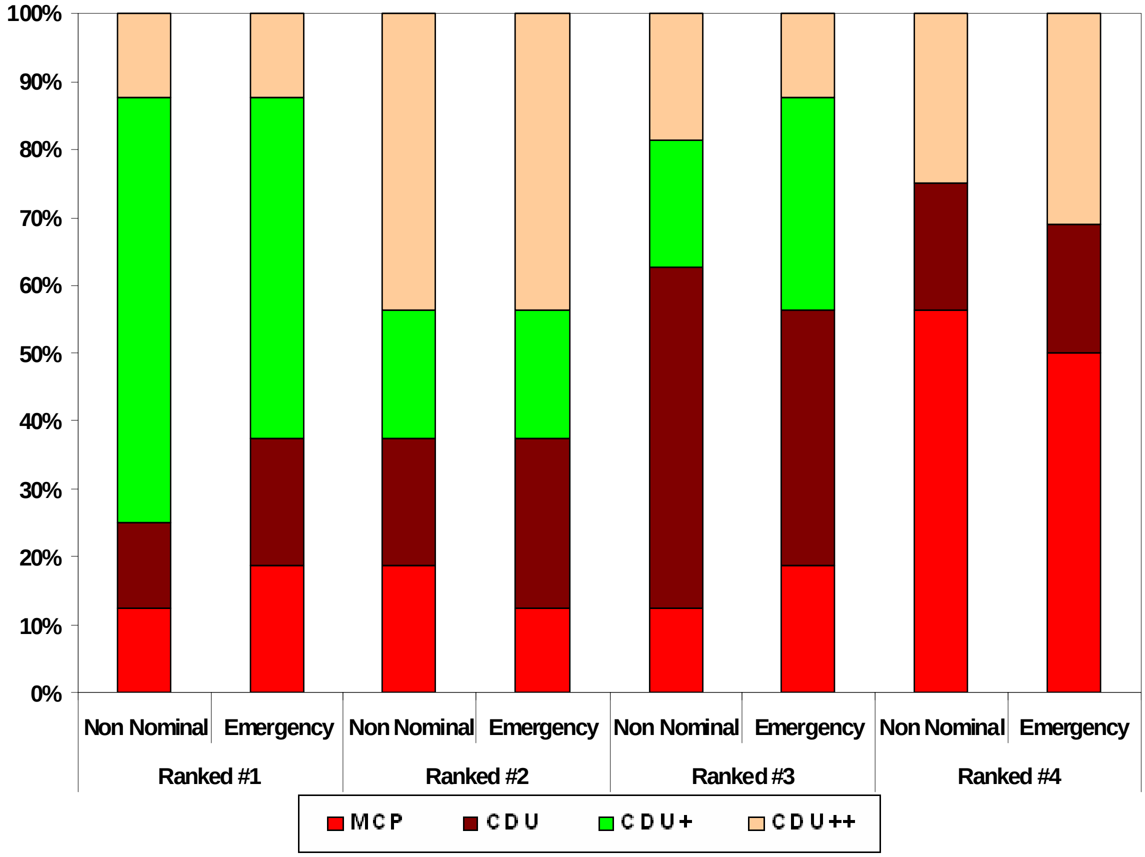


Figure 31 - Pilot Rankings of Automation Types per Scenario Type

From Figure 31 it was quite apparent that the CDU+ was the automation preferred by the pilots in the experiment with 62.5% of pilots rating it the best for the non nominal scenarios and 50% rating it the best in the emergency scenarios. Interestingly, 56% of pilots rated the MCP the worst for the non nominal scenarios and 50% rating it the worst in emergencies. The complete response to the end of experiment questionnaire for each pilot is given in Appendix C.3. A Wilcoxon signed ranking test (non parametric) was performed on the above response for both scenario types. In both scenario types, the CDU+ was rated as the best type of automation.

Finally pilots were also asked to describe the performance of the Autoplan. This was not specific to any scenario type. **Error! Reference source not found.** shows the response of each pilot to the question: *"How would you describe the performance of the Autoplan? Please elaborate."* , and it can seen that all but two pilots approved of the Autoplan function although some also stipulated caveats such as wanting to double check the route it suggests.

Table 3 - Pilot Responses to Performance of Autoplan

How would you describe the performance of the Autoplan? Please elaborate.	
Pilot 1	It gave a very viable option that you could choose or reject. It would save effort and thought process if it was elected
Pilot 2	I found Autoplan very easy to use and it made my workload much less.
Pilot 3	Autoplan is a great idea if implemented correctly. It needs the ability to pick waypoints that are likely to be used in a given airspace. I think this could be accomplished in part by surveying ATC and having them suggest alternate route in their airspace. Another constraint is CDU memory, which is in short supply in the 757/767s I fly. As long as Autoplan has the ability to pick a logical, likely route, it will be a good thing. If however, it picks routes that will not be used in real life, it will become a button that never gets used.
Pilot 4	Helpful as a suggestion, that can be easily modified. Adds fixes that can be used without typing.
Pilot 5	Autoplan has no way of knowing what the objective is. Therefore, it may offer a long route when a short route is desired. I believe in most cases, I would not use Autoplan.
Pilot 6	I would not have picked most of the routes it did. A little aggressive for passenger operations and routes were longer.
Pilot 7	I liked Autoplan. Not sure that I wanted it to switch to it automatically (CDU++), but I found the displayed alternate route very helpful in picking the route I would use.
Pilot 8	Coupled with the visual representation, it provides me with great options; however, I am concerned about ATC's ability to go along with the plan.
Pilot 9	It may offer a good solution, then again it may not. Autoplan is not the best solution in all cases but at least look at it to evaluate it
Pilot 10	Good. It gave a quick route with an appropriate lead into final.
Pilot 11	Good. It gives a viable routing to destination and allows you to refine as necessary.
Pilot 12	I think it can be a useful system because it can save cockpit workload. It depends on how closely it would match optimum route and how likely pilot could stay on that route and not be altered by ATC.
Pilot 13	Generally good, but needs to be modified based on current factors.
Pilot 14	I think the Autoplan is a great tool, but it needs to be treated only as a tool to help me make rerouting decisions.
Pilot 15	It provided a shorter route to the airport. However ATC usually does the same to the extent that traffic allows.
Pilot 16	In general good. In time critical situations, it can give a good plan quickly and then you can take time refining it.

4.4 Workload Assessment

To assess the workload involved in each scenario, the pilot was asked to complete NASA Task Load Index (TLX) ratings at the end of every run. The worksheet probed the pilot for their personal assessment of workload on a continuous scale. Workload itself was broken down into 6 categories: mental demand, physical demand, temporal demand, performance, effort, and frustration. Workload within each type of automation is shown in Figure 34. For each of the above categories, a general linear model was fitted to examine the main effects. Subsequent ANOVA test were done where applicable. Categories which failed normality conditions were subjected to non parametric tests to examine any differences within the independent variables.

In the mental demand category, the residuals of the general linear model failed the Kolmogorov-Smirnov normality test ($p>0.150$), thus disallowing an ANOVA. Subsequently, a non parametric test, the Kruskal-Wallis Test was performed which showed no significant effect of scenario ($H = 1.76$, $P = 0.972$) or type of automation ($H = 0.94$, $P = 0.815$) on mental demand.

As with mental demand, physical demand also failed the Kolmogorov-Smirnov normality test ($p>0.15$), thus rendering the ANOVA test unusable. Similarly, a non parametric test revealed no effect of automation or scenario on physical demand, but run order effects were seen in physical this measure (Figure 32). However, discussions with pilots and observations during the experiment revealed that any physical demand was more a result of using a virtual graphical user interface than of planning.

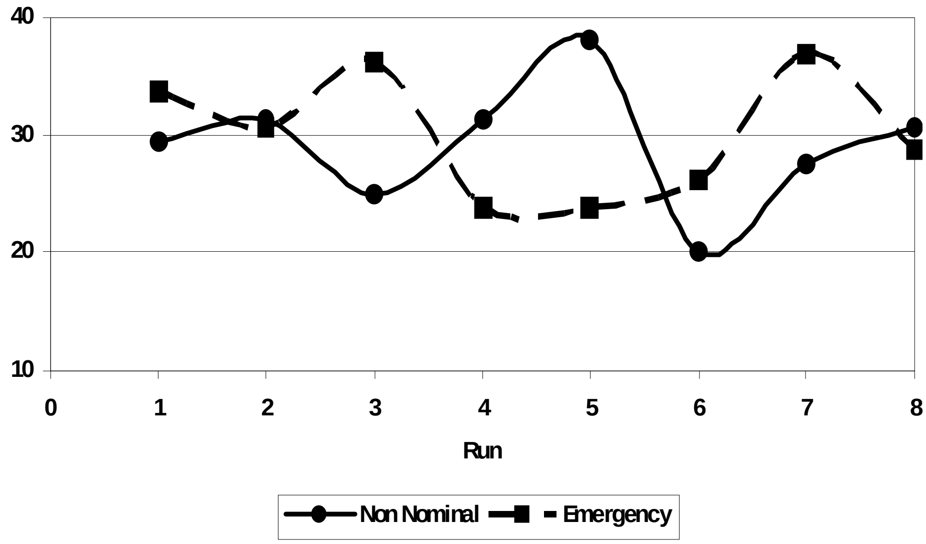


Figure 32 - Run Order Effects in Physical Demand

Temporal demand also failed the normality conditions, when fitted to a general linear model. A non-parametric test revealed no significance of the main effects on this measure. Temporal Demand showed run order effects as can be seen from Figure 33.

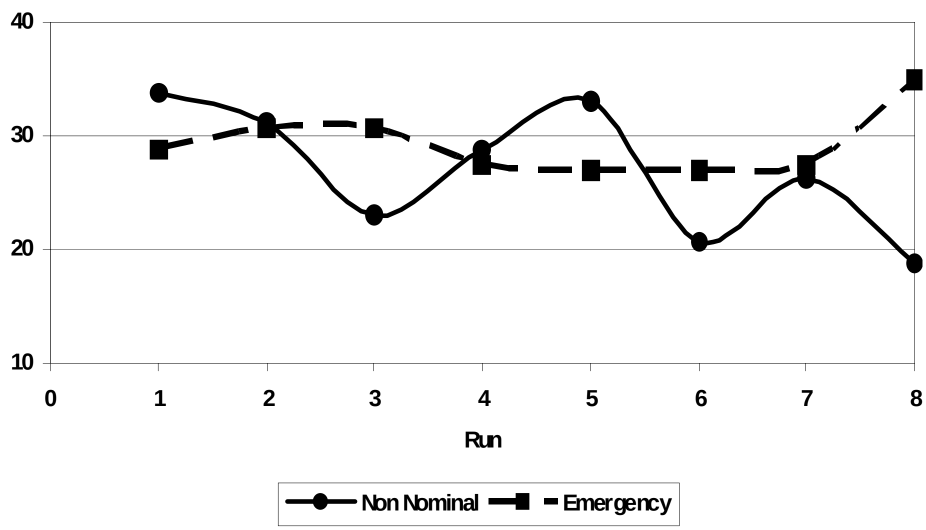


Figure 33 - Run Order Effects in Temporal Demand

The performance rating showed a significant automation effect ($F=15.81$, $p<0.001$). A 95% confidence Tukey test was further performed, which revealed that the MCP had the worst effect on performance.

Pilot ratings of their effort were not affected by the automation types. However, the specific scenario did show a significant effect ($F=4.33$, $p=0.040$) on effort. Specifically, the weather disturbance scenario and the restricted airspace scenario had the most effect on effort among all the scenarios.

Frustration was generally low and none of the variables showed any significant effect on the frustration level experienced by pilots during the task. Pilots may have reported a low frustration level in using the different autoflight systems since they have been exposed to these systems in real aircraft. Subsequent non parametric tests also failed any appreciable difference in any of the main effects.

An online calculator was used to compute the weights for each TLX category to calculate total workload. The average workload rating did not vary much with scenario type. In fact these were more specific to the type of automation wherein the workload rating for both scenario types was highest for the MCP and the lowest for the CDU+ (Figure 35) but was not statistically significant.

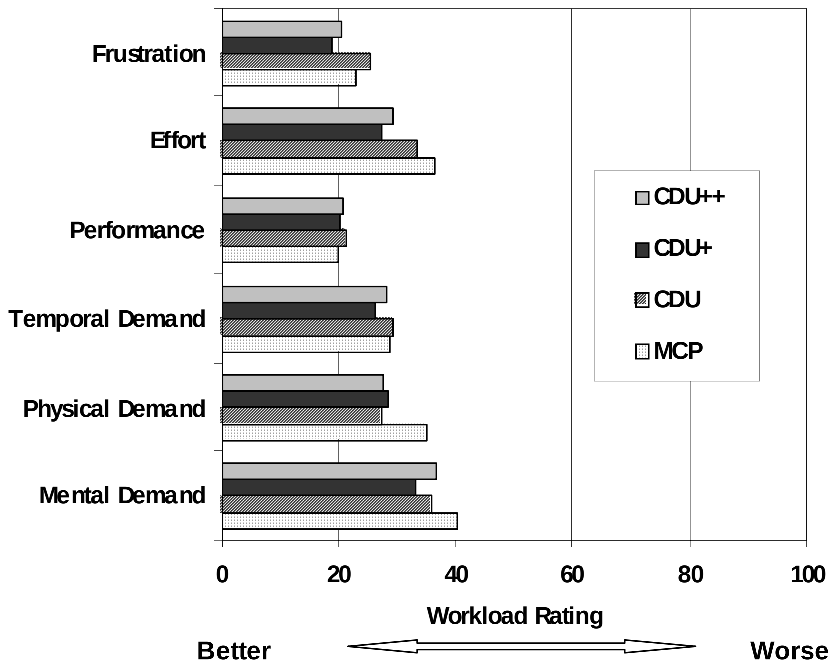


Figure 34 – Average TLX Workload Ratings for the Planning Task

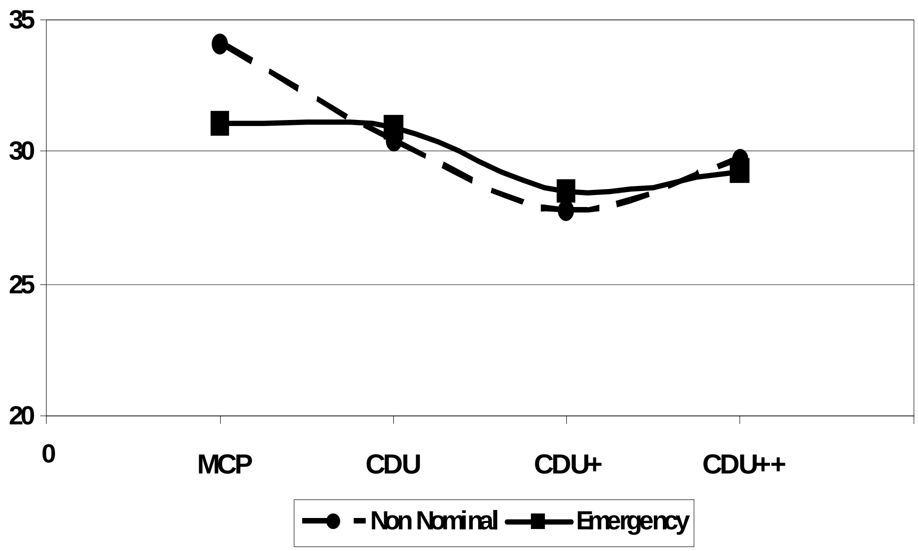


Figure 35 - Average Total Workload

4.5 'Faulty Autoplan' Scenario

The faulty Autoplan scenario that was run after completion of the first eight runs provided insight into the effect that a faulty Autoplan may have on the pilot's performance. Specifically the CDU++ generated a faulty plan which the aircraft would immediately start to follow at the beginning of the scenario. The Autoplan was erroneous in that, in a non nominal scenario type, it would provide a plan that was extremely aggressive and not safe for normal airline operations, i.e., it would generate an over aggressive plan that was suitable for a critical emergency. Likewise, for an emergency scenario type, it would generate a more circuitous route unsuitable for emergency, thereby ignoring the primary measures of time and distance. Eight pilots ran the ninth run in the non nominal scenario and eight pilots ran it for the emergency scenario, thereby giving 16 runs (data points). Figure 36 and Figure 37 shows the flight paths of the pilots in this run for the two scenario types.

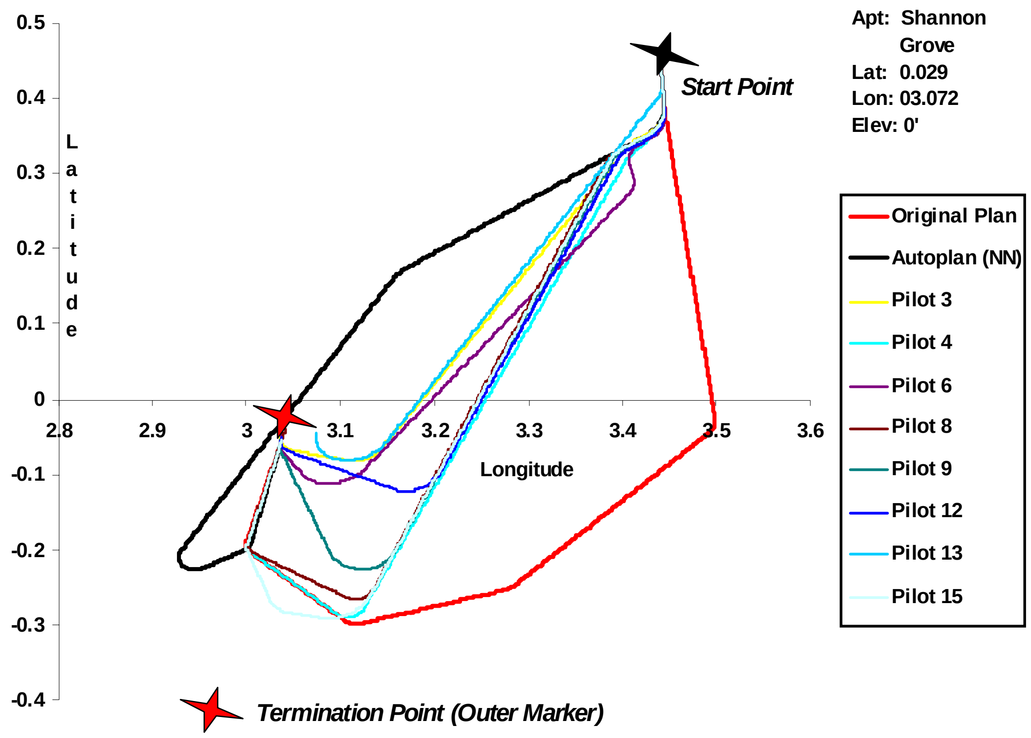


Figure 36 - Flight Paths for Non Nominal Faulty Autoplan Scenario

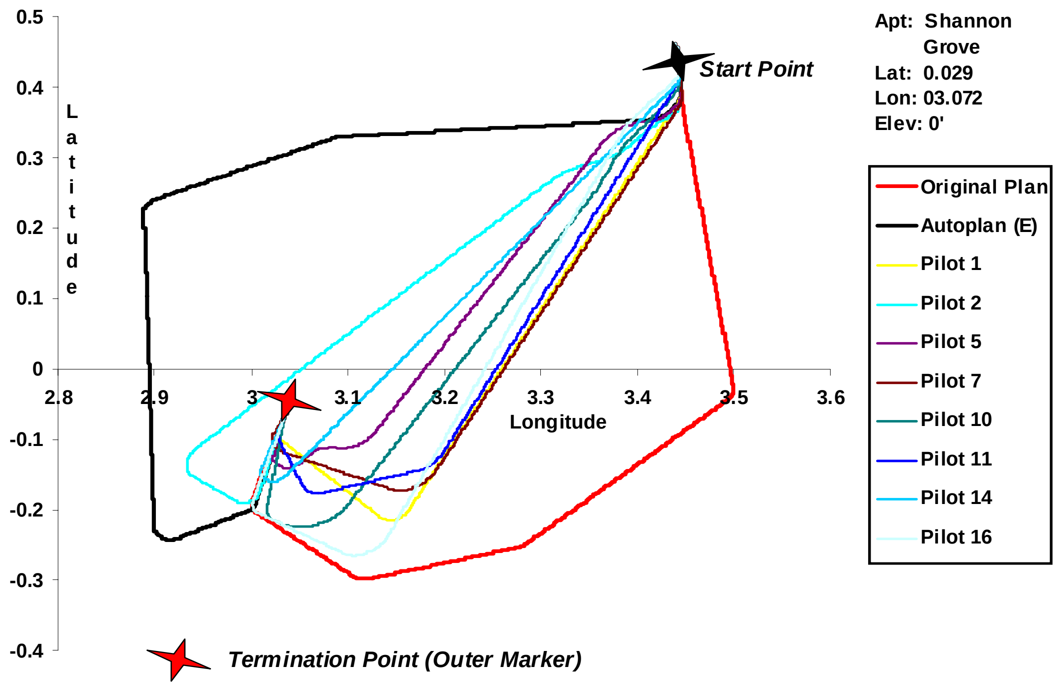


Figure 37 - Flight Paths for Emergency Faulty Autoplan Scenario

Although there are an insufficient number of data points for a statistical analysis, some trends merit discussion. Regardless of scenario type, pilots' primary aim was to minimize time aloft and distance to travel. In the non nominal scenarios six out of eight pilots did not activate the original route (RTE 1) but chose to modify the Autoplan. The two pilots that did activate the original route took, from the start of the run, an average time of 2.131 minutes to activate and 2.489 minutes to start modifying the route (the other six pilots took an average time of 1.261 minutes to start modifying the route). This suggests that they did spend some time evaluating the two plans available and then make their choice.

It was observed that in cases where pilots activated the original route, the average number of modifications to the active plan was six whereas, for the other six pilots, the number of modifications increased to eight, thereby suggesting that the original route was better than the Autoplan and required less modification, which was subsequently verified through observations and comments made by the pilots during the experiment and debriefing.

The number of modifications to the plan was measured by the number of times the pilots pressed the EXEC button to execute a modification. In the emergency scenarios five out of eight pilots did not activate the original route (RTE 1) but chose to modify the Autoplan. The three pilots that did activate the original route, however, took an average time of 0.483 minutes to do so. This suggests that they immediately recognized the erroneous Autoplan and proceeded to activate the original plan. In the non nominal scenario, the average deviation in distance flown was 10.562 miles with a corresponding saving in flight time of 7.027 minutes. For the emergencies these measures corresponded to 10.295 minutes saved in flight time and 25.819 miles saved in flying distance. These were measured by taking the difference in times of the modified route and the unmodified active route. Figure 38 and Figure 39 show a snapshot of the various measures for the faulty Autoplan scenario:

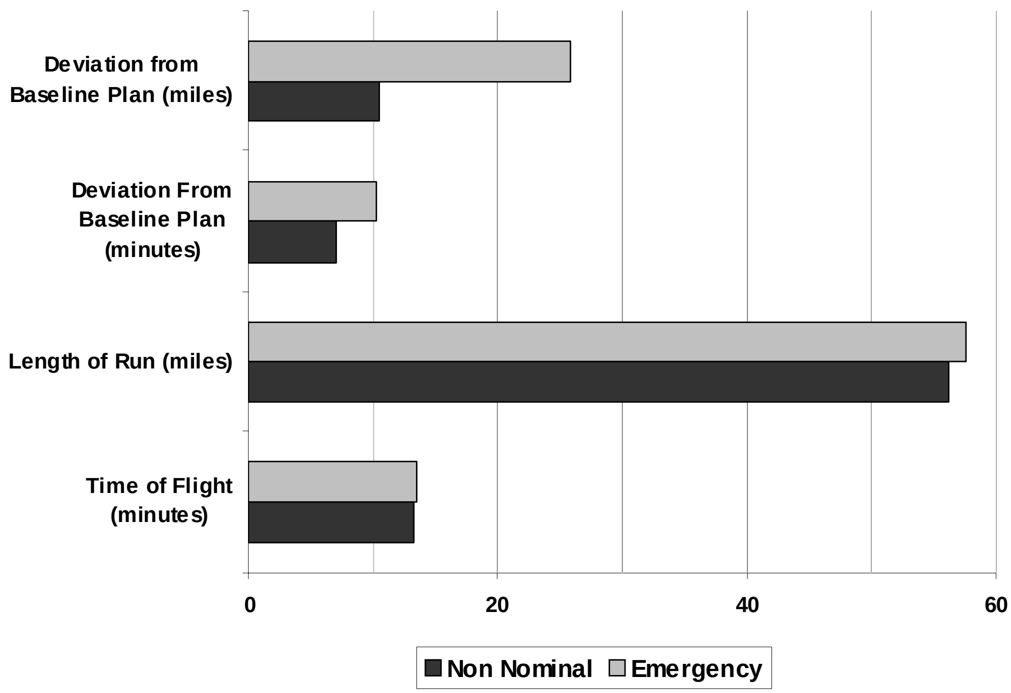


Figure 38 - Planning Performance Measures in Faulty Autoplan Scenario

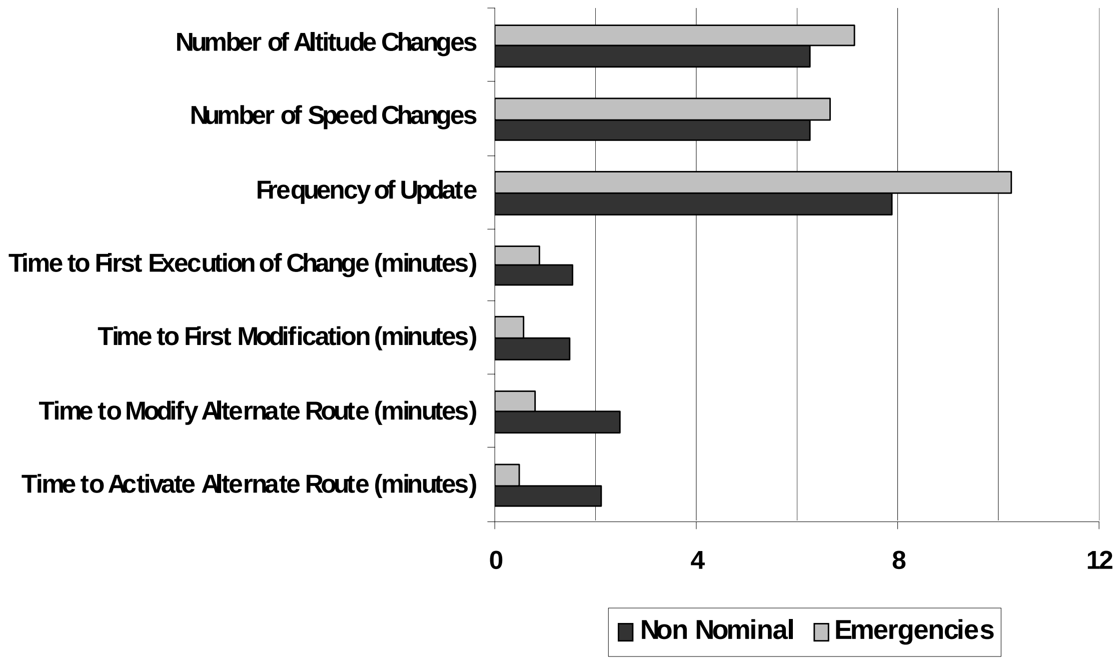


Figure 39 – Planning Behavior Measures for Faulty Autoplan Scenario

CHAPTER 5

CONCLUSIONS

5.1 Discussion of Results

The results of this experiment suggest that pilot behavior and performance differs in different situations, be it non nominal or emergency.

When pilots used only the MCP, the time of flight and the length was lower (i.e., better) than with the other types of automation. With the MCP, the emergency scenarios showed markedly lower values for the primary measures of performance than the non nominal scenarios, which had a stronger effect on the safety of the flight. This was attributed mainly to the fact that pilots did not need to spend too much time creating and modifying fixes, but rather spent more time on speed and altitude changes.

The CDU only, however, showed a slight degradation in pilot performance. The workload assessment showed no significant difference from that with the MCP, but the primary measures of time of flight and length of run were the highest in this type of automation. Average deviations were about the same as that of the MCP suggesting that resulting plans were similar, but the comparative flights varied substantially. The non nominal scenarios show higher averages for time and distance than the emergency scenarios; however, these also show a markedly higher average for the emergency scenarios when compared with the MCP only case with no appreciable change in overall workload. This case did show a higher level of frustration than the other automation types mainly because pilots had to spend time entering and modifying fixes, and, in some cases, pilots had been previously been exposed to the other variants of the CDU.

The variants of the CDU, namely CDU+ and CDU++, were well received by the pilots because of the additional Autoplan feature which was found to tremendously reduce pilot workload during replanning. Though the CDU+ did show a relatively higher temporal demand for both scenario types, it showed overall a much better performance in reducing time and distance and the subsequent total workload.

It was also seen that with all the variants of the CDU, pilots made substantial changes to the Autoplan. The Autoplans were created to meet mind airspace regulations; however, the inability of the plan to take advantage of the air traffic controller giving the pilot discretion over the route explained the changes made by the pilots to the Autoplan. These factors highlight the need for careful design of the Autoplan generator to be context sensitive including the ability to generate plans for both non-nominal and emergency situations and to take advantage of relaxed ATC restrictions. Pilot comments concerning the performance and usefulness of the Autoplan were more favorable than indicated by the performance measures. Indeed, most of the pilots believed that the Autoplan could be useful but at the same time expressed a number of concerns about its implementation.

The results of this preliminary experiment suggest that the functional concept of an automatically generated plan is an endeavor worth pursuing which provides the pilot much needed assistance in replanning a flight route. Additionally, it was observed that pilots tended to think of plans as a two dimensional space at any time.

5.2 Future Directions

Although this research specifically studied airline pilots' planning behavior in glass cockpit using current autoflight interfaces (MCP and CDU), the results suggest several broader implications for cockpit planning aids in general. The most important is the level of intelligence required by the FMS to generate such a plan on its own. While most pilots did say it was useful, some shot down the idea on the ground that they preferred to either create their own plans (even if it increased workload a little and increased time), or hand fly the aircraft as it afforded more control of the aircraft. In this experiment, for example, some pilots pointed out that the Autoplan did give a very good initial routing with minimal route changes, but was not very effective with the speed and altitude management.

Successful implementation of such a concept is highly dependent on the level of artificial intelligence, context sensitivity to and the sensing of external factors such as traffic, weather and terrain. The objective function or the goal of the plan should coincide with the specific situation at hand, be it non nominal or emergency in nature and whether the aircraft has been compromised or not.

Some pilots also observed that such a concept would be more useful in an en-route environment as terminal area traffic control is far stricter and more stringently regulated. A more dynamic and real time update of the plan would also be useful with additional information in the form of ETA to active waypoints would also be helpful to pilots.

Perhaps a more important question is the location of such a system. Though the Autoplan (and subsequently the CDU+) did not have much effect on pilot behavior, it could be located in the aircraft FMS or used by air traffic control level to create better aircraft routings, perhaps updated when the situation changes.

Other additions that may prove to be helpful are a complementary display which shows a vertical and horizontal display of the Autoplan in a space relative to other routes and traffic, weather, and terrain, as well as supplemental information of estimated time to travel, estimated distance to go, estimated fuel consumption and savings on time and distance compared to the previous plan. These additions, with subsequent testing, can better confirm the effectiveness of such a concept.

With the development of free flight, the concept of an automatic plan generator would greatly enhance in-flight re-planning tasks and could have better context sensitivity if, in addition to the above mentioned enhancements, Autoplan could incorporate 'Party Line' Information (PLI) such as real time and current pilot reports about weather and traffic, Collaborative Decision Making (CDM) information such as airspace system status, equipment availability and weather, and the output of other tools such as the User Request Evaluation Tool (URET) for conflict prediction, passive Final Approach Spacing Tool (pFAST) for terminal area arrival and departure streaming operations, and Traffic Management Advisor (TMA) for en-route traffic management.

Results also bring into focus the effectiveness of the control display unit as a replanning interface. With its text display and keystroke method of data entry, planning interfaces such as touch screens which allow pilots to graphically pick waypoints and define a flight path may prove to be both easier to use and facilitate pilots in creating better plans. Such a system does not call for elimination of the CDU from the flight management system, but current methods of using planning interfaces in flight decks do call for a more efficient interface. Such a system would be efficient in that pilots would have the system in front of them (thus allowing pilots to monitor other flight instruments simultaneously), reduce physical movements in terms of data entry into the FMS and not requiring the pilot to constantly go heads down when creating the plan and then looking up to verify the plan.

APPENDIX A

PILOT BRIEFING

Objective

This experiment is an investigation of in-flight re-planning using various conventional (existing) and enhanced autoflight systems that assist pilots to replan and fly their route of flight following an emergency or a non-nominal situation.

Experiment Summary

This experiment will last approximately six hours. At any time you may request a break, ask for further explanation, or, if necessary, terminate the simulator runs.

[*We will be videotaping each of your test runs. The only purpose of the videotape is so that we may go back after testing and review the runs. These videotapes and all other data obtained during the experiment will be kept confidential. You may request to see the videotapes and any other information recorded by us throughout the course of the experiment*.]

You'll be flying our simulator, which is based on a Boeing 747-400. In each run, you will be asked to use a particular type of autoflight system. We will begin with tutorial flights to familiarize you with the experimental setup, procedures, and the autoflight systems. We will only progress to the actual data runs when you feel ready to proceed.

Once you are ready to move onto the data runs, you will be asked to fly nine flights. Each flight will have just experienced either an emergency or a non-nominal situation. You will be placed into the scenarios after the problem has been diagnosed and immediate danger averted (in the case of an emergency). Your task will be to plan and fly your route as you would in a real aircraft. Each run will end after you have passed the final approach fix or are within glideslope intercept.

Throughout the course of the experiment, please feel free to verbalize your thought process. For example, please tell us any important steps you follow or decisions you make during re-planning. Following each test run, you will be asked to fill out a questionnaire about your workload, the cockpit displays and your planning activities pertaining to the run. At the end of the experiment, we will also give you a more complete questionnaire regarding the tool in general.

Please do your best to act naturally and fly the aircraft in the same manner in which you would fly your own aircraft. We would like to get the best estimate of a 'real-life' response.

Scenario Introduction

You are the Captain of a 747-400 style aircraft. Your F/O is fresh out of training with little experience in type. For each run, you are on a scheduled flight along a pre-planned route which must be re-planned due to some problem: four of your runs will be under a non-nominal situation (i.e., not time-critical) and four under an emergency situation (i.e., time-critical). Prior to each run you will be briefed on what has happened, which runway you need to plan your descent to, and what type of autoflight system interface we would like you to use. Normal flight deck displays will be available to you, as well as Jeppesen style en-route (Figure 40) and STAR charts (Figure 41) and approach plates (Figure 42).

In each scenario, assume that all normal and abnormal procedures have been conducted (and will continue to be conducted) by the F/O. Your task is to get the aircraft down by planning and flying a safe route. You will not be required to land the aircraft. In each case, ATC will be giving you discretion, so your choice of route should be that you would pick in real life when not constrained by ATC. You should, however, communicate to your F/O your planned flight route as you come up with it so that he can communicate it back to ATC. You are welcome to modify your planned flight route throughout the flight as long as you communicate your changes to the F/O. To help us understand your strategies and needs in these types of situations, please also verbalize your thoughts throughout the flight.

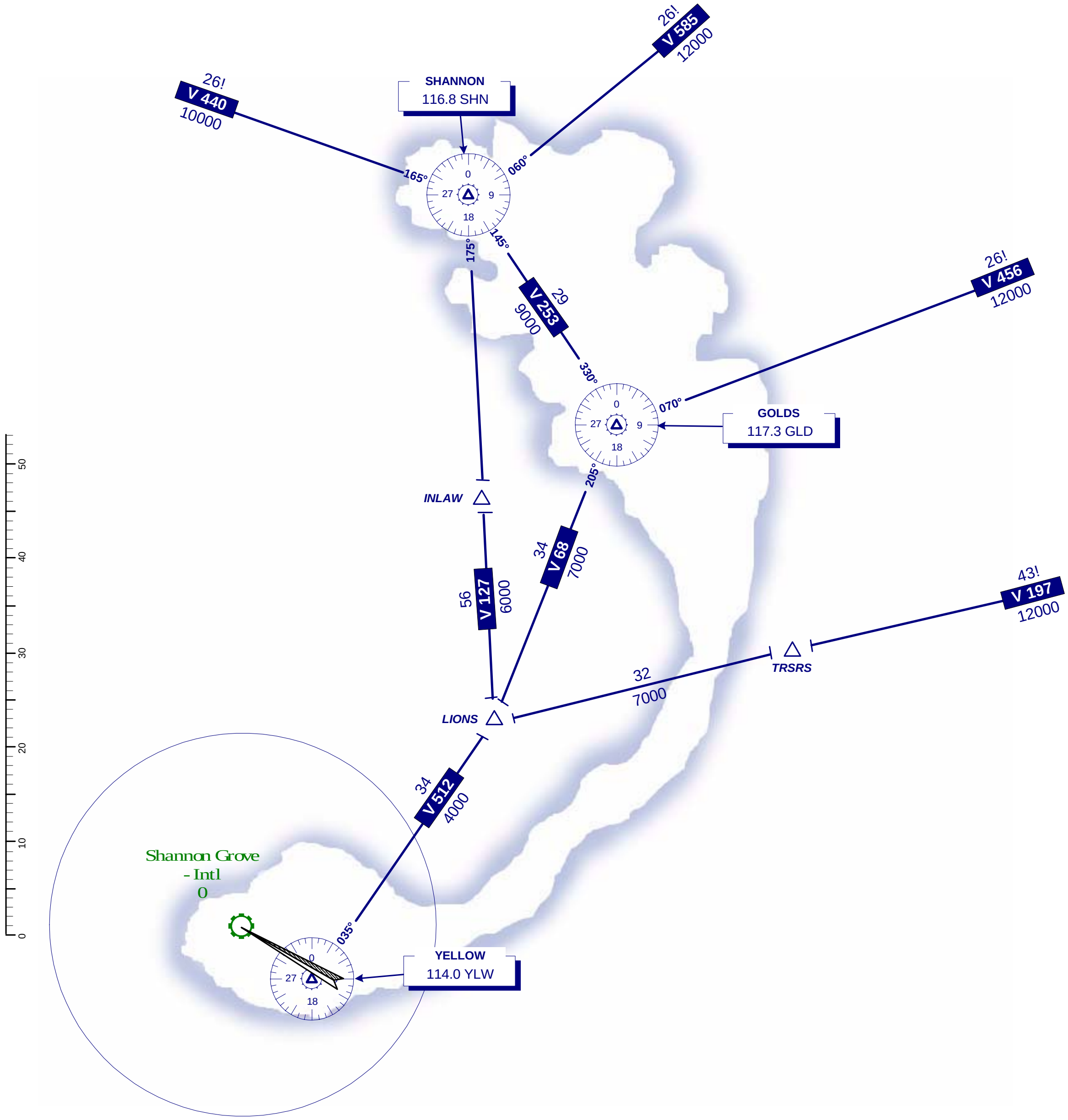


Figure 40 – En-route Chart for Shannon Grove International Airport

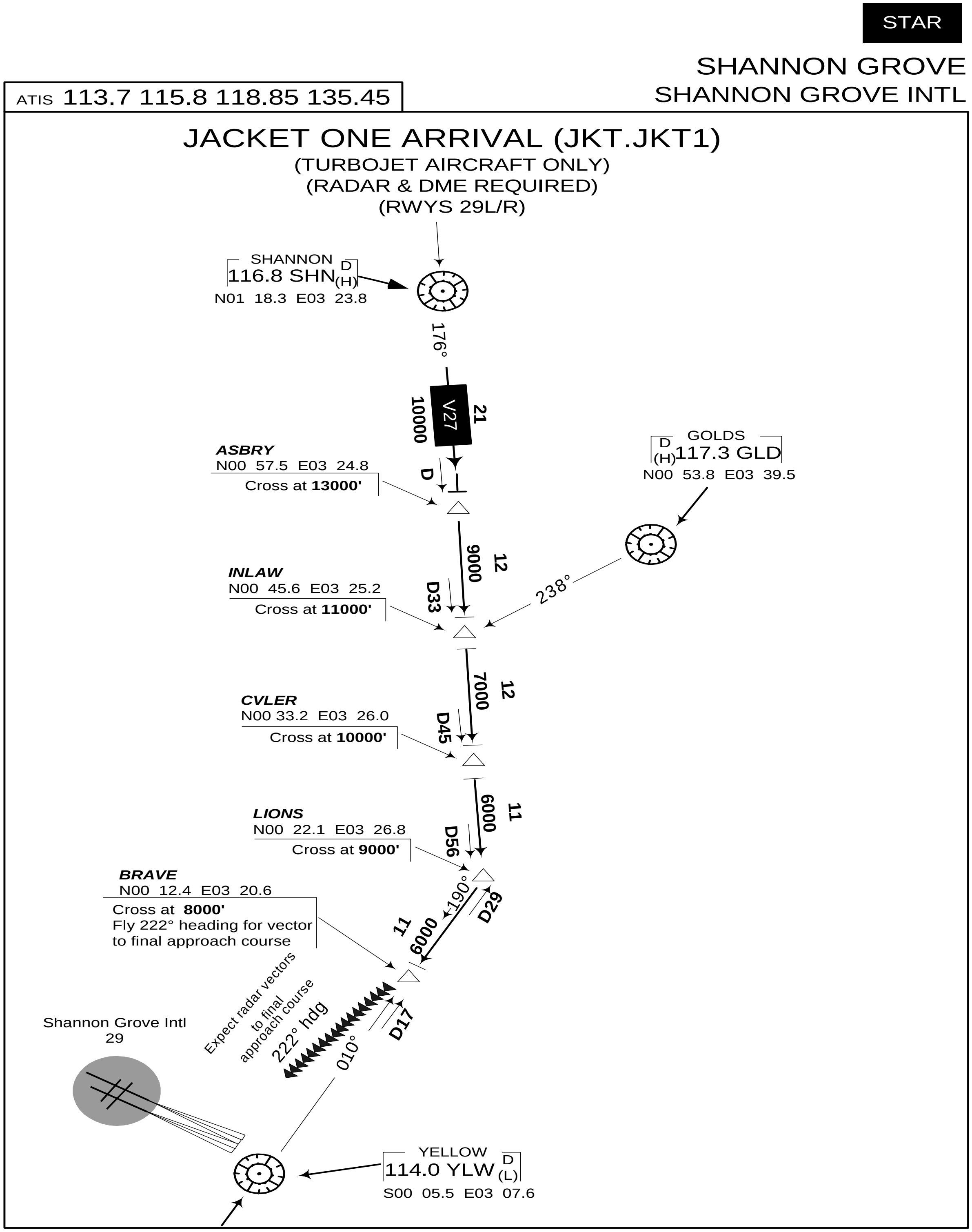


Figure 41 - STAR Chart for the Jacket One Arrival at Shannon Grove International Airport

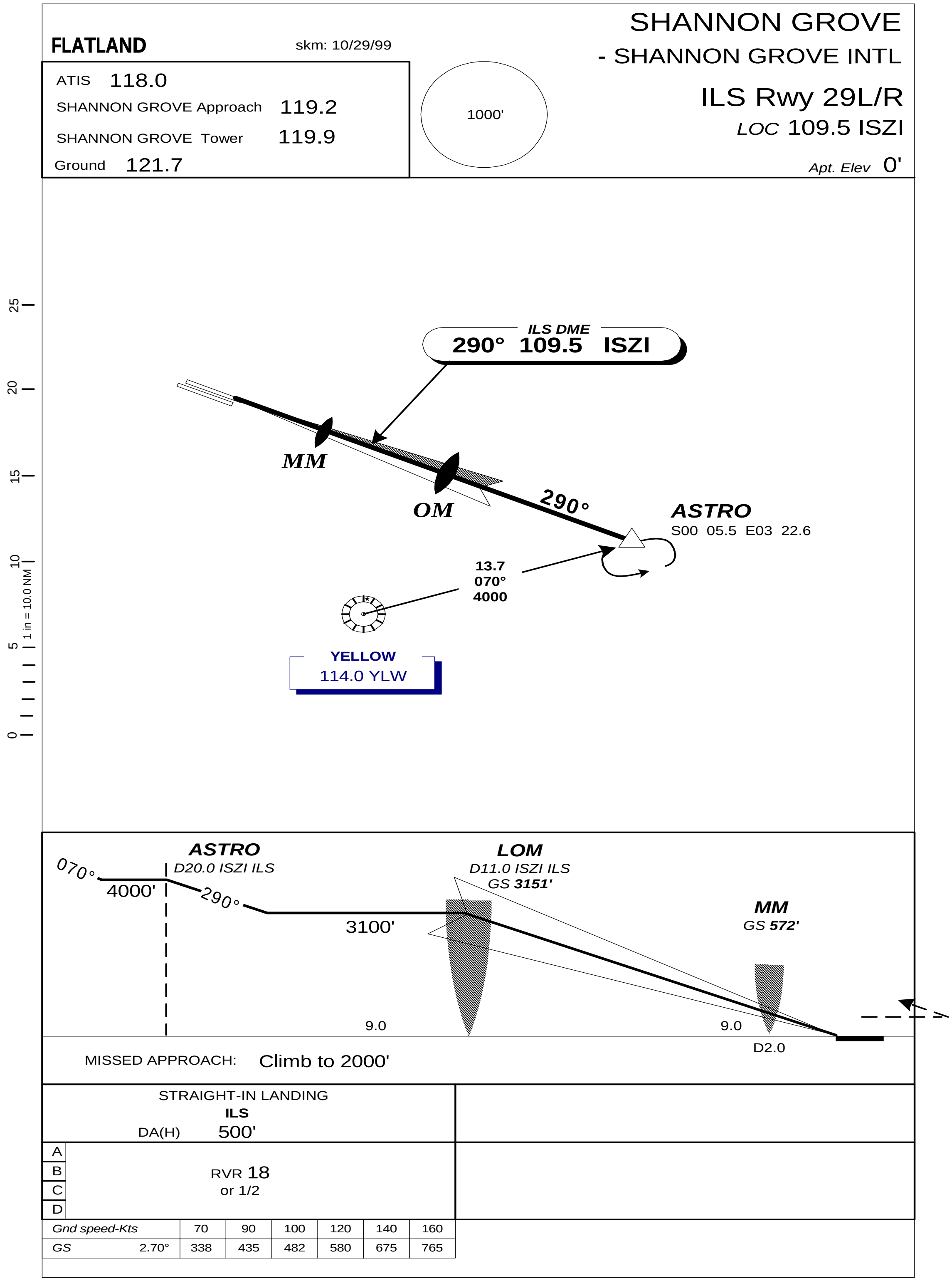


Figure 42 - Approach Plates for RW29L/R at Shannon Grove International Airport

Autoflight Systems

For this experiment we'll use four different types of autoflight systems. Briefly, these are described below – we'll go through a tutorial on them next.

- **MCP**: In this experimental condition you will be asked to fly the aircraft using only the Mode Control Panel (MCP) using the HDG, V/S, ALT, FLCH and SPD modes.
- **CDU:** In this experimental condition you will be asked to fly the aircraft by programming the FMS by entering in routes and waypoints into the Control Display Unit (CDU). This simulator's CDU functions similar to ones in current Boeing aircraft.
- **CDU+:** In this experimental condition an additional button called 'AUTOPLAN' will be available on the CDU. This is an enhancement which, when pressed, causes the FMS to generate a flight plan on its own accord and display it. You may make changes to this plan or disregard it totally. The decision is left to you.
- **CDU++:** In this experimental condition the FMS will generate an AUTOPLAN on its own accord, display it, and will start to follow it automatically when we start the simulator at the beginning of the run. You are still welcome to override the plan.

Flying The Aircraft

Primary Flight Display

Two primary flight instrument displays are available to you on the screen in front of you: the primary flight display (PFD) and the navigation display (ND). The PFD is based on that of a Boeing 747-400 (Figure 43). The tape on the left is airspeed in knots; the one on the right is altitude (MSL) in feet. The heading is magnetic, and the magnetic variation for all scenarios will be zero. The vertical speed indicator is on the far right, and is in feet per minute. Note the flight mode annunciators at the top.

Figure 43 - RFS Primary Flight Display

Navigation Display

The ND is also modeled on the Boeing 747-400 (Figure 44). The stippled magenta line shows the pre-selected heading. The solid magenta line shows the active route in the CDU. The modified route is shown as a stippled white line.

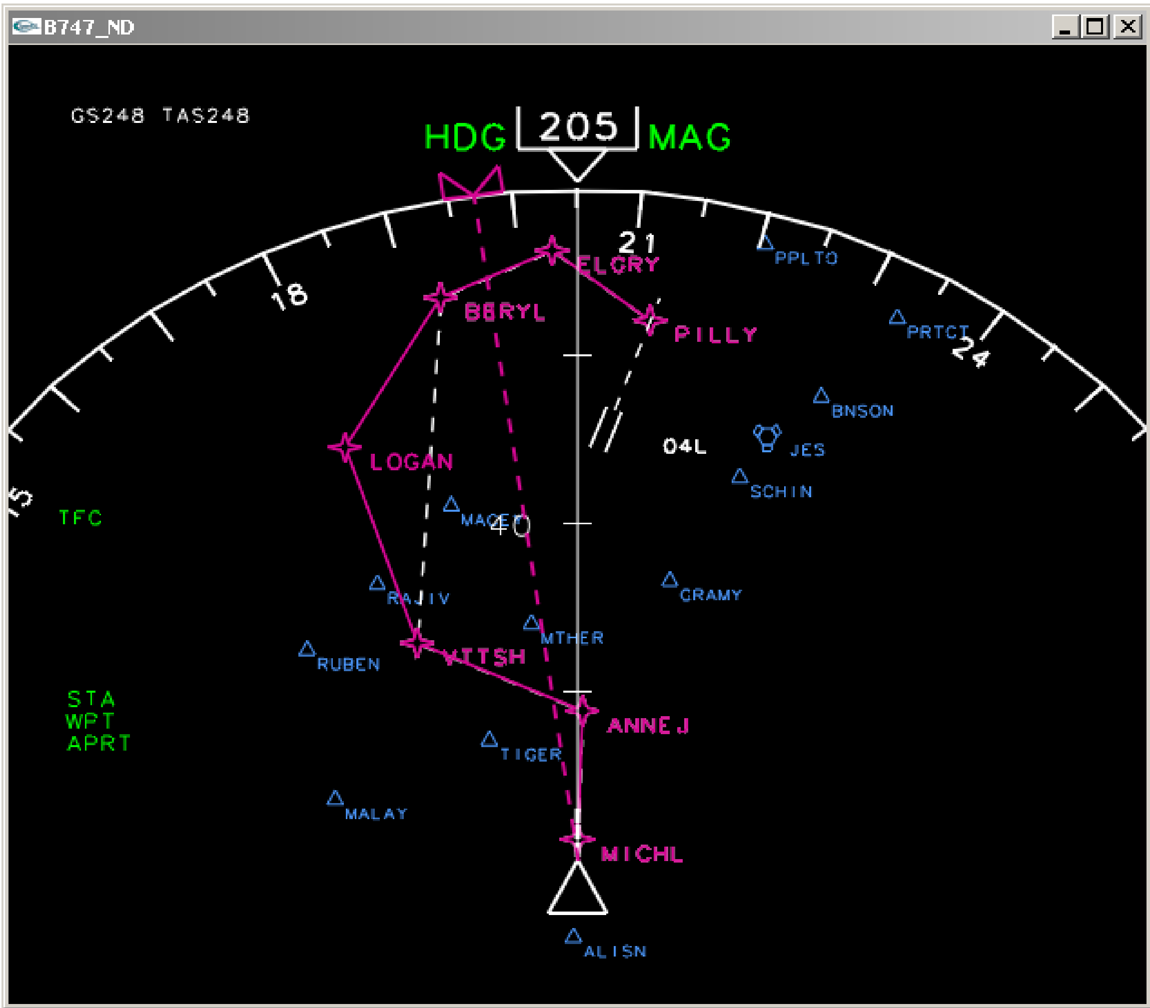


Figure 44 - Navigation Display showing pre-selected heading, active route and modified route

When the AUTOPLAN option is available, it shows up on the navigation display as an orange stippled line as shown in Figure 45. This turns white if modified and into a solid magenta line if activated.

Note the green arc (the ‘banana’) which shows the distance (from the aircraft) at which you will arrive at the desired altitude. This arc shows up on the ND irrespective of the plan being displayed on the CDU.

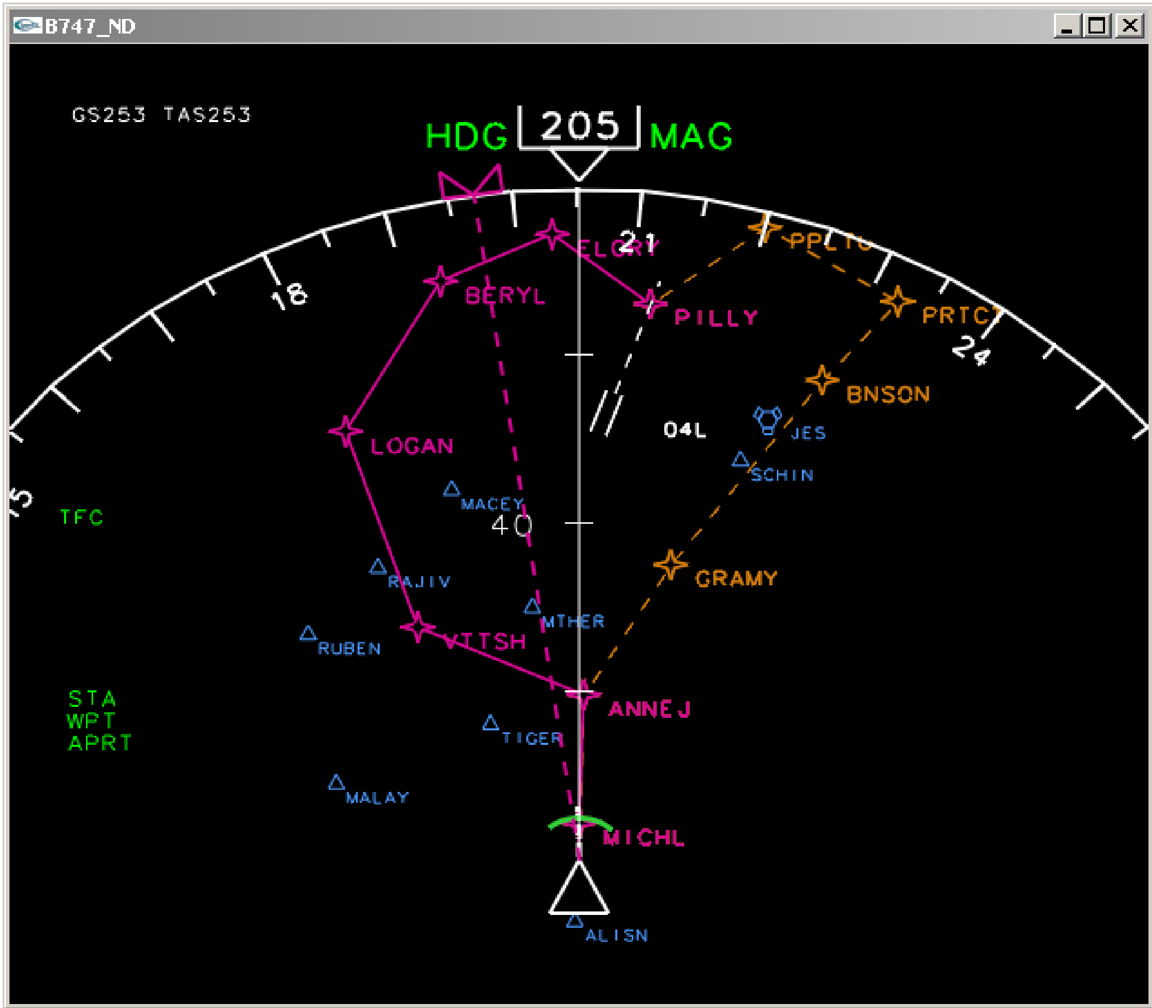


Figure 45 - Navigation Display showing Autoplan route in orange and green arc

In addition to the above instruments, in some runs you will also have available to you an MCP and a CDU. When asked to use only the MCP, you can use it to fly the aircraft using the airspeed, vertical speed and altitude controls (shown in Figure 46). You will need to adjust speed and altitude yourself to meet your spacing requirements and altitude constraints. The MCP is controlled through the mouse. HDG, V/S, ALT, FLCH and SPD modes are available. To increase the value of speed, altitude or vertical speed commands, click on the upper pink box of the roller dial of the target window with the left button of the mouse; to decrease, click the lower pink box with the left button of the mouse. Bear in mind that to enable the values that you have input into the MCP, you have to click on the appropriate button for the command to be sent to the aircraft so that it can follow it.

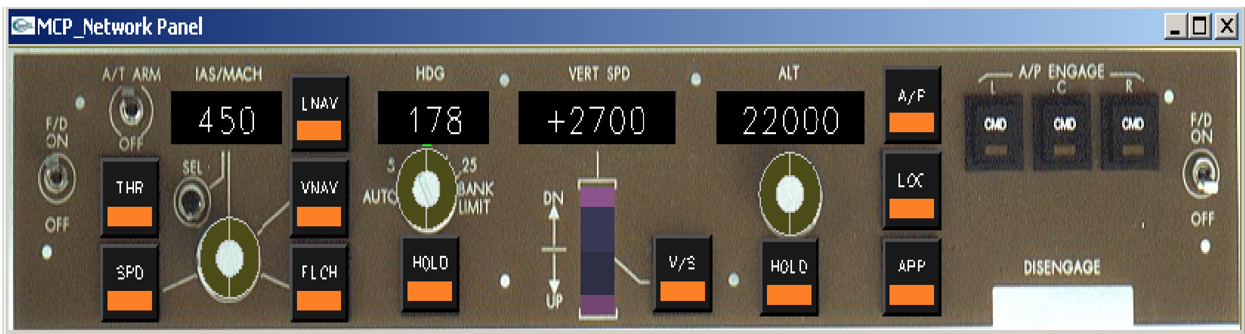


Figure 46 - Mode Control Panel

The RFS Control Display Unit (v1.0) Made Easy

The following tutorial will help to familiarize you with the working of the control display unit (CDU). The CDU (shown in Figure 47) in this simulator is modeled on the Boeing 747-400 CDU and functions very similarly with a few modifications. The line select keys are placed inside the screen regions themselves. To copy to or from the scratchpad just click on the screen region and the entry is copied from the region to the scratchpad or vice versa. The alphanumeric keys are also functional. Programming the CDU is described in step-by-step detail next. In the CDU that will be used in this experiment, apart from alphabetic and numeric keys, only the RTE, FIX, LEGS, EXEC, AUTOPLAN, PREV and NEXT buttons are enabled.

Figure 47 - Control Display Unit

1. Viewing the RTE Pages:

The RTE button will bring up the screen pertaining to RTE 1 (Figure 48).The page title (top center) shows the name of the current route and its mode i.e. MOD or ACT. The highlight shows that the particular button is currently under the mouse's cursor.

Figure 48 - CDU Screen Showing RTE Page 1

1.1 Modifying entries in the CDU:

The screen regions in this CDU act as line select keys. Modifying an existing route is the same as in a real aircraft CDU. Click on the desired screen region. If the region can be changed or selected then the entry will be highlighted in green. Select the waypoint TIGER (on page 2/3) and click on it. If the scratchpad is empty then that entry is down - selected to the scratchpad as shown in Figure 49.

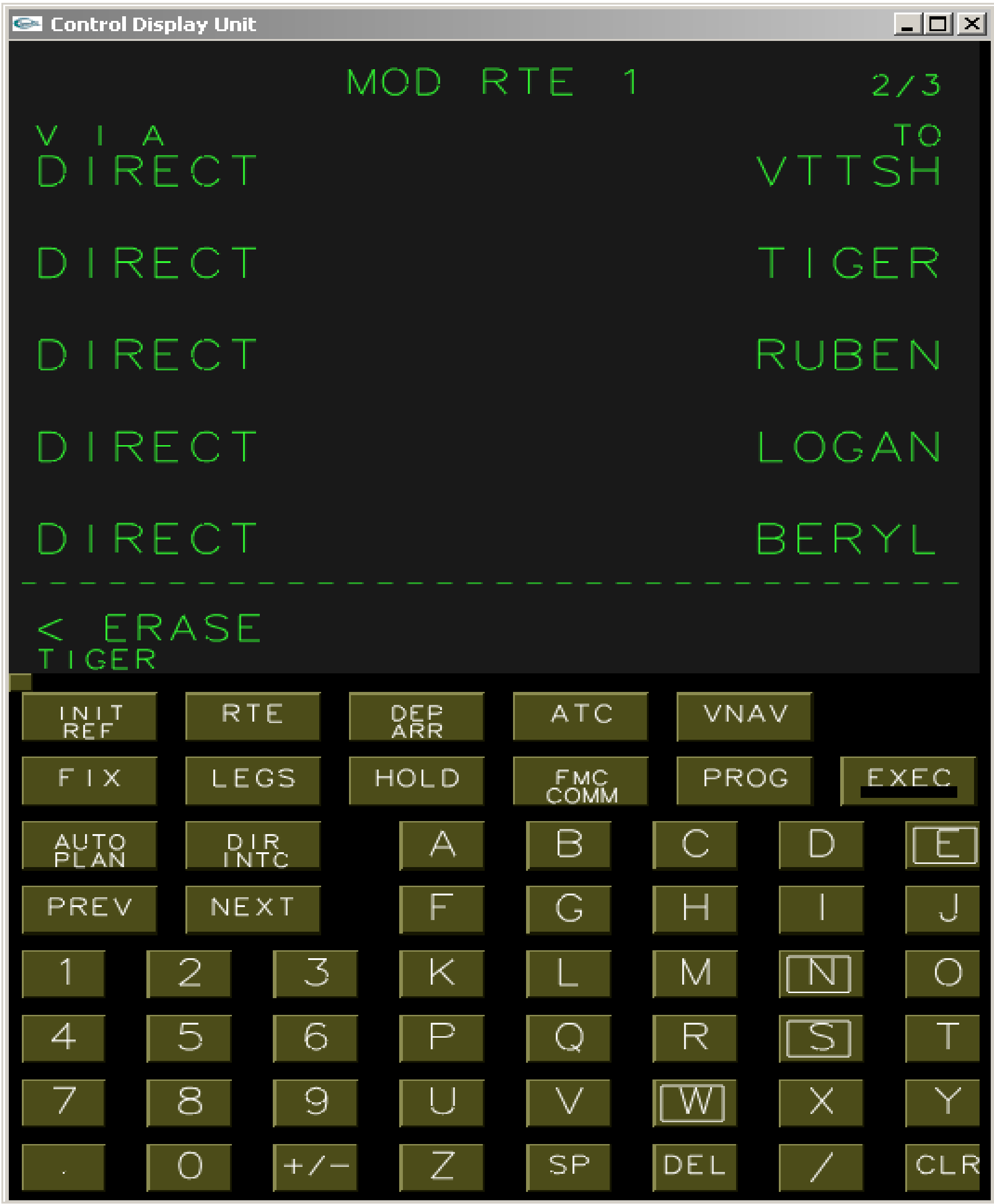


Figure 49 - CDU Screen after down selecting TIGER to scratchpad

Figure 50 - CDU Screen after up selecting entry from scratchpad

Click on the line select key you want to place this entry to and the entry in the scratchpad is up-selected to the chosen region. For example, LIONS (in the scratchpad) can be up-selected to replace ANNEJ (on page 1/3). When you click on ANNEJ the change is made and is reflected on both the RTE page (Figure 50) and the LEGS page of that route. Note that the EXEC button lights up waiting for a confirmation of the modification. Until the page title of the page will show MOD. Also notice the white stippled line on the ND which denotes the modified route. Pressing the EXEC button (when lit) will cause the page mode to change from MOD to ACT. The page title will now show ACT RTE 1.

Figure 51 - Confirming the MOD by pressing EXEC to change page mode to ACT.

1.2 The AUTOPLAN Feature:

The AUTOPLAN feature is an enhancement on the existing CDU. Two of the four autoflight systems (namely CDU+ and CDU++) have a feature wherein the FMS itself charts out a plan. The FMS generated plan can be manipulated like any of the other routes. To view the AUTOPLAN, simply click on the button marked AUTOPLAN and the CDU displays it.

Figure 52 - CDU Screen showing AUTOPLAN

Notice that the ND will show an orange stippled line denoting the AUTOPLAN. This can be treated and modified like any other plan. You will see that Region 6R says "ACTIVATE >". This means that the AUTOPLAN is in the CDU database, but is not the active route. To activate the AUTOPLAN, press the screen region saying "ACTIVATE >". The EXEC button lights up (provided there are no route discontinuities) waiting for a confirmation.

Figure 53 - Lit up EXEC button after ACTIVATE > is pressed

To confirm, press the EXEC button and the AUTOPLAN gets activated. The page title changes to “ACT RTE AUTOPLAN”.

Figure 54 - Confirming the AUTOPLAN activation

1.3 Route Discontinuities on the RTE Page

A ROUTE DISCONTINUITY is created whenever there is no defined path between successive waypoints in a flight plan. Discontinuities may be created by waypoint deletion, line selection or procedure stringing. These show on the RTE and LEGS pages as boxes wherever there is a break in the route and the FMS does not know where to go next (Figure 55).

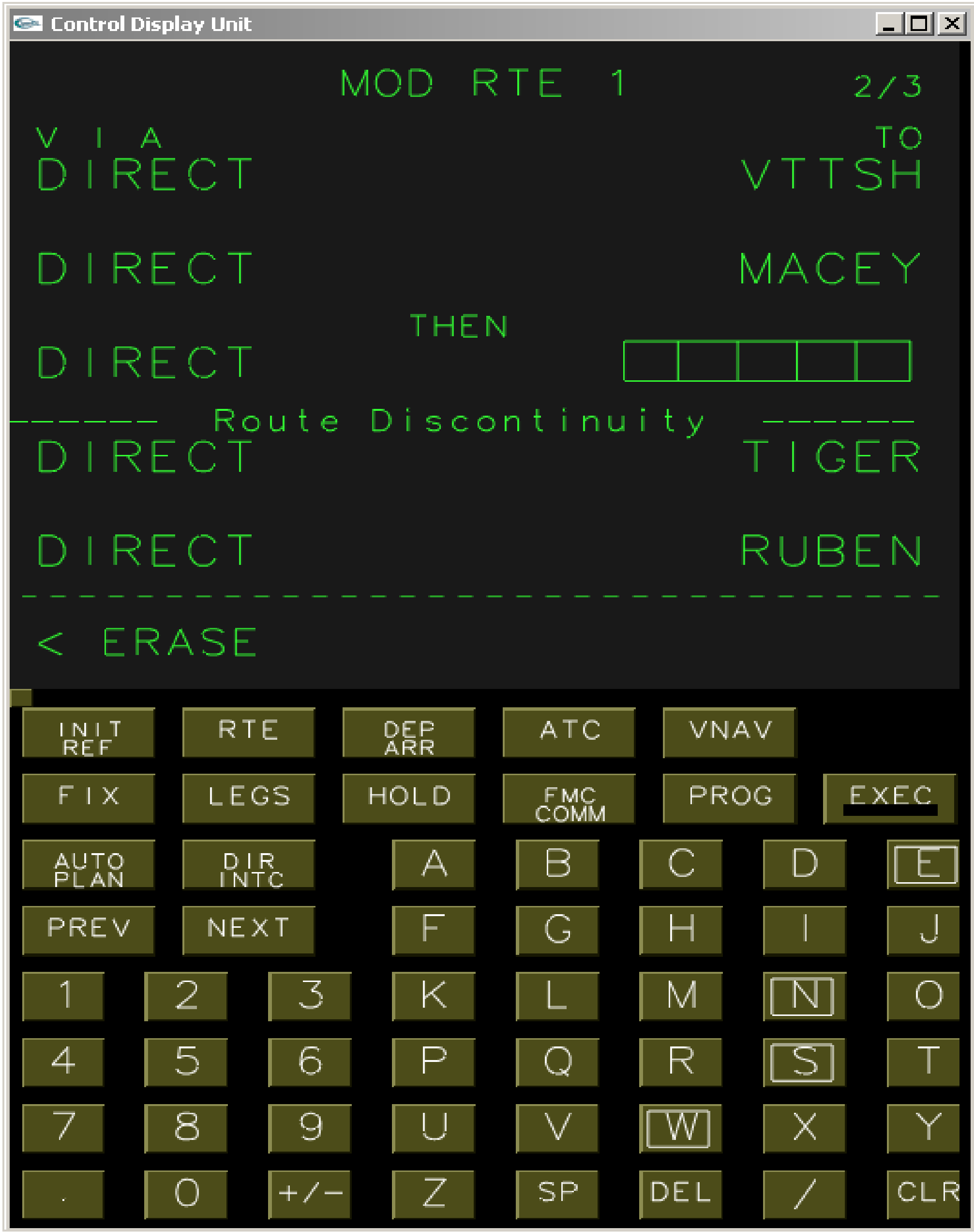


Figure 55 - RTE Page showing route discontinuity

1.3.1 Resolving a Route Discontinuity:

To resolve a route discontinuity, click on the desired waypoint after the route discontinuity to down select it to the scratchpad (Figure 56) or type in a waypoint name to the scratchpad.

Figure 56 - Down selecting desired waypoint BERYL (on page 3/3) to scratchpad

Next, click on the region where the route discontinuity is displayed. The EXEC button will light up (Figure 57)

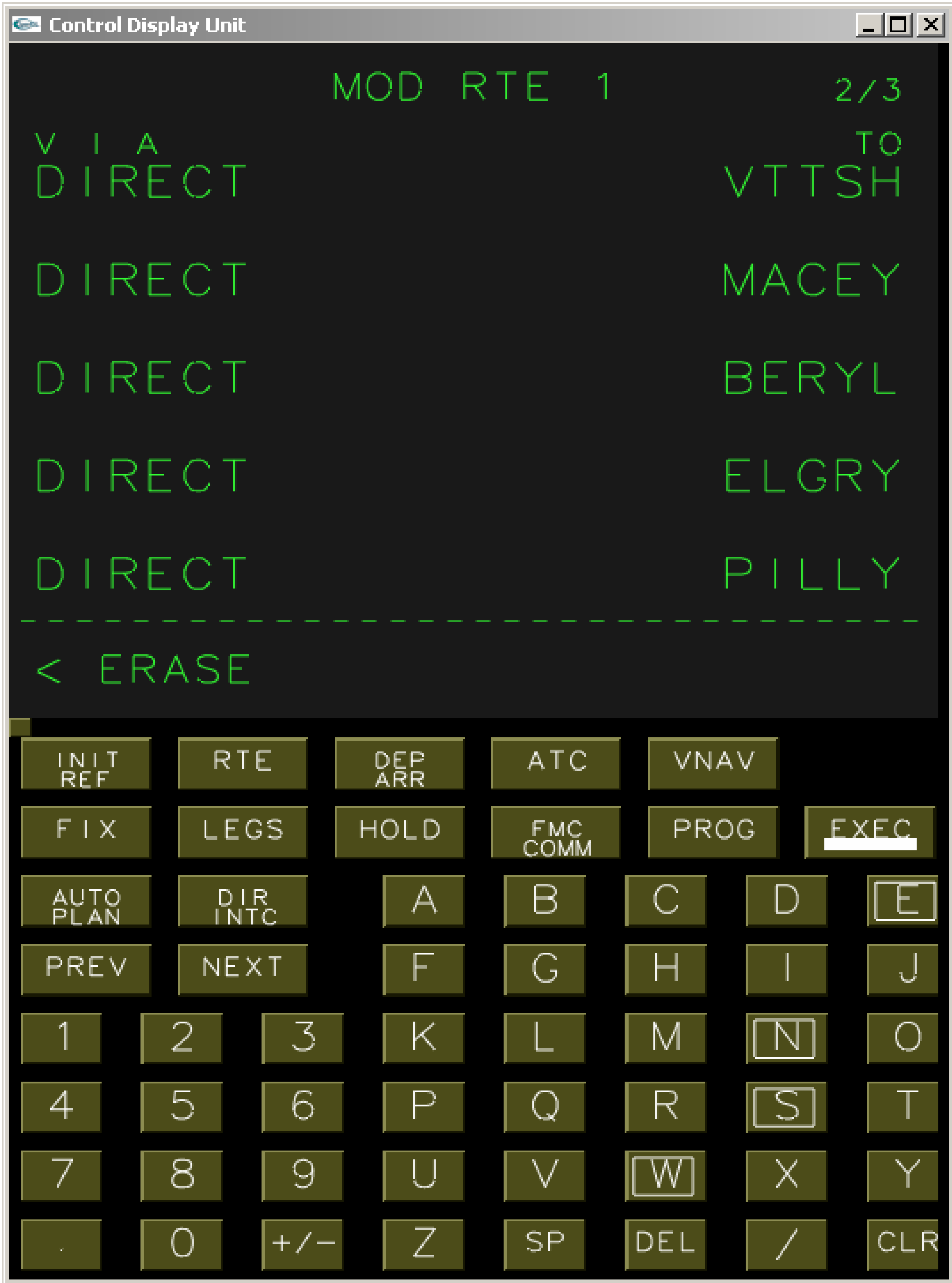


Figure 57 - EXEC button lights up when BERYL is up-selected to route discontinuity

Click on the EXEC button to confirm the action and the entry in the scratchpad will be up selected to the target line and the route discontinuity resolved (Figure 58). Also notice that the ND display changes to a solid magenta line showing that the route is activated.

Figure 58 - Route Discontinuity resolved and route activated after clicking EXEC

2. Viewing the LEGS Pages:

To view the LEGS pages of the current route, there must be a current route on display in the system (RTE 1 or AUTOPLAN). Press the LEGS button. The screen will refresh showing you the different legs in the flight plan in the order of flight (Figure 59). Modifications to the LEGS pages are similar to that of the RTE pages.

Figure 59 - CDU RTE LEGS Page

The legs page shows the details in the same conventions used in real aircraft. The heading to each waypoint is displayed above the waypoint identifier. For example, the heading 162^o brings you on course to intercept waypoint MICHL (from your current position). The center column shows the distance to the next waypoint in nautical miles. For example, the distance to the active waypoint MICHL is 5 nm and from MICHL to ANNEJ is 14 nm. The altitude and speed constraints are displayed on the rightmost column of the corresponding waypoint. For example, MICHL has an altitude constraint of 10000ft and a speed constraint of 250 knots.

2.1 Route Discontinuities on the LEGS Page

As with the RTE pages, route discontinuities also show up on the LEGS pages. Figure 60 shows a route discontinuity on a LEGS page. In the LEGS pages, the route discontinuities show up only on the left hand column of the screen region.

Figure 60 - LEGS page showing route discontinuity

2.1.1 Resolving a Route Discontinuity on the LEGS Page

Resolving a route discontinuity in The LEGS page is similar to that of the RTE pages, i.e. down-select the desired waypoint after the route discontinuity to the scratchpad, or type in a waypoint into the scratchpad and then up-select it to the region showing the discontinuity. The EXEC button will light up. Press the EXEC button to confirm, and the route discontinuity will be resolved and the updates legs displayed.

2.2 DIRECT-TO

Direct-to flight plan entries allow you to fly directly to a particular waypoint. The waypoint may be part of the active or modified active route, or it may be off path.

A direct-to can be performed by entering the desired fix into screen region 1L on page 1 of the ACT RTE LEGS page or the MOD RTE LEGS page. This is the same as any other legs page modification. Additionally, this can also be done via the DIR/INTC Page. To do this:

- Click on the DIR/INTC button.
- Screen Region 1L will show box prompts with "Direct To" displayed above it (Figure 61).
- Down select the desired direct-to waypoint to the scratchpad or type in the name of the waypoint desired into the scratchpad.
- Up-select the scratchpad contents to the box prompts and the direct-to action is completed. You will then have the option of erasing the direct-to action or activating the modification (Figure 62).

Figure 61 - The Direct-To Page

Figure 62 - Direct-to BERYL completed with modification created

3. Advanced Flight Planning

3.1 Pilot Created Waypoints

This section describes the various ways in which you can create waypoints to assist in flight planning.

Waypoints and fixes can be created in 2 ways:

- Place Bearing/Distance (PBD) and
- Latitude/Longitude

3.1.1 Creating Waypoints by Place/Bearing Distance (PBD):

You can create a fix by PBD into the scratchpad and up-selecting to the desired position. These waypoints are identified by the first three characters of entry (which should be the name of the reference Navaid) followed by a two-digit sequence number. This can be done by:

- Typing the name of the reference Navaid with bearing and the desired distance from the Navaid as one word into the scratchpad. The bearing and distance should be separated by a '/' (forward slash).
- Up-selecting it using the line-select keys to the desired location.

Example: If you want to create a waypoint bearing 205 degrees at a distance of 10 nm from the Navaid JES, simply type 'JES205/010' into the scratchpad (Figure 63).The Waypoint JES01 (Figure 64) will be created and the latitude and longitude computed automatically where the 01 is FMC assigned and since this is a pilot defined waypoint, a route discontinuity will also be inserted after the created waypoint. You can proceed with subsequent flight planning only after this route discontinuity has been resolved.

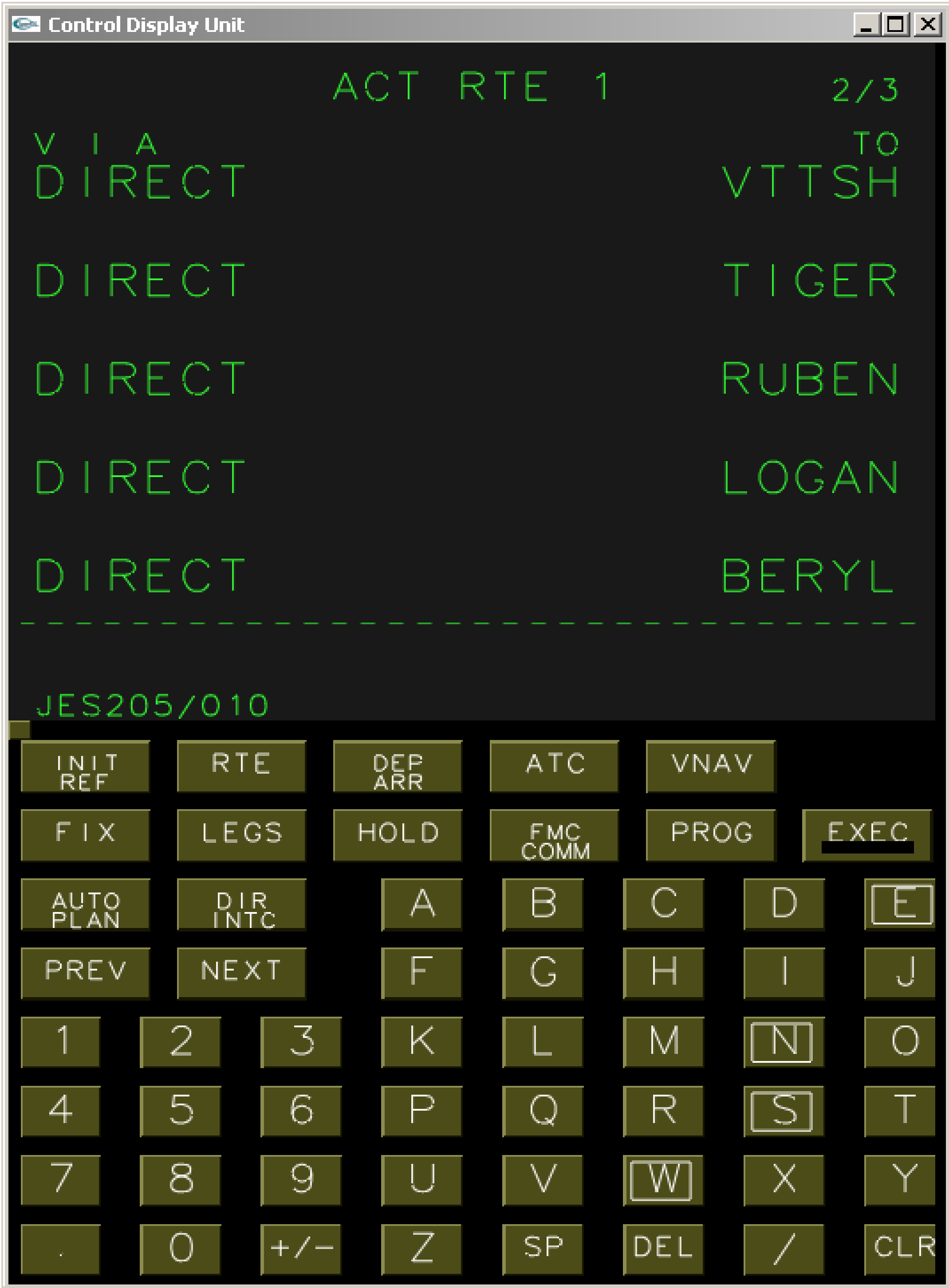


Figure 63 - Creating Waypoints by Place/Bearing Distance (PBD)

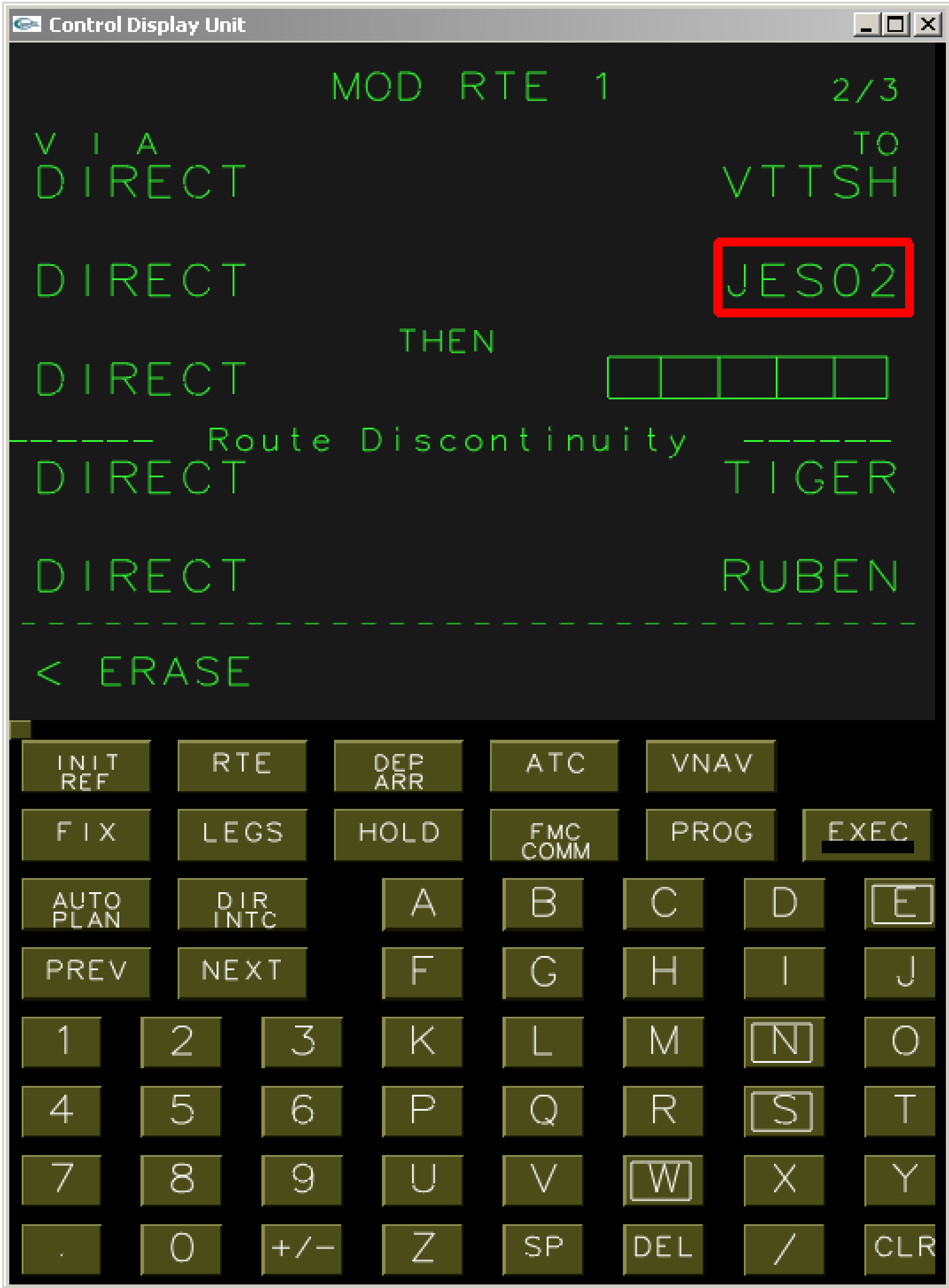


Figure 64 - Pilot created Place/Bearing Distance waypoint JES01 (circled in red) and route discontinuity

Multiple waypoints created using the same reference Navaid will have FMC assigned numbers in the sequence of waypoints created. Example: If PPA01 already exists and you wish to create another waypoint from PPA bearing 210 at a distance of 8 miles, then type ‘PPA210/08’ into the scratchpad and up-select to the desired screen region. The FMC will create the waypoint PPA02 and compute the latitude and longitude automatically.

3.1.2 Creating Waypoints by Latitude/Longitude:

You can create a fix by entering the latitude and longitude into the scratchpad and up-selecting to the desired position. This can be done by entering the name of the waypoint along with the coordinates as one word in the scratchpad and up-selecting it to the desired location.

Waypoints entered as latitudes and longitudes are displayed in a 15 character format up to a tenth of a decimal without spaces. Leading zeroes must be entered.

Example: If you wish to create a waypoint by simply specifying latitude (N01°26.5”) and longitude (W003°12.8”), then type the following into the scratchpad ‘N0126.5W00312.8’ (Figure 65).

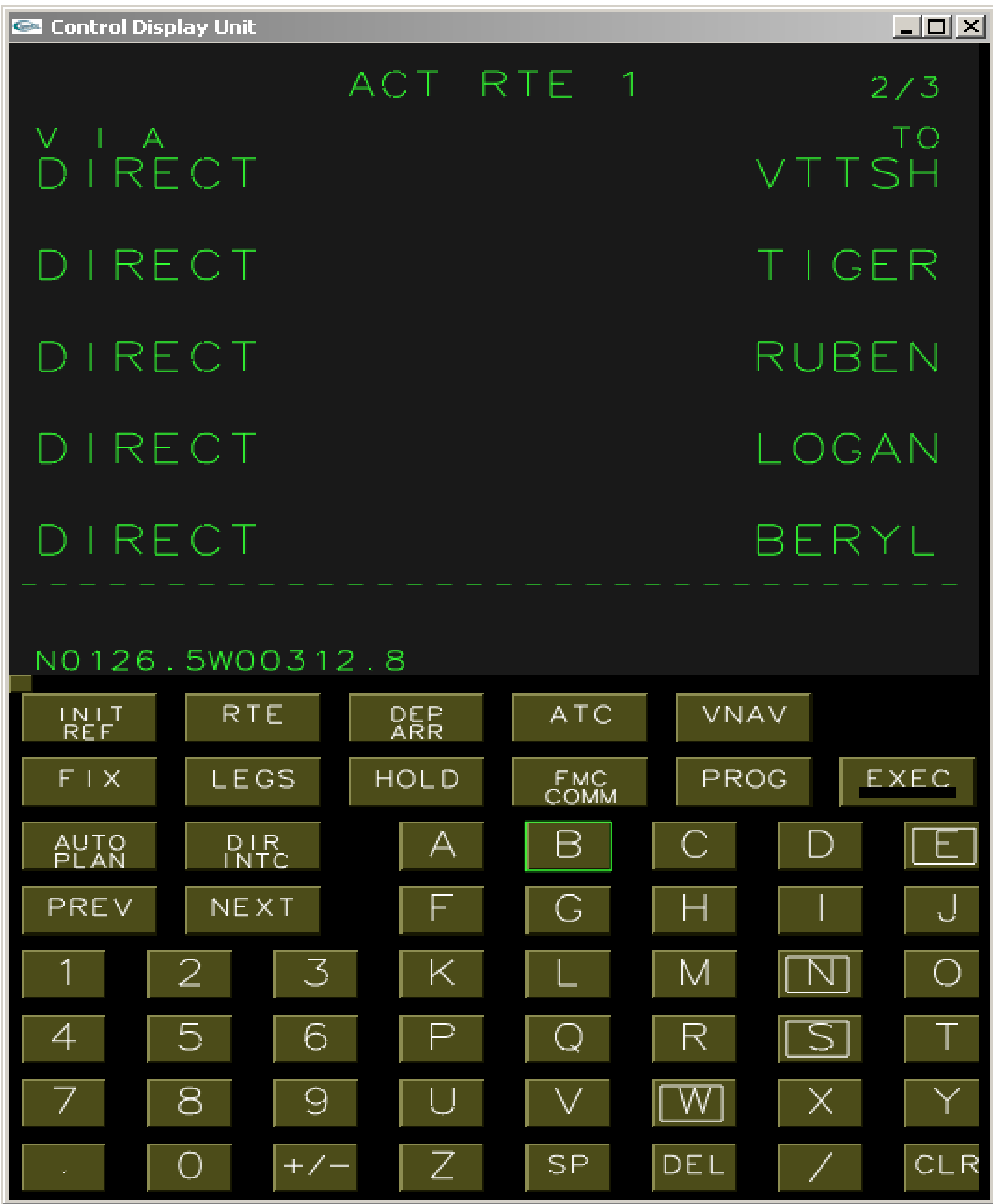


Figure 65 - Creating Waypoints by Latitude/Longitude

Entering this string into the desired screen region causes the waypoint to be created and added to the existing plan with a route discontinuity after. The route discontinuity needs to be resolved before any further planning takes place.). This will be displayed as N01W003 in the RTE and Legs Page (Figure 66).

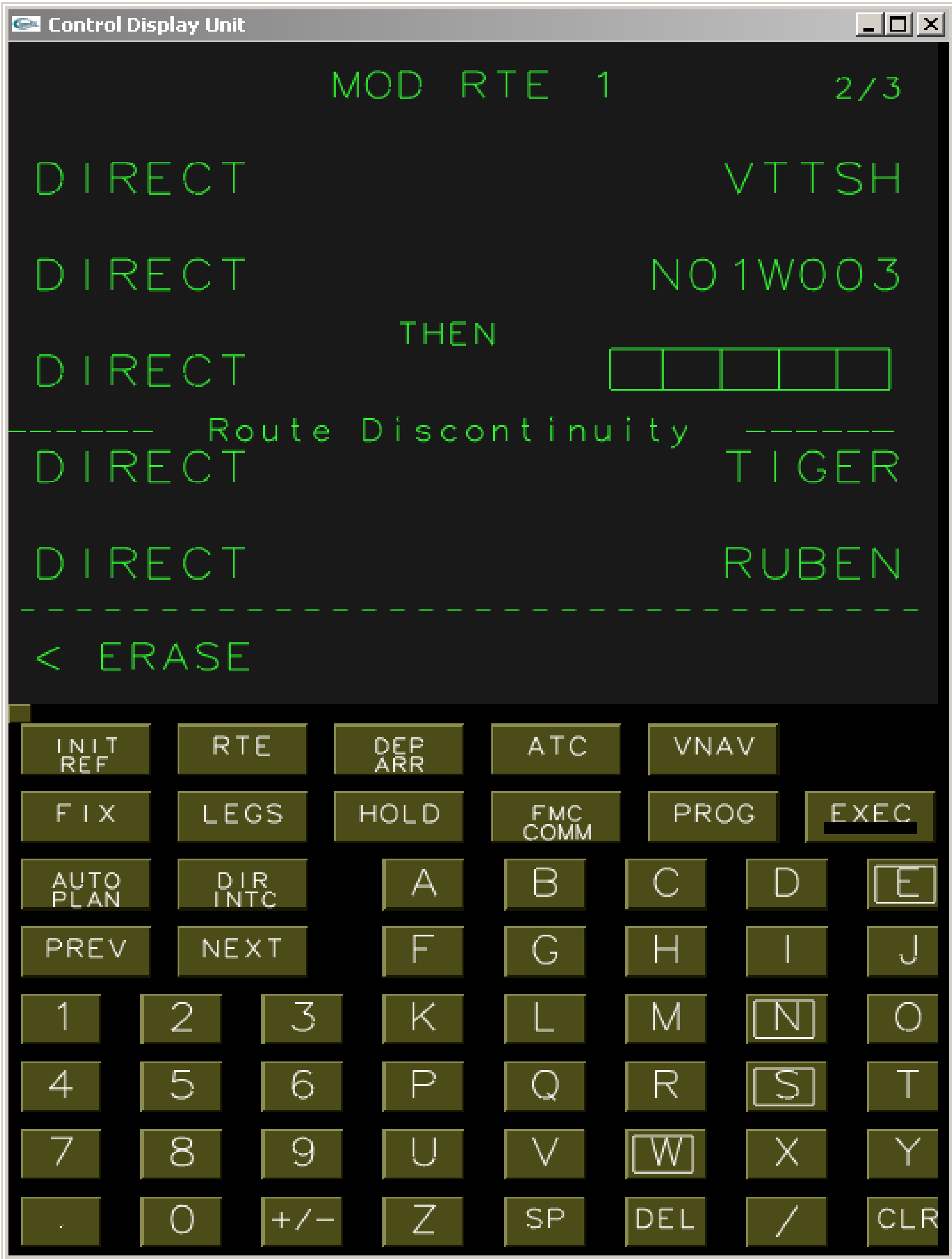


Figure 66 - Pilot created waypoint by latitude/longitude and route discontinuity

3.2 Adding a Waypoint from the FMS database:

Waypoints can be entered into your flight plan, if they exist in the FMS database, simply by entering the five-letter identifier for the waypoint into the scratchpad and up-selecting it to the desired screen region.

Example: You have looked at your en-route chart and seen that waypoint MACEY is close to a point you would to get to and would like update your plan to fly to MACEY. Enter the five-letter identifier MACEY in the scratchpad and up-select to the desired point in the plan. The waypoint MACEY will show up on the RTE or LEGS page followed by a ROUTE DISCONTINUITY (Figure 67).

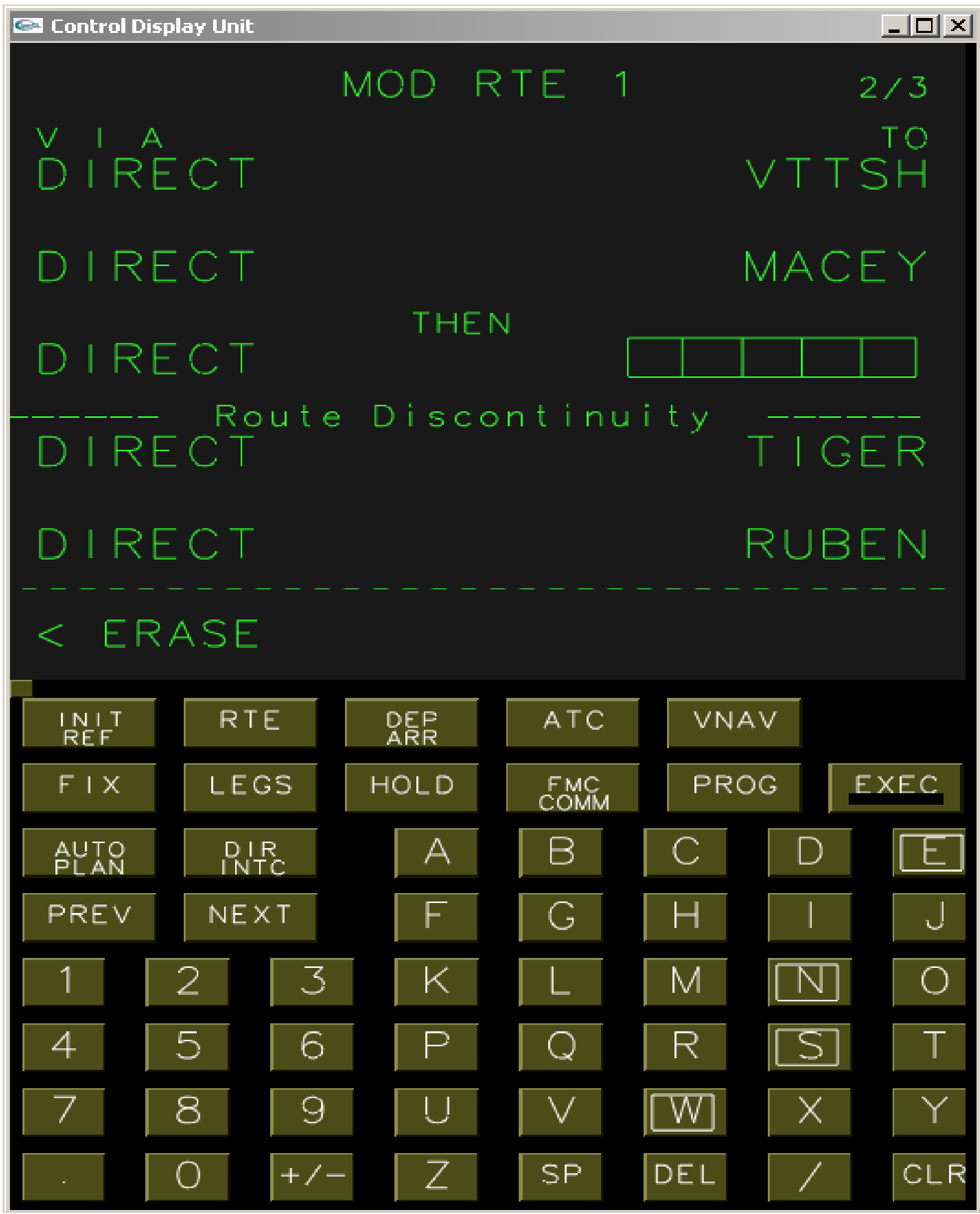


Figure 67 - Inserting a waypoint/fix from the FMC database

3.3 Entering Altitude and Speed Constraints for User Defined Waypoints

When a waypoint created or added from the FMS database, it creates only a latitude and longitude. Speed and altitude parameters are usually not associated with it as these are characteristic of the route being flown. When you do create/add a fix, the computer interpolates a speed and altitude between the waypoint previous to and after the pilot defined waypoint and assigns these parameters to the pilot defined waypoint. The rightmost column on the LEGS page will now show the interpolated values of speed and altitude for that waypoint.

These values are displayed in a distinctly smaller font size than the non pilot defined waypoints. This is to alert the pilot that he/she has entered a waypoint and he/she may change it if desired. You can create these constraints by entering the speed and altitude separated by a '/' (forward slash) as one word into the scratchpad and then up-selecting it to the desired screen region. Once these values are changed and the changes confirmed, the new values of speed and altitude are treated as non pilot defined and displayed in regular sized font.

Example: You have just added waypoint FLCNS from the FMS database. The speed/altitude column shows you the interpolated values of speed and altitude (Figure 68). Enter the speed/altitude directed by ATC or as desired and then up-select (Figure 69).

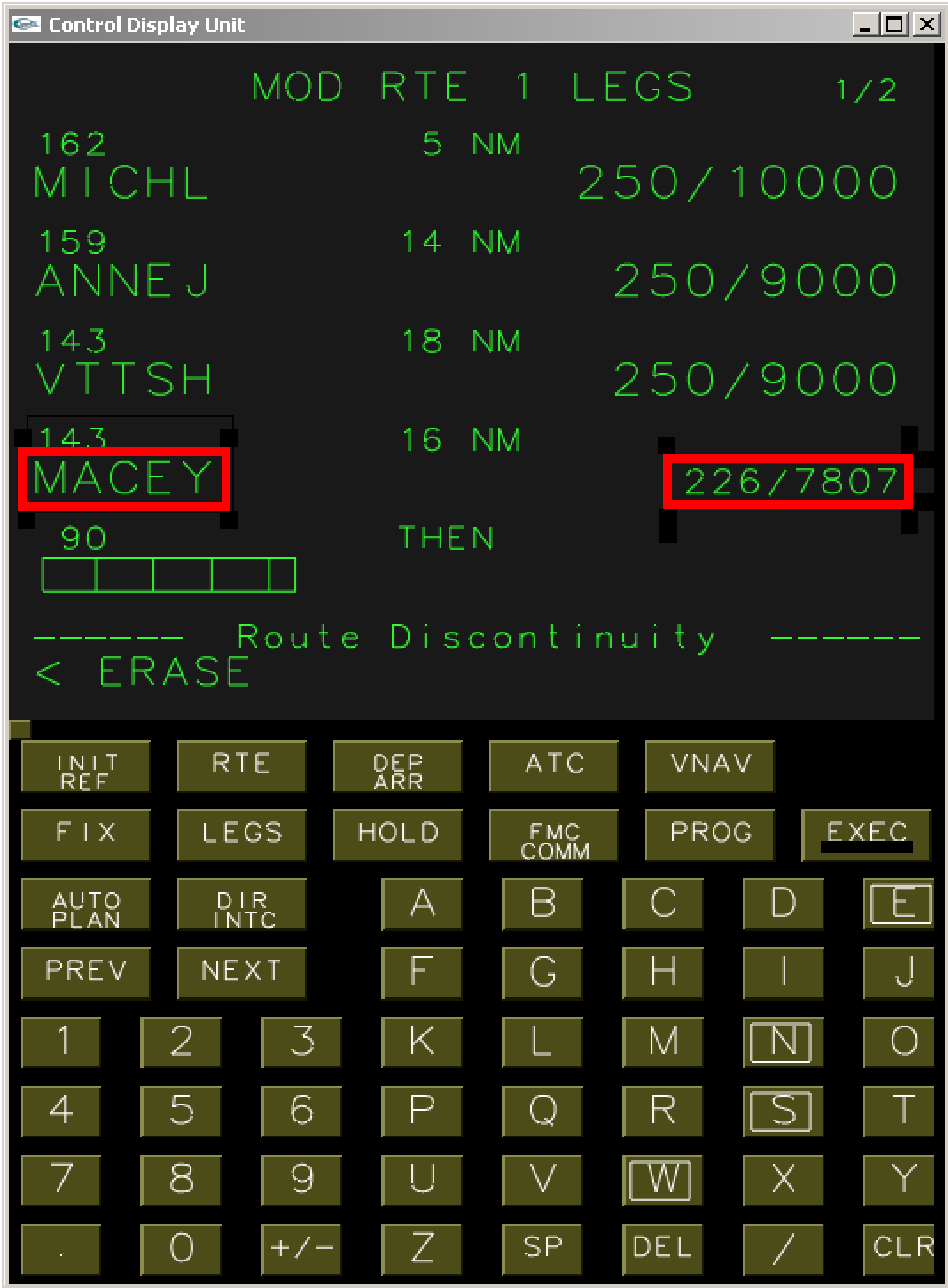


Figure 68 - Pilot added waypoint from FMC database showing interpolated speed and altitude

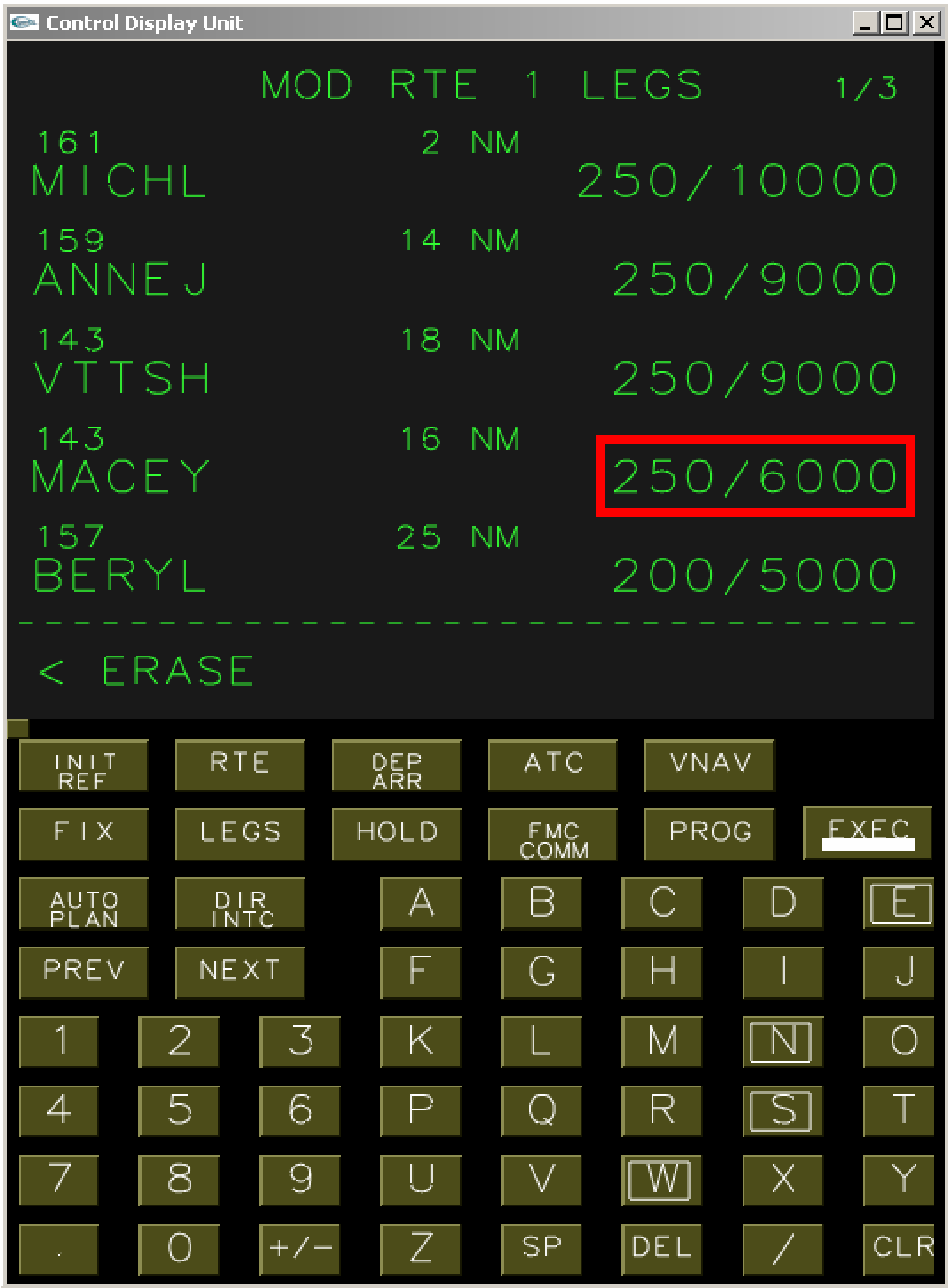


Figure 69 - User Entered speed/altitude constraints

Training Run #1: Replanning in a non-nominal condition

Welcome to Shannon International Airport. In this training run you will learn how to fly our simulator using each of the types of automation in a non-nominal situation. The actual simulation runs for data acquisition will not begin until you have given the signal that you are comfortable with the system. This tutorial flight will be an example of a non-nominal situation so that you can also experience the type of scenarios that we'll be asking you to fly during the data runs.

Here is the en-route chart for the Shannon Grove area, STAR chart for Shannon International Airport, and the approach plates for RW29L.

ATC at Shannon has communicated to you that there is very light traffic around you and that you have been cleared to take any route of your choice to the destination. You did not anticipate before that they would want you to land on RW29L, but that's you have just been cleared for. You are currently at:

- An altitude of 17000 feet.
- At a heading of 190^o
- At a speed of 330 knots.
- At a distance of 30 miles from VOR GOLDS (117.3 GLD)

Please communicate with your F/O about your flight plan throughout, so that he can communicate with ATC. He will also be performing all system monitoring and checklists, so that you can focus on planning and flying your route.

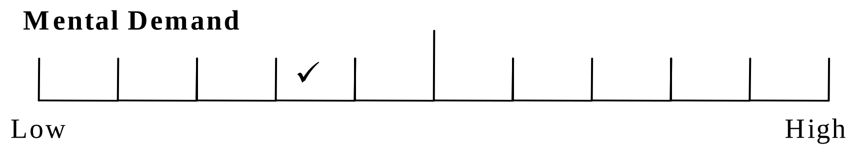
We'll start with flying the aircraft through the MCP. Once you are comfortable with that, then we'll try the CDU, CDU+, and CDU++.

At the end of run, we'll ask you to fill out an end-of-run questionnaire that pertains to the autoflight system used for the run. Please try filling it out now in case you have any questions about it, and to review the four autoflight systems that you have just used.

Part of each questionnaire will be a quick survey regarding the workload you experienced during the run. Workload is split up among Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration Level. Please note that all scales go continuously from Low to High *except* Performance, which goes from Good to Poor. Please place a '✓' (check mark) **anywhere** along the scale like the one shown below:

Example:

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



Training Run #2: Replanning in an emergency condition

Welcome to Shannon International Airport. In this tutorial you will learn how to fly our simulator using each of the types of automation that we'll be trying out in the data runs later today. The actual simulation runs for data acquisition will not begin until you have given the signal that you are comfortable with the system.

In the middle of the flight you suddenly notice that one of the alarms systems on the aircraft have gone off indicating loss of hydraulic pressure in one hydraulic system (of three) in the aircraft. The damage has been assessed and found to be harmless in terms of aircraft stability and performance. You have already performed all emergency procedures and declared an emergency. Now you need to bring the aircraft in for a landing as soon as possible. Your F/O will monitor the systems on the way down, so your task is to plan a safe route and fly the aircraft. RW29L is the only available runway. You are currently at:

- An altitude of 17000 feet.
- At a heading of 190^o
- At a speed of 330 knots.
- At a distance of 30 miles from VOR GOLDS (117.3 GLD)

Use this as a starting point for your plan.

APPENDIX B

SUBJECTIVE QUESTIONNAIRES

APPENDIX B.1

End Of Run Questionnaires

MCP

Question 1: Outline your strategy for replanning the flight. What factors did you consider important?

____

____

____

Question 2: In what ways (if any) did using the MCP help you replan your flight?

____

____

____

Question 3: What would you have done differently if you could use any type of autoflight system (including none) ?

____

____

____

Question 4: How would you rate the ease of planning in this run (with the MCP) compared to planning using the autoflight system in question 3?

More Difficult	**Slightly More Difficult**	**No Difference**	**Slightly Easier**	**Easier**

CDU

Question 1: Outline your strategy for replanning the flight. What factors did you consider important?

____

____

____

Question 2: In what ways (if any) did using the CDU help you replan your flight?

____

____

____

Question 3: What would you have done differently if you could use any type of autoflight system (including none) ?

____

____

____

Question 4: How would you rate the ease of planning in this run (with the CDU) compared to planning using the autoflight system in question 3?

More Difficult	**Slightly More Difficult**	**No Difference**	**Slightly Easier**	**Easier**

CDU+

Question 1: Outline your strategy for replanning the flight. What factors did you consider important?

____

____

____

Question 2: How much did you rely on the Autoplan?

____

____

____

Question 3: In what ways (if any) did using the CDU+ help you replan your flight?

____

____

____

Question 4: What would you have done differently if you could use any type of autoflight system (including none)?

____

____

____

Question 5: How would you rate the ease of planning in this run (with CDU+ with the optimal Autoplan) compared to planning using the autoflight system in question 4?

More Difficult	**Slightly More Difficult**	**No Difference**	**Slightly Easier**	**Easier**

CDU++

Question 1: Outline your strategy for replanning the flight. What factors did you consider important?

____

____

____

Question 2: How much did you rely on the Autoplan? If you decided to override or modify the automatically generated plan, what was it about the Autoplan you did not like?

____

____

____

____

Question 3: In what ways (if any) did using the CDU++ help you replan your flight?

____

____

____

Question 4: What would you have done differently if you could use any type of autoflight system (including none) ?

____

____

____

Question 5: How would you rate the ease of planning in this run (with the automatically loaded Autoplan) compared to planning using the autoflight system in question 4?

More Difficult	**Slightly More Difficult**	**No Difference**	**Slightly Easier**	**Easier**

NASA TLX (Workload) Sheet

Rating Scale Definitions

Mental Demand: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or

Mental Demand

Low High

demanding, simple or complex, exacting or forgiving?

Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Physical Demand

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? Was the pace slow and leisurely or rapid and

Temporal Demand

Low High

frantic?

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?

Performance

Good Poor

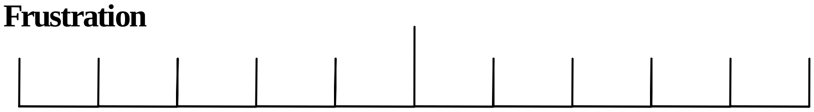
Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Effort

Low High

Frustration Level: How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Frustration



Low High

APPENDIX B.2

End Of Experiment Questionnaire

Background Questions

Total Hours ________________________________

Hours in Glass (CRT) ______________________________________

Aircraft Current in ______________________________________

Hours in Current Type ______________________________________

Captain or Flight Officer? ______________________________________

Base Airport ______________________________________

Initial Training (Civilian or Military)?________________________________

Prior Glass Aircraft ____

Do you have any experience with flight planning software? Yes________, No ________

If yes, was it: On-Board Based?__________ Ground Operations Based?___________

If so, what tool(s) have you used: _________________________________

Have you ever needed to replan a flight route during an emergency? Yes ____ No ____

If yes, please describe:

Cause of emergency: ____

____

Approximate time to landing:____

Approximate distance to landing: ____

Type of autoflight system used:____

____

____

How often do you need to replan your route due to non-nominal (but not emergency) conditions?
Please indicate your answer as a percentage (%) of flights.__________________________

What aspects of the autoflight system do you prefer to use in these conditions?

____

____

What factors influence your choice of how to use the autoflight system when re-planning a route?

____

____

____

QUESTIONS ABOUT IN-FLIGHT REPLANNING

In Non-Nominal Scenarios:

Under the given circumstances, did you feel comfortable planning your own route or would you rather have received vectors from ATC? Why?

____

____

____

____

What was your strategy in choosing the route that you planned and implemented?

____

____

What factors did you consider when you were planning a reroute?

<u>In Emergency Scenarios:</u>

Under the given circumstances, did you feel comfortable planning your own route or would you rather have received vectors from ATC? Why?

What was your strategy in choosing the route that you planned and implemented?

What factors did you consider when you were planning a reroute?

____

____

____

____

QUESTIONS ABOUT IN FLIGHT REPLANNING SYSTEMS

Which type of autoflight system interface were you most comfortable with? Why?

____

____

____

____

How would you describe the performance of the Autoplan? Please elaborate.

____

____

____

____

In each of the following scenarios, what would the FMS need to be able to do for you to feel comfortable following an automatically generated plan? Why?

Non-Nominal:____

____

____

Emergency: ____

____

____

Any additional comments about the role of autoflight systems in in-flight replanning?

____

____

____

APPENDIX B.3

Informed Consent Form

Subject #:___________

School of Industrial and Systems Engineering
Georgia Institute of Technology

Partially Sponsored by the NASA Langley Research Center Grant
"Intelligent Pilot Aids For Flight Re-Planning In Emergencies"

HUMAN SUBJECT CONSENT

1. **Title of project: FLIGHT DECK AUTOMATION AND IN-FLIGHT RE-PLANNING**
2. **Principal Investigator**: Dr. Amy Pritchett, 404-894-0199, amy.pritchett@isye.gatech.edu
   Graduate Research Assistant: Vittesh Kalambi, 404-226-7863, vkalambi@isye.gatech.edu
3. **Introduction**: You are being asked to participate in a research project investigating cockpit aids that assist in in-flight replanning and the usefulness/effectiveness of these aids in emergency and non-nominal situations. If you volunteer, you will be among about 16 pilots with experience in "glass cockpit" aircraft. Given the length of the experiment, you are welcome to take a break between runs.
4. **Procedures**: You will be operating an aircraft simulator set up on 2 networked desktop personal computers. You will be using a graphic user interface with a mouse as an input device for in-flight replanning. You will have a briefing session at the beginning, then you will undergo training runs until you are comfortable using the simulator setup. You will then fly 9 data runs with a questionnaire to be filled out at the end of each run and subsequently a final questionnaire at the end of the experiment. An experimenter will act as your first officer (F/O). He will not assist you in any way with in-flight replanning. However, please communicate your intentions to him as if he will then transmit them to air traffic control. Data will be collected on basic aircraft parameters (e.g. position, speed, control inputs, etc.) and changes made to flight plan throughout the runs. The experiment will be conducted in Room 349 at 755 Ferst Drive on the Georgia Institute of Technology campus in Atlanta, GA. The experiment will be conducted within one day session and is expected to last approximately 6 hours plus breaks.

5. **Foreseeable Risks or Discomforts**: This study is considered to have minimal risk, which is risk that is not greater than those encountered in normal daily life. In particular, this study involves the use of a desktop computer, and will carry risks associated with normal computer use, including, but not limited to, eyestrain and repetitive motion injury.

6. Benefits: This study provides no direct benefit to you other than experience in in-flight replanning in a variety of scenarios. The study is intended to evaluate automation that would help in flight replanning, to gain more insight into the planning processes used by pilots and situation awareness of pilots, and to identify required cockpit systems, displays, and procedures.

7. Compensation: You will receive monetary remuneration for the experiment of $300 at its completion. Due to the nature of the experiment, we can only use fully completed data sets in our analysis, and thus can only compensate subjects who have completed all 9 data runs.

8. Costs: The only cost to you will be the cost of transportation to the experiment venue.

9. Confidentiality: All information concerning you will be kept private and confidential. Any videotapes will only be used for the Georgia Tech experimenters to review your actions in re- replanning your flight, and to examine for unexpected events during runs that may impact the our planning data analysis; the videotapes will not be released to anyone else. All raw data from this experiment, including videotapes, will be stored in a locked facility on the Georgia Tech campus. Once the analysis and documentation of this experiment are complete, the videotapes will be destroyed; electronic and paper stores of results will be archived in a locked facility within the principal investigator's Georgia Tech office or laboratory. Personal information about you will not be published or made available to any third party in any form whatsoever. If information about you is published, it will be written in a way that you cannot be recognized and may include, but not be limited to, categorizations of piloting experience which will be a common statistic with other pilots (e.g. number of hours in a glass cockpit, number of years as F/O and Captain etc.). However, research records, like hospital charts, may be obtained by court order. Only data gathered from a completed experiment will be used for the purposes of analysis. To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology Institute Review Board (IRB) will review study records.

10. Injury/Adverse Reactions: Reports of injury or reaction should be made to the Principal : Investigator or to the Graduate Research Assistant assisting with this research. Neither the Georgia Institute of Technology nor the principal investigator has made provision for payment of costs associated with any injury resulting from participation in this study.

11. Contact Person: If you have questions about the research, call or write Dr. Amy Pritchett at: (404) 894-0199, School of Industrial and Systems Engineering, 755 Ferst Ave., Atlanta, GA 30332-0205.

12. Voluntary Participation/Withdrawal: You are free to withdraw your participation at any time throughout the experiment without consequence. If you choose to do so, you may leave and any data collected during the experiment resulting from your participation will be expunged.

You have rights as a research volunteer. Taking part in this study is completely voluntary. If you do not take part, there will be no penalty. You may stop taking part in this study at any time with no penalty. If you have any questions about your rights as a research volunteer, call or write:

Alice Basler
Office of Research Compliance
Georgia Institute of Technology
Atlanta, GA 30332-0420
Voice (404) 894-6944
Fax (404) 385-2081

A signed copy of this form will be given to you. Your signature indicates that the researchers have answered all of your questions to your satisfaction, and that you consent to volunteer for this study.

Subject's Signature: ___________________________

Date:_______________________________

Subject's Name: ______________________________

Investigator's Signature: ________________________

Date: _______________________________

Investigator's Name: ___________________________

APPROVED Consent Form Approved by Georgia Tech IRB: April 7, 2004 - April 6, 2005

APPENDIX B.4

Scenario Briefings

Atlantic Briefing

You are heading along the Townhouse One Arrival at Atlantic International Airport and are 13 miles past VOR CLR[114.0 CLR], when you receive word from ATC that there is severe turbulence directly in your path ahead and spanning the area shown in your enroute chart.

The destination is runway RW29L at Atlantic International. Your current state is:

- heading 347°
- 13000 ft altitude (-1200 fpm)
- 290 IAS

Start your replanning from this point.

Bruin Briefing

You were heading along the Braddock Arrival, when your alarm systems detected a fire in the cargo hold. The fire has been put out by the flight attendants, but the extent of the damage is not clear. You are 52 miles past VOR BRN[114.0 BRN], by the time you decide to declare an emergency and all standard procedures and checklists have been completed.

The destination is runway RW18R at Bruin International Airport and your current state is:

- heading 34°
- 9000 ft altitude (-1200 fpm)
- 250 IAS

Start your replanning from this point.

Centennial Briefing

You were heading along the Centennial Arrival, when your alarm systems detected a loss of hydraulic pressure in one of three hydraulic systems. This loss of pressure is not severe enough to affect the aircraft, but serious enough to for you to declare an emergency. You are 48 miles past VOR Billy[114.0 BLY], by the time you decide to declare the emergency and all standard procedures and checklists have been completed.

The destination is runway RW18L at Centennial International Airport and your current state is:

- heading 10°
- 9000 ft altitude (-1200 fpm)
- 250 IAS

Start your replanning from this point.

Flyer Briefing

You were heading along the Elk Arrival, when your alarm systems detected a problem with the fuel filter. The severity of the problem is unknown and serious enough for you to declare an emergency. You are 42 miles past VOR Clint[114.0 CLT], by the time you decide to declare the emergency and all standard procedures and checklists have been completed.

The destination is runway RW04L at Flyer International Airport and your current state is:
- heading 197°
- 10000 ft altitude (-1200 fpm)
- 250 IAS

Start your replanning from this point.

Home Park Briefing

You were heading along the Kroger Arrival, when you receive word from the head flight attendant that there is a medical emergency in the cabin. The severity of the patients medical is serious enough to for you to declare an emergency. You are 50 miles past VOR Gold[114.0 GLD], by the time you decide to declare the emergency and all standard procedures and checklists have been completed.

The destination is runway RW31R at HomePark International Airport and your current state is:
- heading 130°
- 10000 ft altitude (-1200 fpm)
- 250 IAS

Start your replanning from this point.

Springfield Briefing

You were heading along the Shotgun Arrival, when you receive a communiqué from ATC that Air Force One has had to make an unexpected departure from a nearby military base. As a result a certain area directly in your path has been declared a restricted airspace, which is shown as the shaded area on your enroute chart. At this point you are 20 miles past VOR Court[114.0 CRT].

The destination is runway RW01R at Springfield International Airport and your current state is:
- heading 170°
- 11000 ft altitude (-1200 fpm)
- 270 IAS

Start your replanning from this point.

Whoville Briefing

You were heading along the Sword Arrival, when you receive a communiqué from ATC that the ILS system on your original destination runway, RW04L, has malfunctioned. You decide to reroute to RW18R. At this point you are 50 miles past VOR Welsh[114.0 WSH] and have already entered your destination runway into the flight management computer upon receiving the communiqué

The destination is runway RW18R at Whoville International Airport and your current state is:

- heading 25°
- 9000 ft altitude (-1200 fpm)
- 250 IAS

Start your replanning from this point.

Yankosky Briefing

You have just passed CNCTC and heading 060^o, when you receive a communiqué from ATC that your original destination runway, RW06L, has a number of airplanes backed up, waiting to land. You have been told to reroute to RW25R. At this point you are 20 miles from VOR Stats[116.8 STS].

The destination is runway RW25R at Yankosky Island International Airport and your current state is:

- heading 71°
- 9000 ft altitude (-1200 fpm)
- 250 IAS

Start your replanning from this point.

Shannon Grove (E) Briefing

You were heading along the Jacket One Arrival, when you receive word from the head flight attendant that there is a medical emergency in the cabin. The severity of the patients medical is serious enough to for you to declare an emergency. You are 50 miles past VOR Shannon[116.8 SHN], by the time you decide to declare the emergency and all standard procedures and checklists have been completed.

The destination is runway RW11R at Shannon Grove International Airport and your current state is:

- heading 197°
- 10000 ft altitude (-1200 fpm)
- 250 IAS

Start your replanning from this point.

Shannon Grove (NN) Briefing

You are heading along the Jacket One Arrival at Shannon Grove International Airport and are 50 miles past VOR Shannon[114.0 SHN], when you receive word that there is severe turbulence directly in your path ahead and spanning the area shown in your en-route chart.

The destination is runway RW11R at Shannon Grove International Airport and your current state is:

- heading 197°
- 10000 ft altitude (-1200 fpm)
- 250 IAS

Start your replanning from this point.

APPENDIX C

Summary Table of Results

APPENDIX C.1

Objective Measures

Table 4 - Summary of Objective Measures for Primary Experiment

Measure	Scenario Type / Type of Automation	Non Nominal MCP	Non Nominal CDU	Non Nominal CDU+	Non Nominal CDU++	Emergency MCP	Emergency CDU	Emergency CDU+	Emergency CDU++
Time of Flight (minutes)	*Mean*	4.3	3.8	2.6	4.1	2.0	2.0	2.4	3.2
	Std. Dev.	17.7	18.4	17.0	19.1	13.6	14.3	14.9	14.3
Length of Run (miles)	*Mean*	20.3	16.2	9.7	16.5	8.2	9.6	11.2	9.9
	Std. Dev.	76.6	80.7	73.3	86.1	61.4	63.9	66.3	62.1
Time to First Modification (minutes)	*Mean*	0.7	0.9	0.6	0.9	0.7	0.6	0.6	0.5
	Std. Dev.	1.1	1.2	1.2	1.5	0.7	0.7	1.1	0.9
Time to First Execution of Change (minutes)	*Mean*	0.8	0.9	0.7	0.9	0.7	0.6	0.9	0.6
	Std. Dev.	1.4	1.5	1.4	1.6	0.9	0.8	1.4	0.9
Frequency of Update	*Mean*		3.7	4.3	4.6		3.0	3.4	4.1
	Std. Dev.		10.3	9.9	9.5		8.7	9.5	9.8
Number of Speed Changes	*Mean*	2.3	3.1	5.1	3.9	2.3	3.2	2.5	3.4
	Std. Dev.	5.4	6.9	7.5	6.9	5.3	6.4	6.4	6.6
Number of Altitude Changes	*Mean*	2.4	3.7	5.1	3.9	1.5	3.4	2.7	3.4
	Std. Dev.	3.5	7.3	7.6	7.2	2.2	6.7	6.6	6.9
Deviation From Baseline Plan (minutes)	*Mean*	3.0	4.5	3.2	4.6	1.9	4.0	3.9	3.9
	Std. Dev.	6.6	6.2	5.6	6.1	15.0	13.4	8.6	9.3
Deviation From Baseline Plan (miles)	*Mean*	13.2	15.4	8.2	12.2	9.3	12.2	12.0	12.9
	Std. Dev.	14.4	10.9	10.2	7.6	36.6	31.7	15.1	19.8

Table 5 - Summary of Objective Measures for Faulty Autoplan Scenario

Measure	Non Nominal	Emergency
Time of Flight (minutes)	13.245	13.493
Length of Run (miles)	56.180	57.560
Alt Route Activated	Yes - 2 No - 6	Yes - 3 No - 5
Time to Activate Alternate Route (minutes)	2.131	0.483
Time to Modify Alternate Route (minutes)	2.489	0.799
Time to First Modification (minutes)	1.479	0.580
Time to First Execution of Change (minutes)	1.544	0.854
Frequency of Update	8	10
Number of Speed Changes	6	7
Number of Altitude Changes	6	7
Deviation From Baseline Plan (minutes)	7.027	10.295
Deviation from Baseline Plan (miles)	10.562	25.819

Table 6 - Pilot Preferences of Autoflight System Per Scenario

	Pilot Preference of Automation For Each Scenario Type								
	MCP			CDU			MCP + CDU		
	NN	E	Total	NN	E	Total	NN	E	Total
MCP	6	5	11	7	8	15	3	3	6
CDU	9	11	20	5	3	8	2	2	4
CDU+	8	6	14	8	7	15	2	2	4
CDU++	7	5	12	7	9	16	3	1	4

APPENDIX C.2

Pilot Responses to End of Run Questionnaires

Table 7 - Pilot Responses to End of Run Questionnaires - I

Pilot	Scenario	TOA used	Outline your strategy for replanning the flight. What factors did you consider important?	How much did you rely on the Autoplan? If you decided to override or modify the automatically generated plan, what about the autoplan did you not want to occur?	In what ways, if any, did using this type of automation help you replan your flight?	What would you have done differently if you were not required to use this type of automation? (As part of your answer please describe what autoflight system you would have used including none).	How would you rate the ease of planning in this run compared to planning using the autoflight system described in the previous question?
1	Weather - NN	1	Avoid the weather.	N/A	HDG SEL to line up for known waypoints. Green arc to assist with vertical profile.	Nothing. Would have used MCP with HDG SEL for glideslope/LOC intercept.	No difference.
2	Weather - NN	4	Weather avoidance. Fewest keystrokes to program. Shortest time.	I used the autoplan.	It allowed a reroute to be entered with very few keystrokes.	HDG SEL to avoid the weather.	Slightly Easier.
3	Weather - NN	3	Circumnavigate weather area. Route planning based on shortest time to runway.	For basic primary route. Modified route after execution.	Autoplan.	Used HDG SEL to circumnavigate weather area if CDU was unavailable.	Slightly Easier.
4	Weather - NN	2	Weather avoidance. Direct route to runway extended centerline.	N/A	Entered waypoints displayed on CDU, charts and ND for weather avoidance.	HDG SEL around weather toward extended centerline. FLCH and V/S for altitude and speed control then approach for ILS.	Slightly more difficult.
5	Weather - NN	3	Finding a position relative to the weather and mapping an efficient route around it.	Zero. The route was dictated by weather.	Zero.	Would have used radar return along with HDG modes to navigate, ging direct to the marker.	More difficult.
6	Weather - NN	2	Wind. Shortest route around weather.	N/A	Had to type in waypoints. A little more work.	I would have done the same thing.	Slightly easier.
7	Weather - NN	1	Needed to stay clear of weather. No real time constraint, go either east or west of weather.	N/A	Green arc helps descent planning, trend vectors helps with turns. MCP didn't plan much else.	Would have used MCP to navigate to a waypoint or OM to intercept.	No difference.
8	Weather - NN	4	Shortest distance to runway, smooth transition to final (not 90 deg turn to final). If we had wind, that would entered into decision.	Completely.	Made life very easy to replan. Coordination with ATC would be vital to actual implementation.	Nothing different.	Easier.
9	Weather - NN	2	Avoid weather.	N/A	Used FMS legs page to input new route.	HDG SEL to waypoints I wanted to navigate to. V/S for altitude profile management	Slightly more difficult.
10	Weather - NN	1	Avoiding weather, quick routing, straight in to runway.	N/A	It didn't.	I would have preferred the CDU. It provides more information and requires less monitoring at specific times - turns over fixes for example.	More difficult.
11	Weather - NN	4	Avoid the weather. Find route to accomplish that.	Very much. Gave me a good route around the weather.	It gave me a very good initial route to avoid the weather. I refined it a little to further cut down distance.	Would have planned a route similar to Autoplan using the CDU.	Easier.
12	Weather - NN	3	Stay clear of weather on a stable path.	It was very convenient, so I didn't have to build the entire route. I relied on it with some modifications.	It allowed me to modify route with several fewer steps.	I would probably have used autoplan for LNAV but changed airspeed and altitude with MCP.	No difference.
13	Weather - NN	4	Winds, weather, avoiding turbulence	Use autoplan only if it agrees with my own personal plan.	Provided a good alternate plan	Devise my own plan and input into CDU	Easier
14	Weather - NN	3	I considered prevailing winds, movement of weather system and fuel to decide on which route would be best.	I relied on autoplan to get me headed in the appropriate direction. I then asked for direct points downwind to expedite.	Was integral in helping me plan my flight.	used CDU to manually input waypoints and speed/altitude constraints	Slightly easier
15	Weather - NN	2	Location of airport, ease of lining up with runway.	N/A	Visually let me bypass the weather.	A combination of MCP and CDU	No difference.
16	Weather - NN	1	Weather avoidance. Chose to turn right towards extended runway centerline.	N/A	Having all of the stations and fixes displayed was a big help.	Would have used CDU to proceed abeam of outer marker and used VNAV for descent.	Slightly more difficult.
1	Restr. Air - NN	2	Avoiding restricted area. Extra distance was added due to this, so then minimize route and maximize speed.	N/A	It helped in initially clearing the restricted area.	Again, MCP via HDG SEL for final inetrcept. It makes for a smoother approach.	Slightly Easier.
2	Restr. Air - NN	1	Restricted Airspace avoidance.	N/A	Allowed me to set speed and descent rates.	I would not have done anything different.	Slightly Easier.
3	Restr. Air - NN	4	Avoid the restricted area.	Autoplan was good. However it took a longer route from the right side of the restricted airspace. I took the shorter route from left of the weather.	Generated an alternative plan. Decided on a different one, however.	HDG SEL to intercept final approach course, maybe.	No difference.
4	Restr. Air - NN	3	Avoiding prohibited airspace, planning expeditious route to runway extended centerline.	Used autoplan for initial suggestion, then shortened route for expeditious arrival.	Used autoplan and RTE 1.	HDG SEL for lateral navigation and V/S and FLCH for vertical navigation.	Slightly more difficult.
5	Restr. Air - NN	1	Avoid restricted airspace while making an efficient approach.	N/A	MCP is an efficient, low workload way to fly an aircraft while using map on ND for lateral awareness.	Nothing different. This is optimal way to do it.	No difference.
6	Restr. Air - NN	4	Not penetrating the restricted area.	Used the autoplan. Cut off the initial point and went a more direct route around the restricted area.	Helped a lot.	Would have used the autoplan in this case.	Slightly easier.
7	Restr. Air - NN	3	Had to avoid prohibited area and then just chose what appeared to be the shortest route.	None. Autoplan had me going on a longer route, so I built my own.	Not much in this case.	I ended up building my own route. I would have used HDG SEL toward first point until I had the route complete.	No difference.
8	Restr. Air - NN	2	Figure out where I was and where I wanted to go, then did it. Slowed to give myself back up time.	N/A	Made it easy to visualize arrival.	Nothing	Slightly easier.
9	Restr. Air - NN	4	Required to avoid restricted airspace. I picked shortest deviation to airport considering landing direction at airport.	80% autoplan. Did not want to go to first waypoint (as it was restricted), so I overrode it.	After modifying 1st waypoint, gave me a good autoplan, however, I did tweak it a little to reduce distance and time.	I would have either (1) HDG SEL my route or (2) manually input waypoints that avoided restricted airspace.	Easier.
10	Restr. Air - NN	3	Quicker route to runway, avoid restricted area.	I chose a different route from the autoplan. I picked a route that appeared shorter.	Since I chose a different route, not much , but it was to know I had a back up plan.	What I did - manually input waypoints.	No difference.
11	Restr. Air - NN	2	Avoid restricted area. Minimum flight distance to approach.	N/A	Allowed me to go direct to points outside of approach.	Nothing. Would have used the CDU.	Easier.
12	Restr. Air - NN	1	Avoid restricted airspace. Minimize time aloft and distance.	N/A	It allowed for quick changes to flight parameters.	I would have programmed flight route and relied on computer generated altitude and airspeed for planning.	Slightly more difficult.
13	Restr. Air - NN	3	Avoiding rstricted area with minimum delay.	Used it and then modified it for a more expeditious arrival.	Provided a good, quick alternate routing.	Would have to refer to charts and find a fix abeam of the outer marker for a base turn.	Easier.
14	Restr. Air - NN	2	Restricted airspace, minimize time and distance due to fuel considerations.	N/A	it just allowed me to input my flight plan manually.	I would have manually flown around the weather using my mcp.	Slightly more difficult.
15	Restr. Air - NN	1	Avoid restricted area while minimizing flight time.	N/A	None	A combination of MCP/CDU tp provide a coupled routing, reduce workload and increase situational awareness.	Slightly more difficult.
16	Restr. Air - NN	4	Had to avoid restricted airspace. The distance was about the same in either direction, but the left side lined us up better with the approach.	Autoplan chose to go right, but I chose left.	Not very much at all.	I would have used CDU and handloaded the waypoints.	Slightly more difficult.

Table 8 - Pilot Responses to End of Run Questionnaires - II

Pilot	Scenario	TOA used	Outline your strategy for replanning the flight. What factors did you consider important?	How much did you rely on the Autoplan? If you decided to override or modify the automatically generated plan, what about the autoplan did you not want to occur?	In what ways, if any, did using this type of automation help you replan your flight?	What would you have done differently if you were not required to use this type of automation? (As part of your answer please describe what autoflight system you would have used including none).	How would you rate the ease of planning in this run compared to planning using the autoflight system described in the previous question?
1	RWY Closure - NN	3	Efficiency and economy for an nice approach. I had time to use the constraints for good airspeed and altitude management.	I took as it was initially and then modified it to cut corners laterally.	It allowed precise airspeed and altitude entries.	I would have used MCP HDG SEL to intercept final with a shallower intercept angle.	No Difference.
2	RWY Closure - NN	2	Short route. Fewest keystrokes.	N/A	Allowed me to enter fixes to the new runway.	Nothing.	Easier
3	RWY Closure - NN	1	Runway required by ATC. Shortest practical route. Turn radius(smooth transition to opposite side).	N/A	It really didn't help me plan the flight, it was just a mechanism to put the airplane where I wanted it to go.	CDU would have helped me to plan better. I could have very easily planned a route using available waypoints.	Slightly Easier.
4	RWY Closure - NN	4	Most direct route to new runway.	Used autoplan for initial route, then shortened to runway.	Used waypoints, charts and CDU to shorten the route.	HDG SEL toward runway extended centerline. FLCH and V/S for altitude and speed control then approach mode on intercept heading.	Slightly more difficult
5	RWY Closure - NN	4	Only factor was smooth, efficient (fuel economy) approach.	Autoplan did well. Reduced workload. Went direct to some fixes.	It provided a good efficient route with low workload.	Used ND for position awareness while using HDG modes to navigate.	Slightly more difficult
6	RWY Closure - NN	3	Getting in the correct runway.	Looked at it , then built my own.	didn't really use the "+" part.	Would have used the MCP with HDG SEL to get to final.	Slightly easier.
7	RWY Closure - NN	2	Had to navigate north of field. No time pressure. Wanted to be abeam airport at 3000' then fly a right downwind/base to intercept approach.	N/A	CDU had waypoints in database I could use to build turn points and profile to OM.	I would have used HDG SEL to drive to a point ~3 miles outside of OM. I would have used FLCH as well.	Slightly more difficult.
8	RWY Closure - NN	1	Simplicity, visual confirmation of a good route.	N/A	Kept me from handflying, reducing pilot workload.	Would have flown with CDU engaged to the points I had selected, further reducing workload.	More difficult.
9	RWY Closure - NN	1	HDG SEL to downwind, V/S for descent. Speed interventions.	N/A	Up until approach, I liked using HDG SEL, V/S to put aircraft where I wanted it.	Would have used legs page with altitude constraints for OM and approach.	Slightly more difficult.
10	RWY Closure - NN	4	A more direct route to OM.	Autoplan seemed like a better way to OM. Followed autoplan except for the first waypoint which was out of the way.	Much quicker, easy to view on ND.	I would have manually input waypoints, similar to autoplan's and flown that route	Easier.
11	RWY Closure - NN	3	Change of runway, change routing, most expeditious way.	Very much. Gave me a good reroute to new runway.	Gave me a good autoplan quickly which I accepted and refined.	I would have planned a route similar to autoplan	Easier.
12	RWY Closure - NN	2	Manoeuvre to land economically on new runway.	N/A	It allowed me to quickly proceed to first new fix, then eneter new speeds and altitudes and new fixes to cut corners.	I would have first used HDG SEL and speed and FLCH to control flight path. First CDU fix would have been on approach centerline.	Slightly more difficult.
13	RWY Closure - NN	2	Expeditious arrival	N/A		Radar vectors from ATC.	Slightly more difficult.
14	RWY Closure - NN	1	Time was not an issue, but I chose the most expeditious route to the runway.	N/A	It neither helped nor hindered my progress.	I wouldn't have done anything differently.	No difference.
15	RWY Closure - NN	4	Safe and expeditious arrival.	The routing seemed to be wasteful of time and fuel.	None	First HDG SEL to orient in desired direction, then build waypoints to take me to airport.	No difference.
16	RWY Closure - NN	3	Initially turned to a point abema of initial approach fix., stay left of corridor with enough time to configure.	I used it, even though it was opposite to what I wanted.	Definitely shortened the route and thus the time to landing.	I would have and did use it.	Slightly more difficult.
1	RWY Change - NN	4	Going direct to a known fix for economy. Airspeed was increased to reduce time.	Helped with planning greatly.	Made it a lot easier.	I would have went direct to the marker and modified the route via HDG SEL on the MCP	Easier
2	RWY Change - NN	3	Short route.	I used the autoplan and then modified it.	It allowed a reroute to be entered with few keystrokes.	HDG SEL to a point abeam of the outer marker and then turn in from a left pattern.	Slighty easier
3	RWY Change - NN	2	Plan for the most efficient routing to the new runway.	N/A	Used CDU to input alternate route waypoints.	Used HDG SEL	No difference.
4	RWY Change - NN	1	Expeditous route to runway.	N/A	Used HDG SEL to fly to appropriate points, fixes etc, to runway. Used FLCH and V/S for altitude control.	None	Slightly easier.
5	RWY Change - NN	2	Efficient route to final approach. Time not an issue.	N/A	The CDU part was helpful for altitude awareness, preplanningand lateral awareness as well (on MCP)	Used ND for position awareness while using HDG modes to navigate.	Slightly more difficult
6	RWY Change - NN	1	Wanted a right downwind, not in a hurry though.	N/A	Made inputs quickly.	I would have started with MCP and then used CDU to make a new course with fixes.	Slightly easier.
7	RWY Change - NN	4	Building a waypoint to turn to OM.	Picked out a good route, though initially it zigzagged a little.	It picked out a good autoplan for me which I was able to check and refine.	Would have built my own route. I may well have come up with the same route and profile but autoplan was easier.	Easier.
8	RWY Change - NN	3	Go direct and downwind for a right base. Shortest distance.	Gave me a good route but I elected not to use it because it was longer.	Gave me an offer of an approach but I chose not to use it.	Nothing	Easier.
9	RWY Change - NN	3	Set up for best route for runway change. I wanted to set up a downwind from my present position to enter an ILS box pattern for new runway.	Autoplan got me started in correct direction with appropriate waypoints.	Used initially then I modified waypoints to shorten the approach.	I would have built my own waypoints on LEGS page with speed and altitude constraints.	Slightly easier
10	RWY Change - NN	2	Direct route to OM. Waypoints leading to smooth interception of final course.		Gave me information on distance to waypoints and descents.	Used the MCP to do the same route and manually descend and change speed.	Easier
11	RWY Change - NN	1	Shorter route distance to approach. I could go direct anywhere.	N/A	Only as a vehicle to execute reroute.	Build route with FMS - LNAV.	More difficult.
12	RWY Change - NN	4	Expeditiously create a downwind and crosswind pattern to arrive on runway final at outer marker plus 5 miles for stable approach.	I relied on it initially to get mne started in the direction desired and then modified further cutting corners to reduce distance.	It gave me a very good initial route to the new runway.	Asked ATC for initial vector, used HDG SEL and then used the Autoplan.	Slightly more difficult.
13	RWY Change - NN	1	Use HDG mode to fly downwind, base and then final.	N/A	Use map mode with HDG, V/S, speed control to fly box pattern.	Use CDU to input new approach	Slightly more difficult.
14	RWY Change - NN	4	Time, distance and fuel considerations.	I totally relied on the autoplan for this scenario. I overrode the speeds in the beginning of the plan to expedite the process.	It made the reroute extremely easy.	I would have probably followed a similar route to autoplan.	Easier
15	RWY Change - NN	3	Very routine, no special strategy.	Mostly modified the initial routing to be a bit more direct.	Made route seletion fairly easy.	Probably speed interventions.	Slightly easier.
16	RWY Change - NN	2	Go downwind left of runway.	N/A	Having all of the fixes on the ND was a big help.	Would still have used the CDU.	Slightly more difficult.

Table 9 - Pilot Responses to End of Run Questionnaires - III

Pilot	Scenario	TOA used	Outline your strategy for replanning the flight. What factors did you consider important?	How much did you rely on the Autoplan? If you decided to override or modify the automatically generated plan, what about the autoplan did you not want to occur?	In what ways, if any, did using this type of automation help you replan your flight?	What would you have done differently if you were not required to use this type of automation? (As part of your answer please describe what autoflight system you would have used including none).	How would you rate the ease of planning in this run compared to planning using the autoflight system described in the previous question?
1	Cargo Fire - E	1	Keep altitude in case you have more problems. Go direct to minimize time.	N/A	Good orientation from ND let me use HDG SEL/HLD to get to a good feeder fix.	Would have used LNAV to go direct to intermediate point, then direct to the marker	Slightly more difficult.
2	Cargo Fire - E	4	Shortest Route. Fewest keystrokes.	I used the autoplan with a few shortcuts to save time	None	HDG SEL to a point outside of the outer marker and the turn on with MCP.	No difference.
3	Cargo Fire - E	3	Need to land as soon as possible due to fire. Min time and distance to runway, safely.	For initial routing only.	Autoplan produced a good basic shorter route.	Slam dunk approach would allow high speed to a reasonable point. HDG SEL, FLCH and V/S would be nice to use in this scenario.	Slightly More Difficult
4	Cargo Fire - E	2	Expeditious arrival due to fire considerations. Most direct route to airport.	N/A	Direct intercept to point outside outer marker.	HDG SEL toward outer marker with V/S and FLCH for altitude control.	Slightly More Difficult
5	Cargo Fire - E	3	Time to touchdown a high priority due to fire. Important to expedite but be stable at marker so as not necesitate go around. Reduce mileage as much as possible while allowing 180 deg turn to marker.	Zero. I did not consider using it. Felt I had a good picture of the situation on ND. If terrain was a factor, and autoplan protected you from terrain, I would use it.	Zero.	I would have extended the final leg from the marker and used the MCP to fly the airplane. Essentially flying it as I would a pilot's discretion visual.	Slightly More Difficult
6	Cargo Fire - E	2	Getting on the ground quickly.	N/A	It helped initially. Then I cut the corner to final.	I would have used the MCP to fly.	Slightly more difficult.
7	Cargo Fire - E	1	Get on the ground quickly and safely.	N/A	MCP didn't help plan at all.	With CDU I would have built an approach with turns, altitudes and speeds that I felt appropriate.	More difficult.
8	Cargo Fire - E	4	Fire! Set the aircraft on the ground as soon as possible.	I relied on it greatly.	Reduced pilot workload greatly.	Nothing.	Easier.
9	Cargo Fire - E	2	I wanted to shorten route and get A/C on the ground as soon as possible, cut corners.	N/A	Legs page directly to a navaid to get me pointed in the direction I wanted to go.	HDG SEL, V/S, FLCH and speed interventions.	Slightly more difficult.
10	Cargo Fire - E	1	Landing as quickly as possible.	N/A	No flight planning value.	I would have used the same route, but would have used the information provided by the CDU as a back up.	No difference.
11	Cargo Fire - E	4	Extinguished fire, still want to get on ground as quickly as possible.	A lot. Gave me a more direct route.	Quickly set me on a more expeditious route to landing. I refined it a bit.	Found a more direct routing using CDU.	Easier.
12	Cargo Fire - E	3	Land safely and quickly.	I reliled on it to give me an initial route to the airport.	Saved steps so I did not have to enter a full route individually.	Not much. I would have used MCP for speed.	Slightly more difficult.
13	Cargo Fire - E	4	Most expeditious arrival	Provided a good starting point, Modified autoplan to reduce airborne time to abolute minimum.	A good beginning to reduce flight time.	Direct route to outer marker (or abeam) for minimum enroute time.	Slightly more difficult.
14	Cargo Fire - E	3	Due to nature of the emergency, time was of the essence. With fires you set the aircraft as quickly as possible.	Did not rely on autoplan at all.	I did not rely on the autoplan to provide the best routing due to time being the priority.	I would have used the MCP to fly manually directly to the airport and then manoeuvre aircraft to land.	No difference.
15	Cargo Fire - E	2	Shortest distance to airport.	N/A	Allowed me to build a pattern and see distance to airport.	Mix CDU and MCP for finer control of speed.	Slightly easier
16	Cargo Fire - E	1	Proceed direct to a point abeam of initial approach fix and then turn direct to initial app fix and line up.	N/A	The course line and green arc were very helpful as trend information.	Would have used the CDU to a point abeam of initial approach fix.	Slightly more difficult.
1	Fuel Filter - E	3	Minimize time. Go direct and go fast. This is harder to do with the MCP unavailable.	Did not use the Autoplan. Therefore not applicable.	It allowed altitude & speed constraints. It actually was a hindrance when the MCP could have been used more effectively in a terminal environment.	Use the CDU until about 5-6 miles prior to the OM and then use the MCP.	Slightly More Difficult.
2	Fuel Filter - E	2	Easy workload. Fewest keystrokes.	N/A		HDG SEL and a left downwind.	Easier.
3	Fuel Filter - E	1	Shortest route/time to runway, consistent with safety. Avoidance of weather and terrain.	N/A	MCP was I could use, and probably all I would have used even if I had a CDU.	Nothing, other than distance data from the CDU.	Slightly easier.
4	Fuel Filter - E	4	Took most direct route to airport due to fuel filter problem.	Used autoplan for initial routing, then shortened for expeditious route to airport. Long route to airport occurred with autoplan.	Showed autoplan but to no advantage.	HDG SEL toward airport at max speed, using FLCH and V/S for altitude control. Slow outside marker and then HDG SEL into approach.	Slightly more difficult.
5	Fuel Filter - E	4	Efficient route to final approach. Time not a factor.	Zero. Modified to most direct route to airport.	Zero.	Used MCP with map mode on ND for situational awareness.	More difficult.
6	Fuel Filter - E	3	Getting on the ground fairly quickly.	Initially I used it, and then switched to left downwind.	Helped with initial turn.	I would have used the MCP only.	Slightly more difficult.
7	Fuel Filter - E	2	Need to get on ground quickly, yet safely.	N/A	Could build descent profile in advance, "on the go" with MCP.	Am very comfortable with this CDU. Would have used this only.	No difference.
8	Fuel Filter - E	1	Set aircraft on ground as soon as possible. Reduce distance and time.	N/A	Reduced pilot workload.	I like using MCP to reduce workload, so I would always use it.	Slightly more difficult.
9	Fuel Filter - E	1	Fly to a downwind (via waypoints) to set up for approach.	N/A		Set up a waypoint to an ILS approach, with hard speeds and altitudes on legs page.	No difference.
10	Fuel Filter - E	4	Quicker way to runway.	Not much just went direct to a point outside the OM.	Not much.	Manually input waypoints.	No difference.
11	Fuel Filter - E	3	Shorter route to final. Nature of emergency dictated immediate landing.	Initial routing good. Refined a little to suit a left downwind.	Gave me a possible route, better than RTE 1 and then I was able to improve it.	Direct to point to expedite arrival.	Slightly easier.
12	Fuel Filter - E	2	Quickly but safely arrive at a point where landing would be assured.	N/A	Helpful to show speeds at the points along the way.	I would have used HDG SEL for initial direction and then FLCH for descents.	No difference.
13	Fuel Filter - E	2	Expeditious arrival	N/A	Speed/altitude restrictions at waypoints, creating waypoint short of existing arrival.	Expedite using MCP FLCH mode and speed brakes.	Slightly more difficult.
14	Fuel Filter - E	1	Due to fuel filter problem, did not want to be airborne longer than I had to. Felt most direct route to land was best course of action.	N/A	It kept me directly involved and focussed in the progress of my flight.	I would have chosen to use my CDU and plan the most expeditious route.	Slightly more difficult.
15	Fuel Filter - E	4	Reduce length of flight	I wanted a shorter route to airport.	none	I would have headed directly to OM, turned a bit left of that track to create a base leg.	No difference.
16	Fuel Filter - E	3	With a possible fuel emergency, I wanted to land as soon as possible, so proceeded directly to a point near OM and then turned onto approach.	I used it, even though to the other side of the runway. It was close to what I wanted, and in an emergency, a good plan right now is better than a perfect plan too late.	Definitely shortened the route, and thus the time to landing.	I would have and did use it.	Slightly more difficult.

Table 10 - Pilot Responses to End of Run Questionnaires - IV

Pilot	Scenario	TOA used	Outline your strategy for replanning the flight. What factors did you consider important?	How much did you rely on the Autoplan? If you decided to override or modify the automatically generated plan, what about the autoplan did you not want to occur?	In what ways, if any, did using this type of automation help you replan your flight?	What would you have done differently if you were not required to use this type of automation? (As part of your answer please describe what autoflight system you would have used including none).	How would you rate the ease of planning in this run compared to planning using the autoflight system described in the previous question?
1	Med Emer - E	4	Well being of passenger. Tried to proceed directly to points on the approach while maintaining speed.	None at all. It seemed the autoplan added more time/distance to the evolution.	N/A	Use the MCP in the terminal environment.	No difference.
2	Med Emer - E	3	Stay high and fast and then enter a left pattern.	I used the Autoplan.	It made reprogramming easy by reducing keystrokes.	Nothing.	No difference.
3	Med Emer - E	2	Med emergency requires shortest route/time based on present position and altitude and safe operation.	N/A	Input alternate route waypoints.	MCP HDG SEL mode initially until new route was input and activated.	No difference.
4	Med Emer - E	1	Proceed to point outside marker in expeditious manner, then slow for approach.	N/A	HDG SEL to proceed expeditiously to point outside OM. FLCH and V/S for altitude control.	Nothing.	Slightly Easier.
5	Med Emer - E	2	Time was critical. Planned most direct route.	N/A	Replanning was based on creating a reasonable picture on the ND. CDU allowed me to create a good route to the runway.	Heading mode on MCP to fly laterally using ND to keep track of situational awareness.	More difficult.
6	Med Emer - E	1	Getting on the ground as quickly as possible was #1 priority. I went to downwind fast.	N/A	Took control of aircraft quickly. Similar to handflying just with autopilot on.	I would have used MCP as I did, then gone to handflying when abeam the field.	Slightly easier.
7	Med Emer - E	4	Needed to get on ground quickly for medical attention. Use the shortest rout	Autoplan looked good initially, then started to reduce ground track distance.	It did the initial replanning and then I tweaked it a bit.	I would autoplan initially and then use CDU to refine the route.	Easier.
8	Med Emer - E	3	Go fast, cut corners, land ASAP because of emergency. Visual displays helped greatly.	Very much. It gave me a good plan.	Instantaneous information lowered workload.	Nothing.	Easier.
9	Med Emer - E	3	Get on the ground as soon as possible. No other considerations but safety.	Did not check to see if there was an autoplan.		Build waypoints for my desired routing with speed and altitude constraints.	No difference.
10	Med Emer - E	2	Faster route to runway.	N/A	Gave me info - distances, altitudes at waypoints etc.	Used MCP without back up data in CDU.	Easier
11	Med Emer - E	1	To get on the ground as soon as possible.	N/A		CDU-LNAV to marker.	Slightly more difficult.
12	Med Emer - E	4	Land as soon as possible, stay as fast as possible for as long as possible but not too fast to ensure smooth landing (don't want to overshoot runway).	Again, autoplan was useful to begin flying quickly the approach path, but once on that route I could make further short cuts and still comfortable have a stable approah.	Autoplan being available automatically I think, will be a distraction, and only slightly quicker than selecting it myself.	Used HDG SEL to start aircraft on desired route, then used autoplan and executed it, modify autoplan for more short cuts using MCP for speed control.	Slightly more difficult.
13	Med Emer - E	1	Expedite arrival, enough time to configure for final approach.	N/A	Used map, HDG, V/S and speed control to fly box pattern.	Used CDU to input approach to runway.	Slightly more difficult.
14	Med Emer - E	4	I looked at autoplan and decided to alter the route due to nature of the emergency.	I relied on it to get an initial plan but decided on a more expeditious route.	it just got me started in the right direction.	I woul not have done anything differently.	Slightly more difficult.
15	Med Emer - E	3	Speedy arrival within the bounds of safety.	100%	Simplified the expeditious routing.	Would have turned base a little sooner.	Slightly easier.
16	Med Emer - E	2	Speed up and go as directly as possible, leaving enough room to turn onto final.	N/A	Proceeding direct and VNAV help to alleviate workload.	I would still have used the CDU.	Slightly easier.
1	Hyd. Sys - E	2	Minimizing time aloft. One or two DCT intercepts and airspeed modifications did this for me.	N/A	It made it easier.	I would have went direct to marker and modified the route via HDG SEL on the MCP.	No difference
2	Hyd. Sys - E	1	Shortest Time.	N/A	Using MCP made entering left traffic easy.	Nothing.	Easier.
3	Hyd. Sys - E	4	Hyd. Sys. Emergency requiring landing as soon as possible. Smooth transition to final approach is a thought since I don't really know what systems have been affected by the problem.	Autoplan was fine. I just modified it a little to go direct to a waypoint a little further down the road.	It automatically planned a shorter route after the emergency. The route was shorter and acceptable.	Normal CDU. I would have picked out waypoints and assembled a route manually.	Slightly easier.
4	Hyd. Sys - E	3	Shorter distance. Quicker route to airport. Simplify route. Possible emergency.	None	None	HDG SEL to point outside OM. FLCH to G/S intercept altitude.	Slightly more difficult.
5	Hyd. Sys - E	1	Speed or elapsed time not an issue. Efficient route to final, stable at marker.	N/A	MCP was a very efficient way to fly the airplane, while referencing map on the ND for situational awareness.	This configuration was optimal for this situation. This is the way I would have done it on the line.	No difference.
6	Hyd. Sys - E	4	A fairly quick descent to the field.	Accepted the autoplan route.	Using the autoplan route made it easier.	Probably would have used MCP to a tighter downwind.	Slightly easier.
7	Hyd. Sys - E	3	Minimize distance to landing. Also gentle turns to final due to hydraulics problems.	Activates autoplan initially, then refined route and descent profile. Also speed.	It gave me the initial reroute. I refined a little after that.	Would have used speed intervention on MCP + HDG SEL to manage turns.	Easier
8	Hyd. Sys - E	2	Kept it simple, with no adverse maneuvers due to uncertainty in hydraulics.	N/A	Lessened my workload, no charts, no scrambling.	I would have scrambled into the charts.	Easier.
9	Hyd. Sys - E	4	Direct to a point abeam runway for a downwind entry. Descend to pattern altitude. Set up for a box pattern to intercept ILS.	Autoplan legs used intially to set up for direct route to abeam airport. After abeam OM, the shortened route even more to turn towards OM.	Great initial heading to start things off.	Would have used FLCH to descend and HDG SEL to turn.	Slightly more difficult.
10	Hyd. Sys - E	3	Quicker route to the outer marker.	I viewed it on the ND. It appeared to be a faster way to the OM, so I activated it.	Quicker way to input new points - more time to evaluate situation.	Put new points into CDU manually - probaly a route similar to autoplan and then fly that route.	Easier
11	Hyd. Sys - E	2	More direct routing. Had CDU to work with.	N/A	Enabled me to shorten route.	Nothing. Would have used CDU.	Easier
12	Hyd. Sys - E	1	Land soon but with normal speeds , expeditious route.	N/A	It helped me immediately change route, speed, and altitude parameters.	I would have used the MCP, but I would have used CDU for reference for computer planned altitudes and speeds at waypoints.	Slightly more difficult.
13	Hyd. Sys - E	3	Hyd failure requires time to complete checklists and configure for landing, but try to be expeditious in approach and arrival	I compared it with my plan and they were similar.	Provides an alternative to consider.	Proceed with own arrival plan.	No difference.
14	Hyd. Sys - E	2	I considered not going much past the airport with a possible hydraulic failure. In the event the hydraulics went out totally, the a/c would have been very hard to handle.	N/A	Just aided in programming the FMS to put flight plan together.	I would have flown manually directly to airport and then manoeuvred to land.	No difference.
15	Hyd. Sys - E	1	Expedite arrival without increasing workload.	N/A	none	I would use a mix of MCP and LNAV/VNAV to provide myself with a greater degree of situational awareness.	More difficult.
16	Hyd. Sys - E	4	Initially chose a point too far past the runway but then had time to rectify the error and follow strategy as in weather scenario.	The autoplan selected a good initial route, but I wanted to be more direct. Autoplan speeds were a little slow.	I had a good initial plan except for airspeeds.	Used a normal CDU.	No difference.

<u>How would you rate the ease of planning in this run compared to planning using the autoflight system described in the previous question?</u>

Table 11 - Pilot Ratings of Ease of Planning onLikert Scale of 'Easier' to 'More Difficult'

		Rating				
Type of Automation	**Scenario Type**	**Easier**	**Slightly Easier**	**No Difference**	**Slightly More Difficult.**	**More Difficult.**
MCP	**Non Nominal**	0	4	4	6	4
	Emergency	1	3	3	7	2
CDU	**Non Nominal**	3	3	2	8	0
	Emergency	4	2	5	4	1
CDU+	**Non Nominal**	3	6	4	2	1
	Emergency	3	2	4	7	0
CDU++	**Non Nominal**	8	2	2	4	0
	Emergency	3	2	5	5	1

APPENDIX C.3

Pilot Responses to End of Experiment Questionnaires

*** All number except percentages and averages indicate the number of pilots**

<u>Have you ever needed to replan a flight due to an emergency?</u>

Yes: 14
No: 02

Average Approximate Time to Landing: 34 minutes

Average Approximate Distance to Landing: 125 miles

<u>Type of Autoflight System Used</u>

MCP:	10
FMS/CDU:	05
Hand Flown:	01

<u>How often do you need to replan your route due to non-nominal conditions? Please indicate your answer as a percentage (%) of flights.</u>

Average: 20%

<u>What type of autoflight system do you prefer to use in these conditions? (As part of your answer please describe what type of autoflight systems would you have used, including none)</u>

MCP Only:	02
CDU Only:	06
MCP+CDU:	06

<u>What factors influenced you choice of how to use the autoflight system when replanning a route?</u>

Distance:	5
Time:	4
Fuel Available:	1
Weather:	5
Vectoring:	1
Safety:	*2*

QUESTIONS ABOUT IN-FLIGHT REPLANNING IN NON NOMINAL SCENARIOS

Under the given circumstances did you feel comfortable planning your own route or would you rather have received vectors from ATC? Why?

Own Planning: 10
Vectoring: 2
Own Planning + Vectoring: 4

What was your strategy in choosing the route that you planned and implemented?

Minimize Time: 9
Minimize Distance: 8
Aircraft Performance: 4
Safety of Maneuver: 3
Efficiency: 3
Weather: 3
Fuel: 3

QUESTIONS ABOUT IN-FLIGHT REPLANNNING IN EMERGENCY SCENARIOS

Under the given circumstances did you feel comfortable planning your own route or would you rather have received vectors from ATC? Why?

Own Planning: 8
Vectoring: 8
Own Planning + Vectoring: 1

What was your strategy in choosing the route that you planned and implemented?

Minimize Time: 15
Minimize Distance: 13
Aircraft Performance: 3
Safety of Maneuver: 2
Efficiency: 7
Fuel: 5

<u>Which type of autoflight system interface were you most comfortable with?</u>

MCP Only:	5
CDU (including variants):	7
MCP + CDU:	5

Table 12 - Pilots Evaluation of the Performance of the Autoplan

How would you describe the performance of the Autoplan? Please elaborate.	
Pilot 1	It gave a very viable option that you could choose or reject. It would save effort and thought process if it was elected
Pilot 2	I found Autoplan very easy to use and it made my workload much less.
Pilot 3	Autoplan is a great idea if implemented correctly. It needs the ability to pick waypoints that are likely to be used in a given airspace. I think this could be accomplished in part by surveying ATC and having them suggest alternate route in their airspace. Another constraint is CDU memory, which is in short supply in the 757/767s I fly. As long as Autoplan has the ability to pick a logical, likely route, it will be a good thing. If however, it picks routes that will not be used in real life, it will become a button that never gets used.
Pilot 4	Helpful as a suggestion, that can be easily modified. Adds fixes that can be used without typing.
Pilot 5	Autoplan has no way of knowing what the objective is. Therefore, it may offer a long route when a short route is desired. I believe in most cases, I would not use Autoplan.
Pilot 6	I would not have picked most of the routes it did. A little aggressive for passenger operations and routes were longer.
Pilot 7	I liked Autoplan. Not sure that I wanted it to switch to it automatically (CDU++),but I found nthe displayed alternate route very helpful in picking the route I would use.
Pilot 8	Coupled with the visual representation, it provides me with great options, however, I am concerned abot ATC's ability to go along with the plan.
Pilot 9	It may offer a good solution, then again it may not. Autoplan is not the best solution in all cases but at least look at it to evaluate it
Pilot 10	Good. It gave a quick route with an appropriate lead into final.
Pilot 11	Good. It gives a viable routing to destination and allows you to refine as necessary.
Pilot 12	I think it can be a useful system because it can save cockpit workload. It depends on how closely it would match optimum route and how likely pilot could stay on that route and not be altered by ATC.
Pilot 13	Generally good, but needs to be modified based on current factors.
Pilot 14	I think the Autoplan is a great tool,but it needs to be treated only as a tool to help me make rerouting decisions.
Pilot 15	It provided a shorter route to the airport. However ATC usually does the same to the extent that traffic allows.
Pilot 16	In general good. In time critical situations, it can give a good plan quickly and then you can take time refining it.

<u>For non nominal scenarios, please rank the types of automation (1-Best to 4-Worst) according to the automation you would choose in that situation.</u>

	1	2	3	4
MCP	2	3	2	9
CDU	2	3	8	3
CDU+	10	3	3	0
CDU++	2	7	3	4

<u>For emergency scenarios, please rank the types of automation (1-Best to 4-Worst) according to the automation you would choose in that situation.</u>

	1	2	3	4
MCP	3	2	3	8
CDU	3	4	6	3
CDU+	8	3	5	0
CDU++	2	7	2	5

APPENDIX C.4

Background Questions

Total Hours

>= 5000 and < 10000:	8
>= 10000 and < 12000:	3
>= 12000 and < 15000:	3
>= 15000:	2

Hours in Glass Cockpits

>= 2000 and < 4000:	9
>= 4000 and < 6000:	5
>= 6000:	2

Aircraft Current In

B737:	4
B747:	0
B757:	1
B767:	5
B777:	2 (1 retired)
MD-11:	0
MD-80:	0
MD-88:	4
Other:	1

Hours in Current Type

>= 100 and < 1000:	4
>= 1000 and < 2000:	6
>= 2000 and < 3000:	3
> 3000:	3

Captain or First Officer?

Captain:	8
First Officer:	8

Initial Training

Civilian: 04
Military: 11
Both: 01

Do you have any experience with flight planning software?

Yes: 6
No: 10

If yes, was it: On Board or Ground Based?

On Board: 1
Ground Based: 6

If yes, what tool(s) have you used?

Global Data Systems
Jeppesen Flitesoft
BART
TAMPS

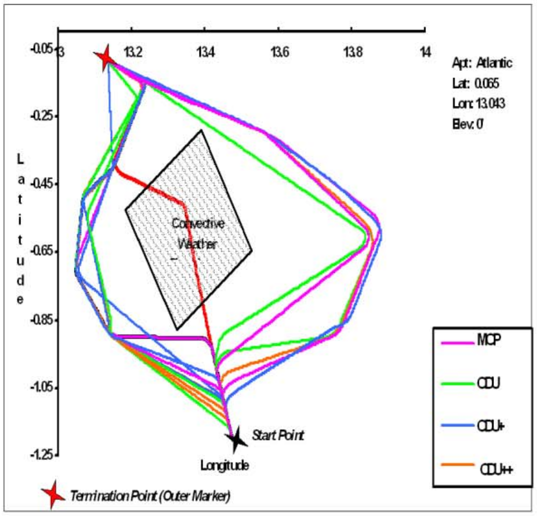
APPENDIX D

Comparative Measures and Descriptive Statistics

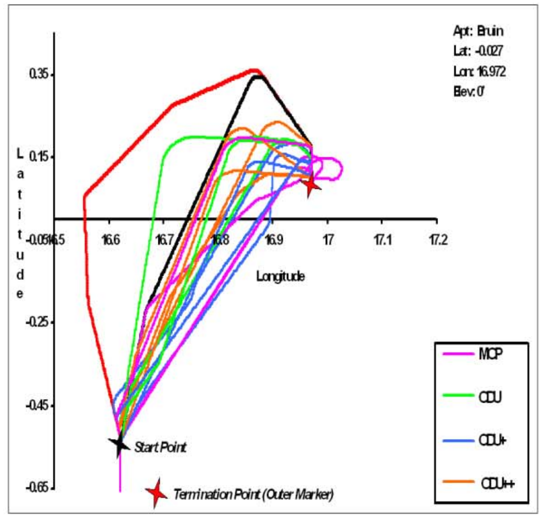
APPENDIX D.1

Real Flight Paths by Automation

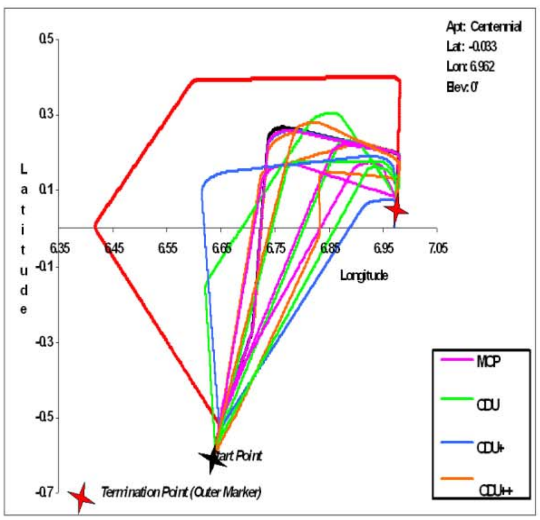
Comparative Flight Paths per Scenario



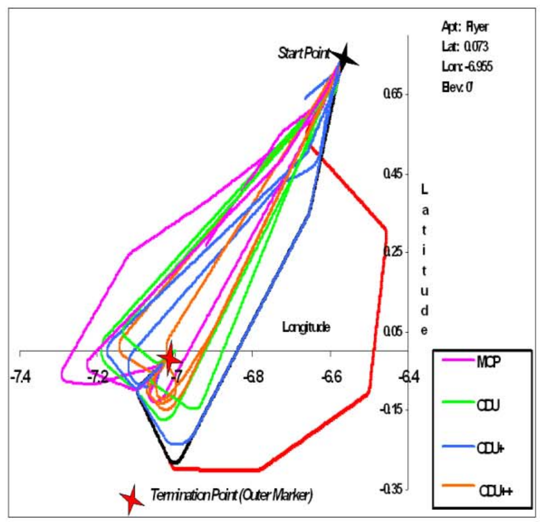
Atlantic International Airport
Non Nominal - Weather Disturbance



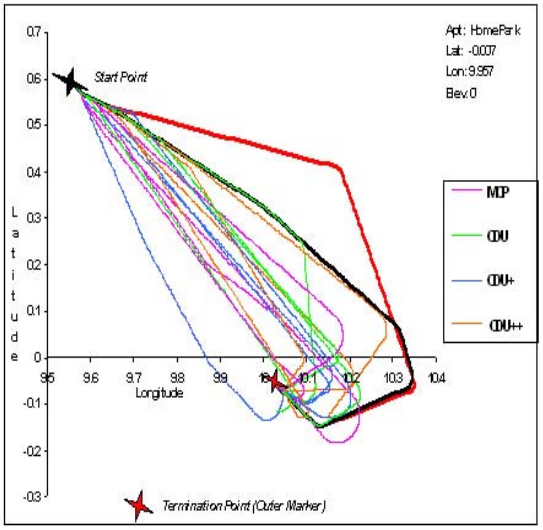
Bruin International Airport
Emergency - Cargo Fire



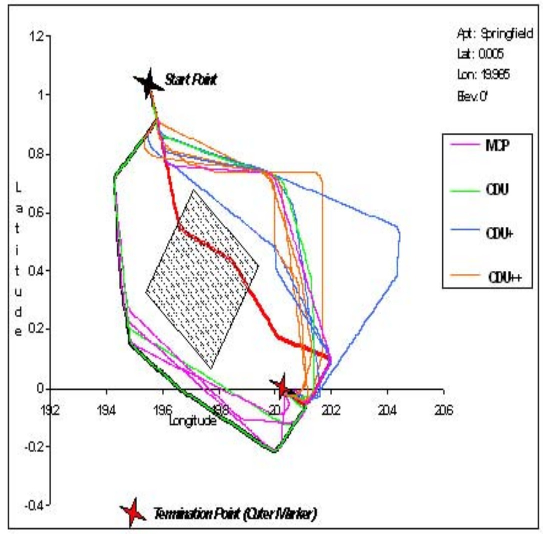
Centennial International Airport
Emergency - Loss of Hydraulic Pressure



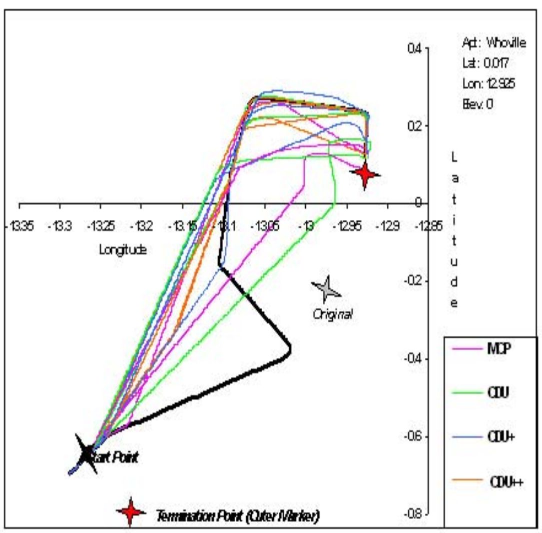
Flyer International Airport
Emergency - Fuel Filter



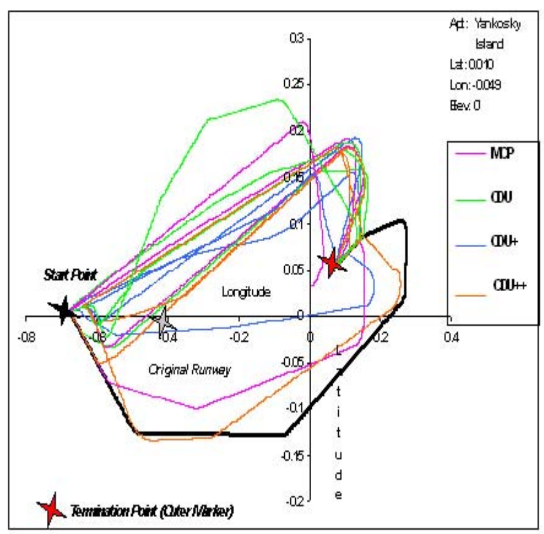
Homepark International Airport
Emergency - Mediacl Emergency



Springfield International Airport
Non Nominal - Restricted Airspace



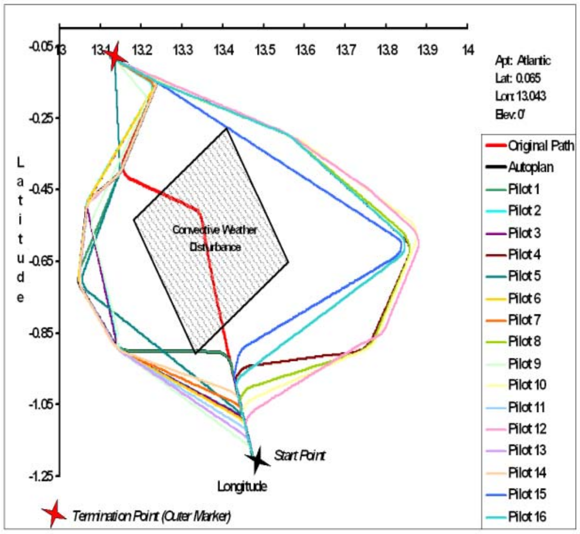
Whoville International Airport
Non Nominal - Runway Closure



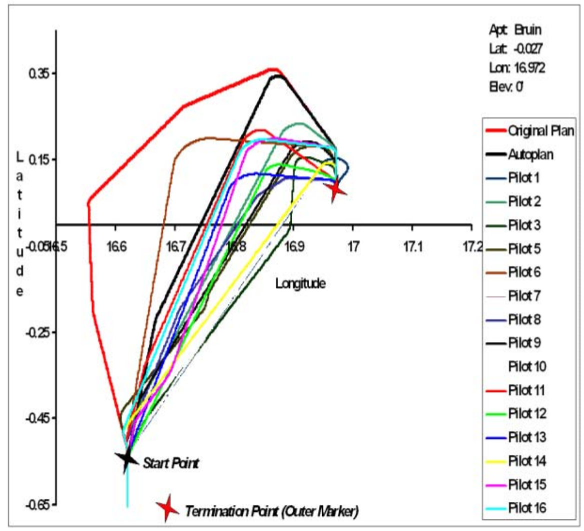
Yankosky Island International Airport
Non Nominal - Runway Change

APPENDIX D.2

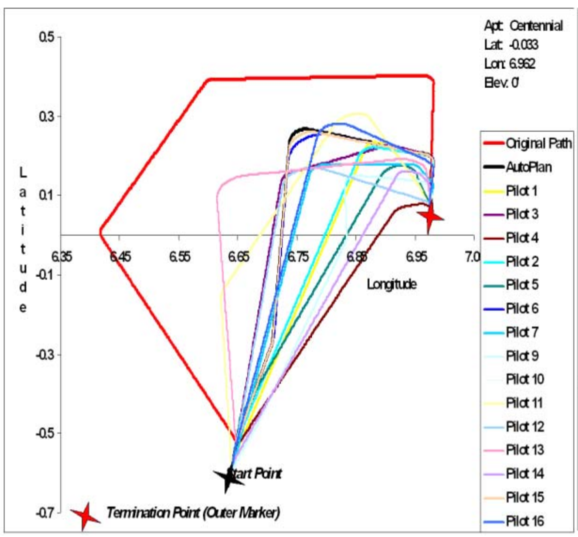
Real Flight Paths by Pilot and Specific Scenario



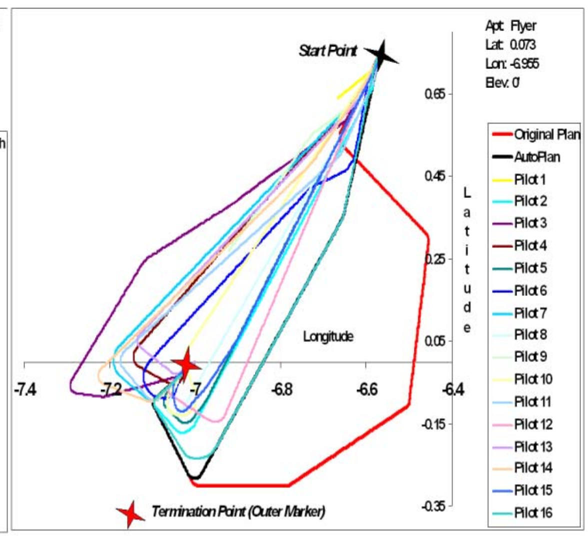
Atlantic International Airport
Non Nominal - Weather Disturbance



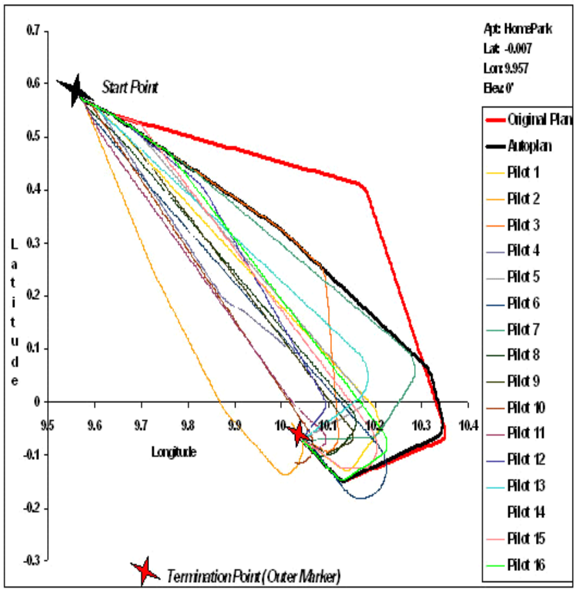
Bruin International Airport
Emergency - Cargo Fire



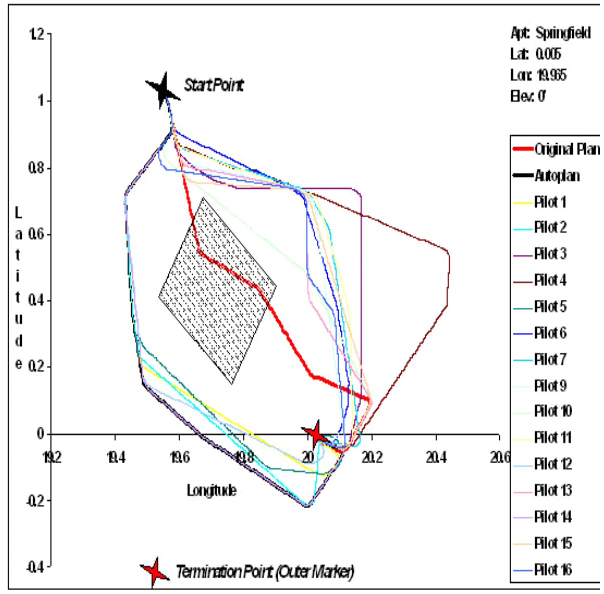
Centennial International Airport
Emergency - Loss of Hydraulic Pressure



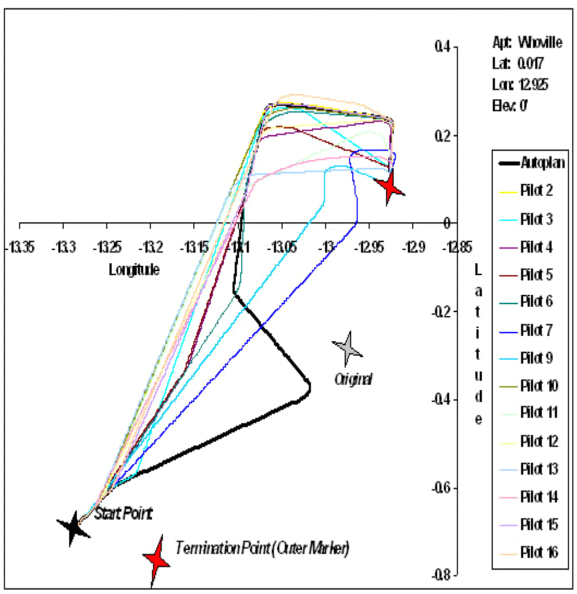
Flyer International Airport
Emergency - Fuel Filter



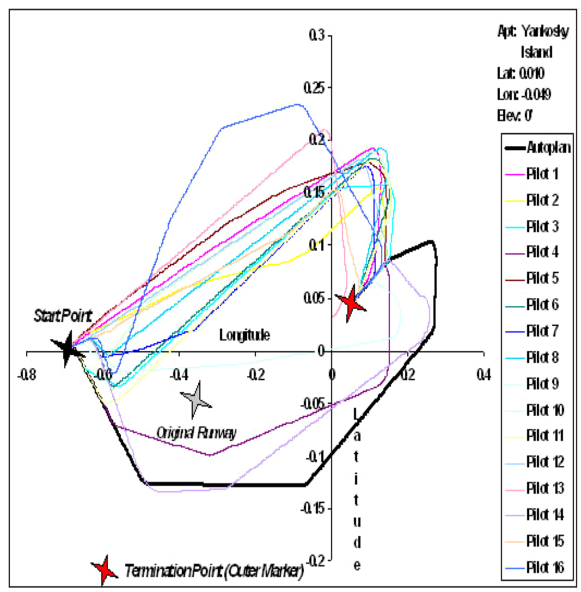
Homepark International Airport
Emergency - Medical Emergency



Springfield International Airport
Non Nominal - Restricted Airspace



Whoville International Airport
Non Nominal - Runway Closure

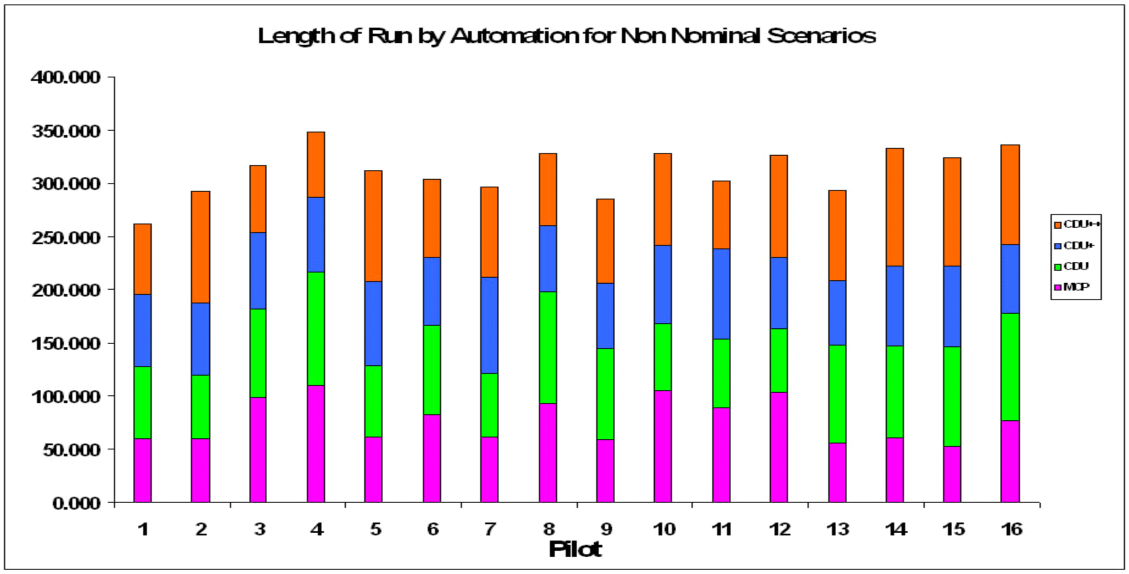


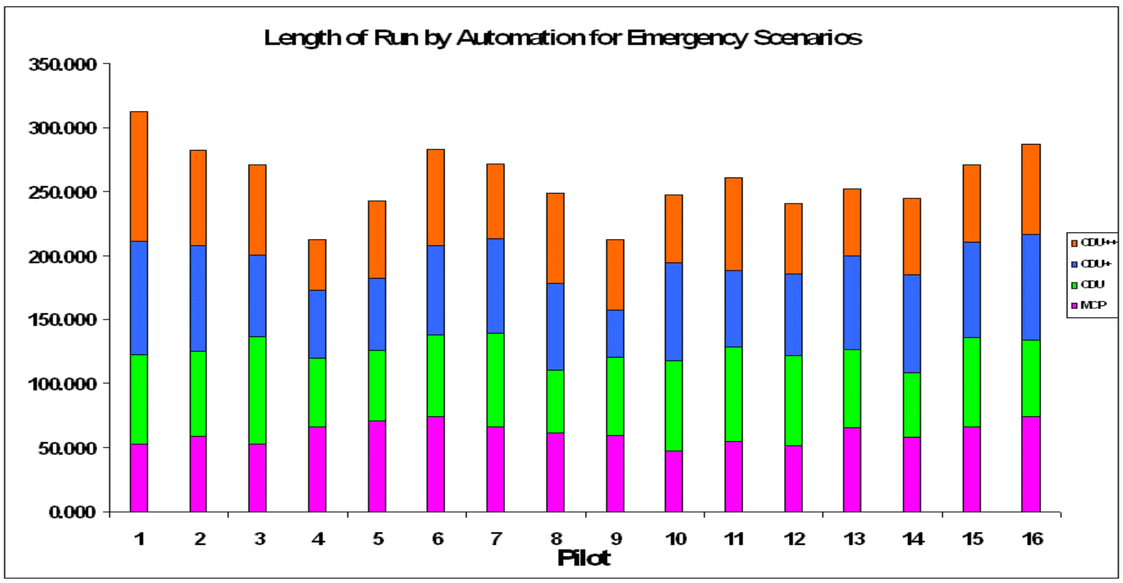
Yankosky Island International Airport
Non Nominal - Runway Change

APPENDIX D.3

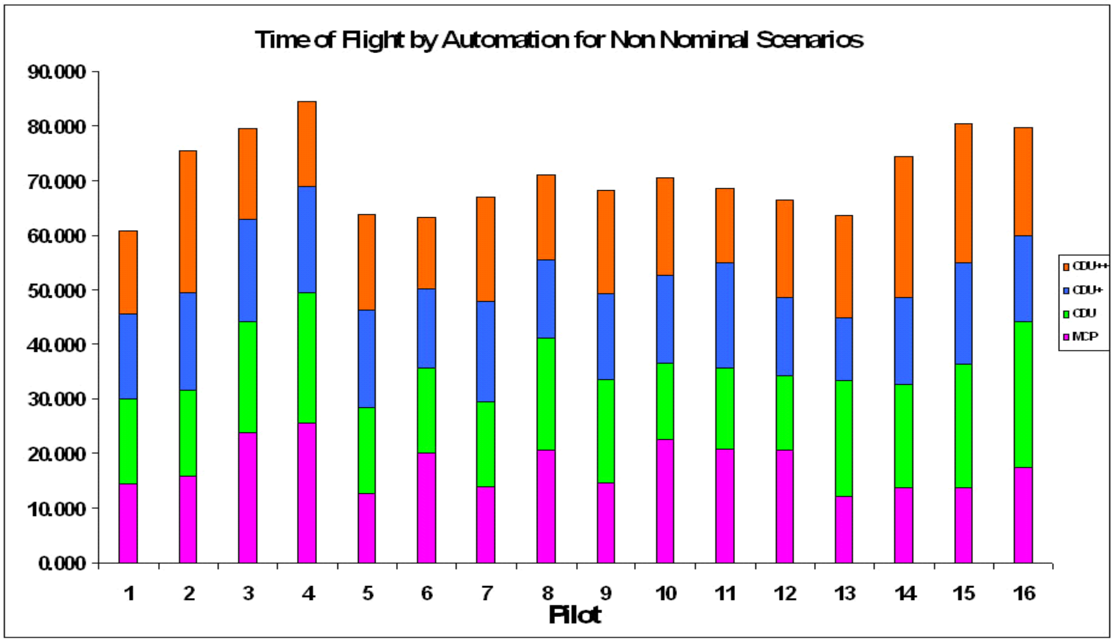
Comparison of Measures for Each Scenario Type by Automation

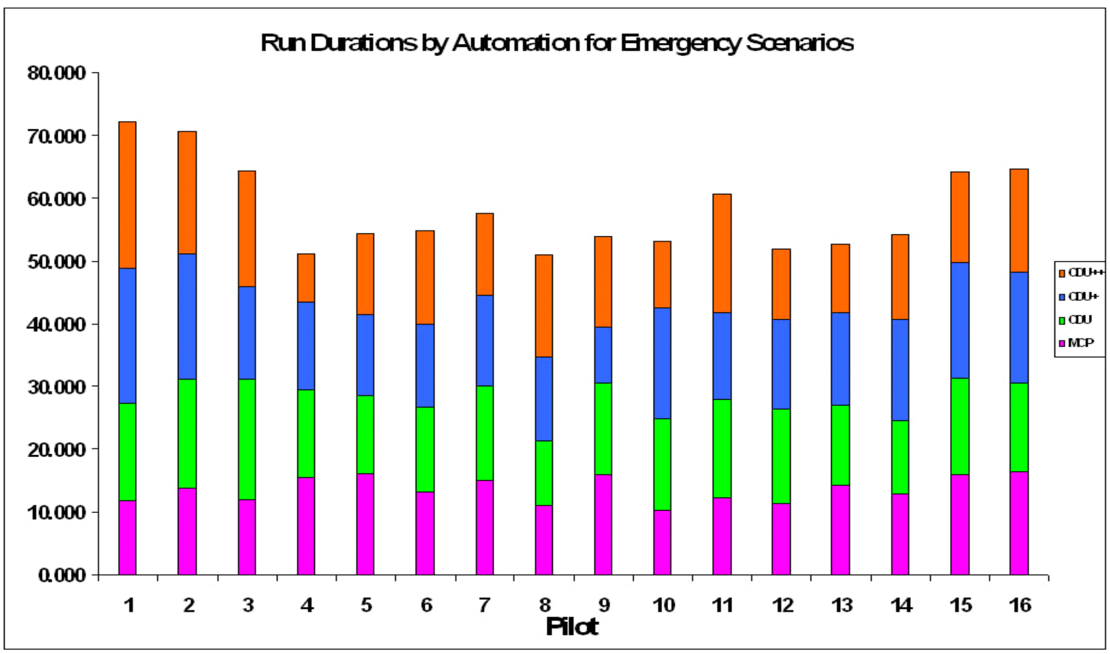
Length of Run



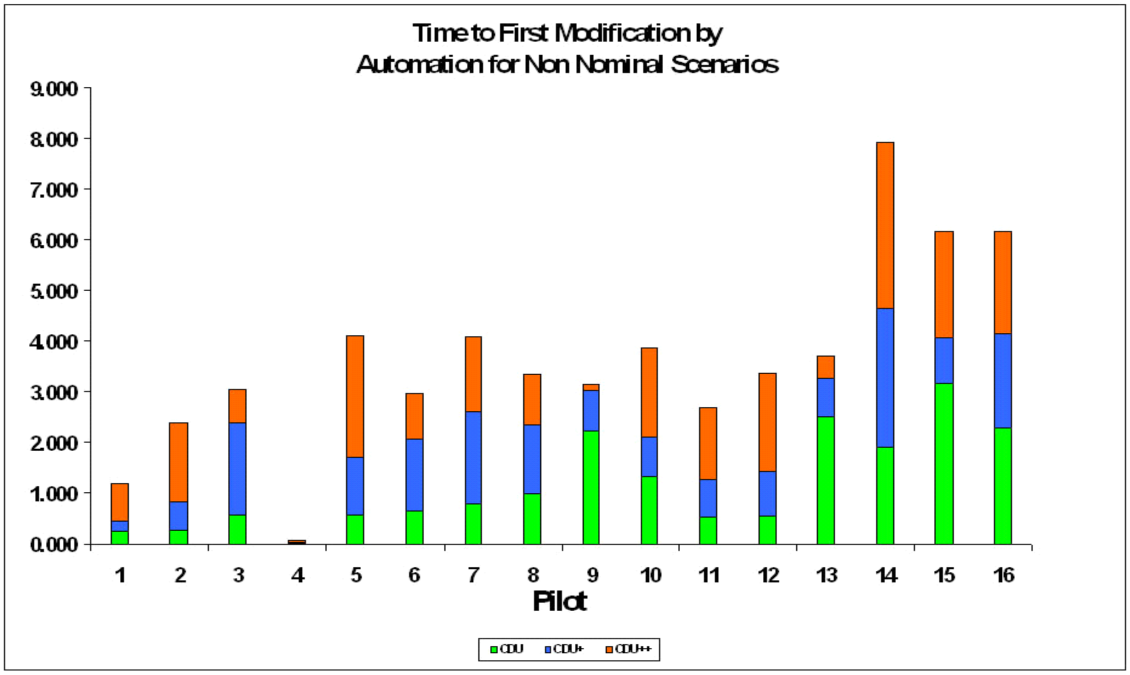


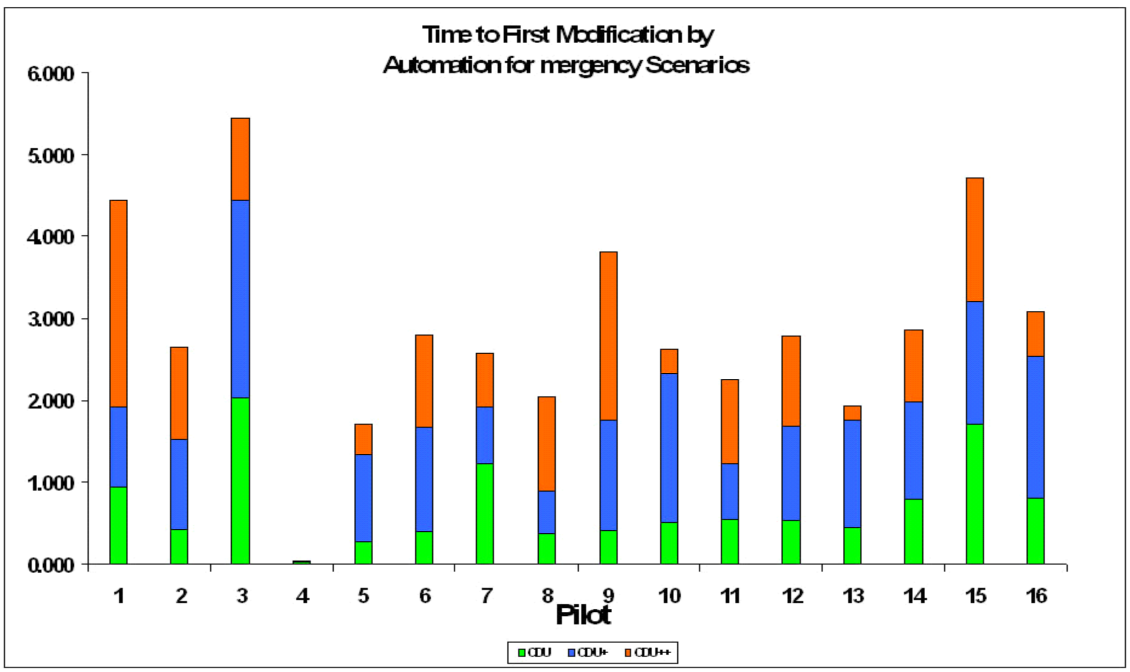
Time of Flight



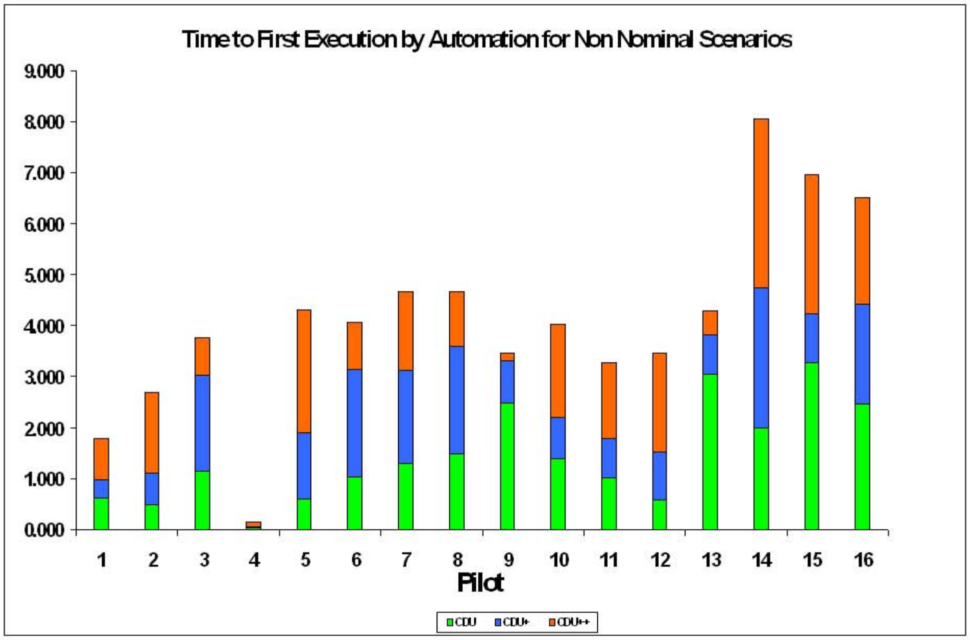


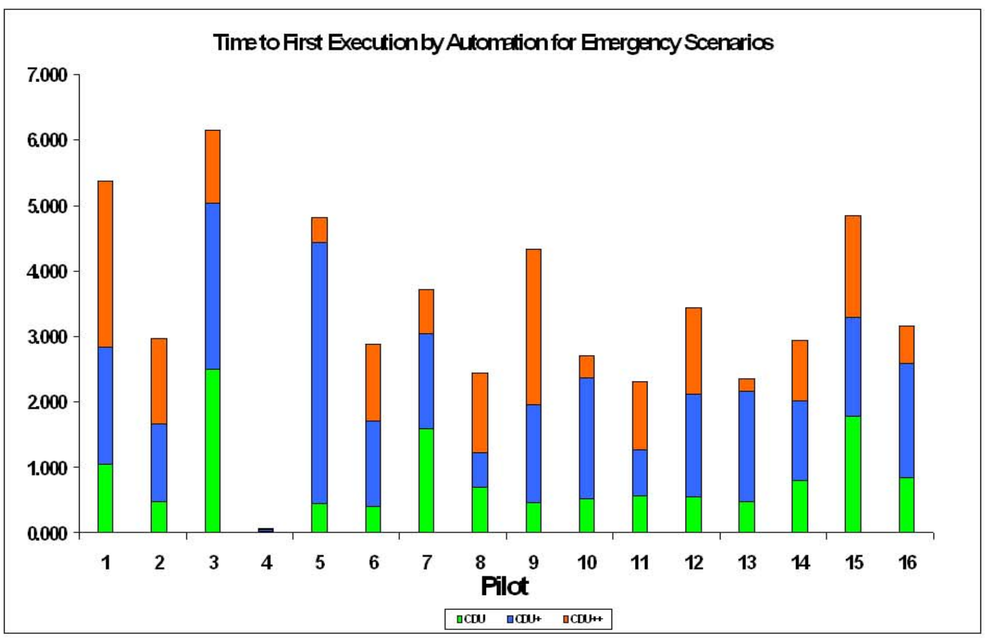
Time to First Modification of Plan



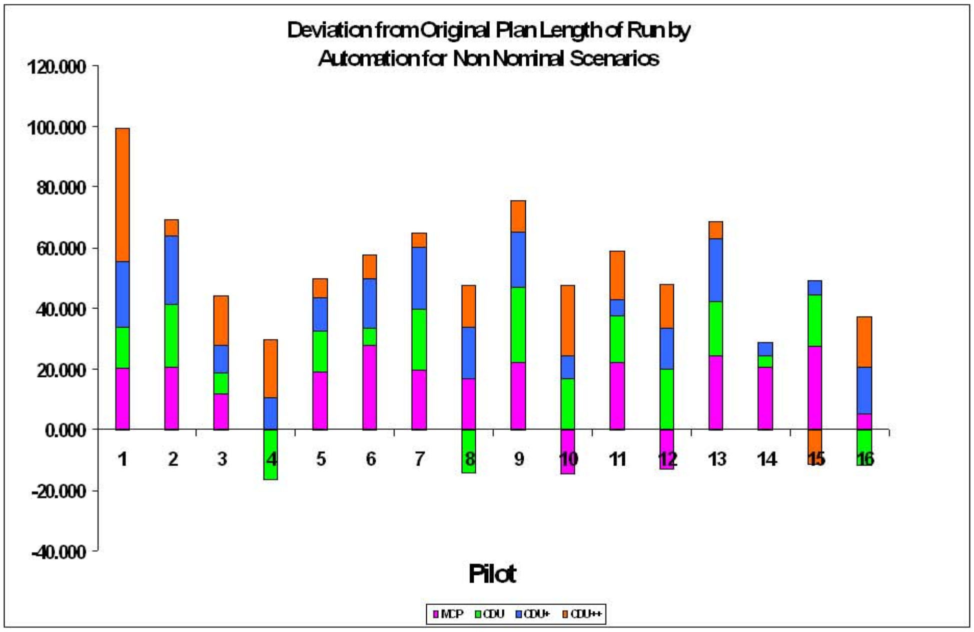


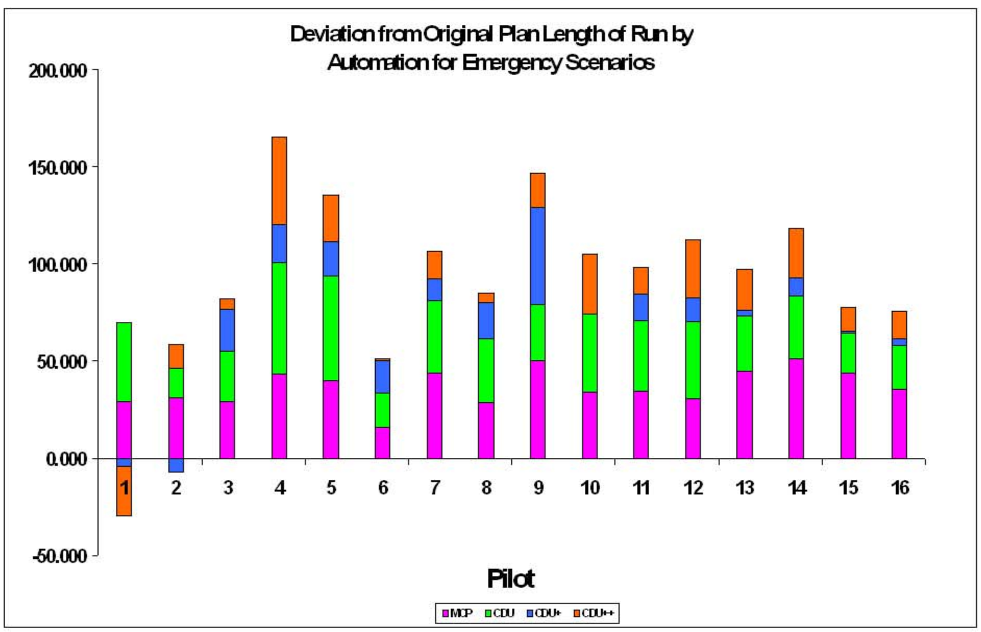
Time to First Execution of Modified Plan



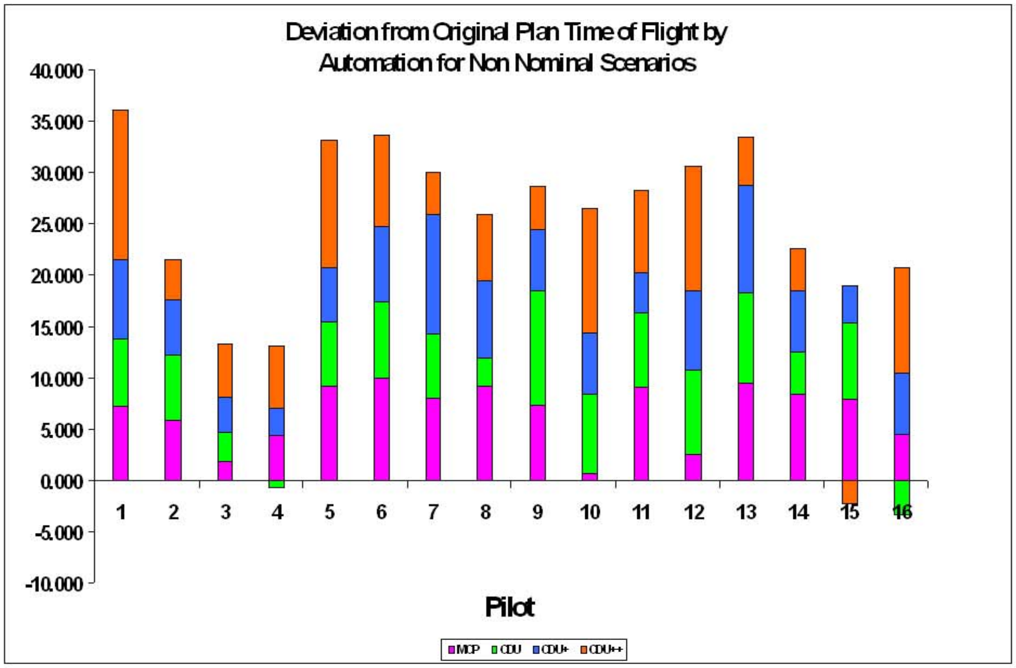


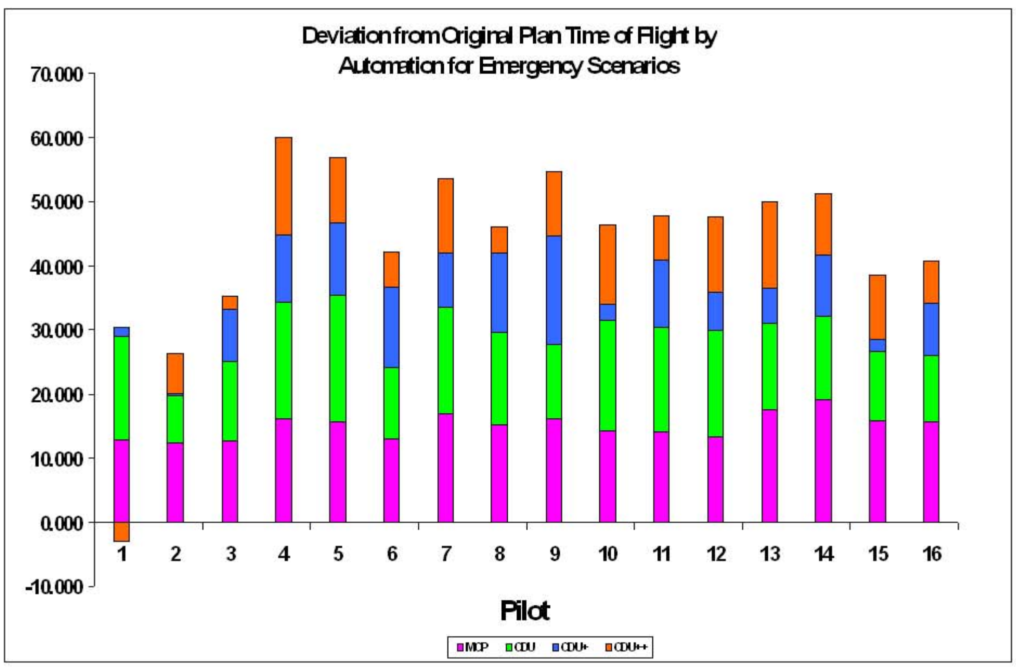
Deviation from Baseline Plan: Length of Run



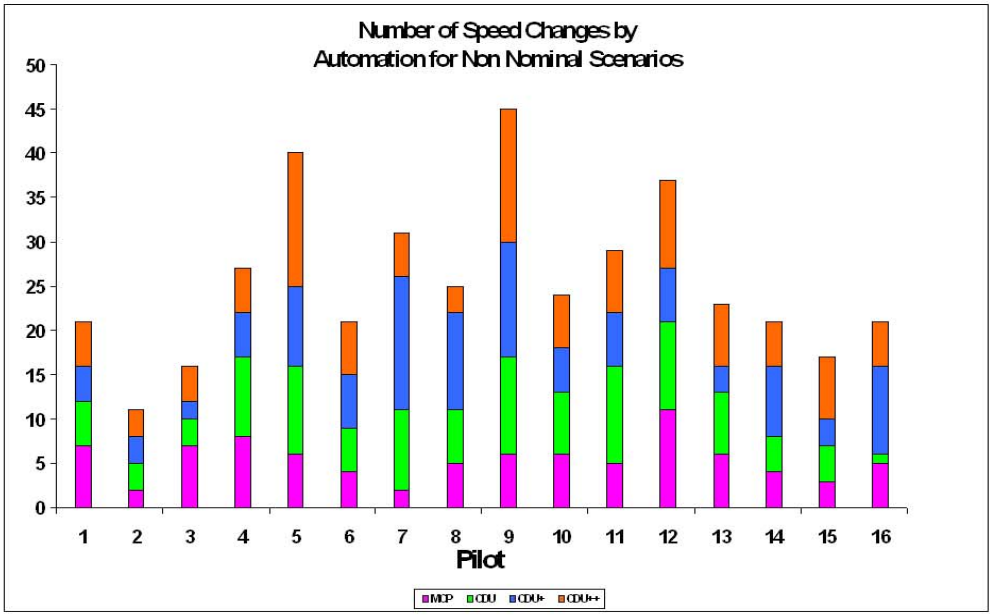


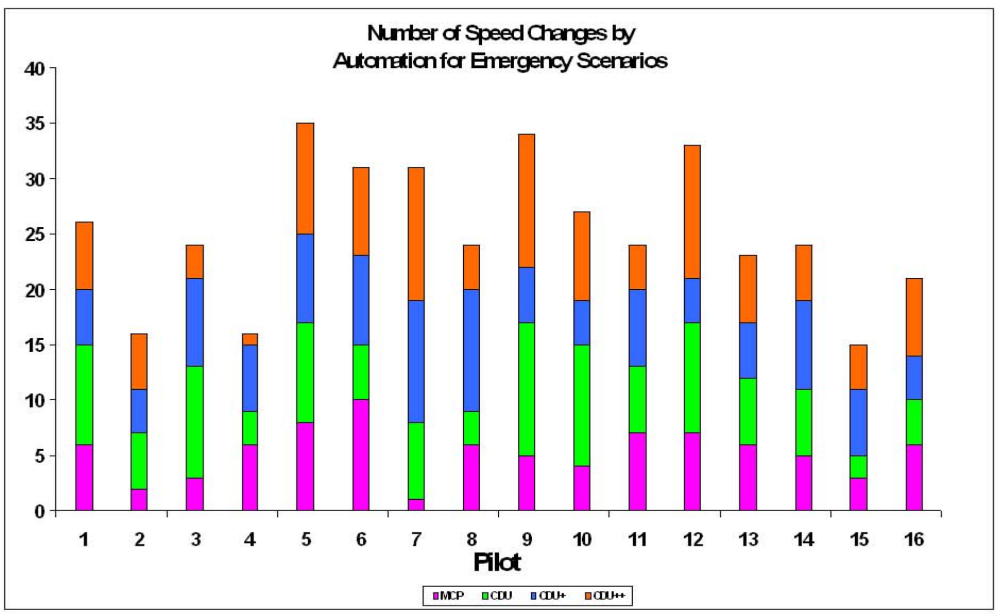
Deviation from Baseline Plan: Time of Flight



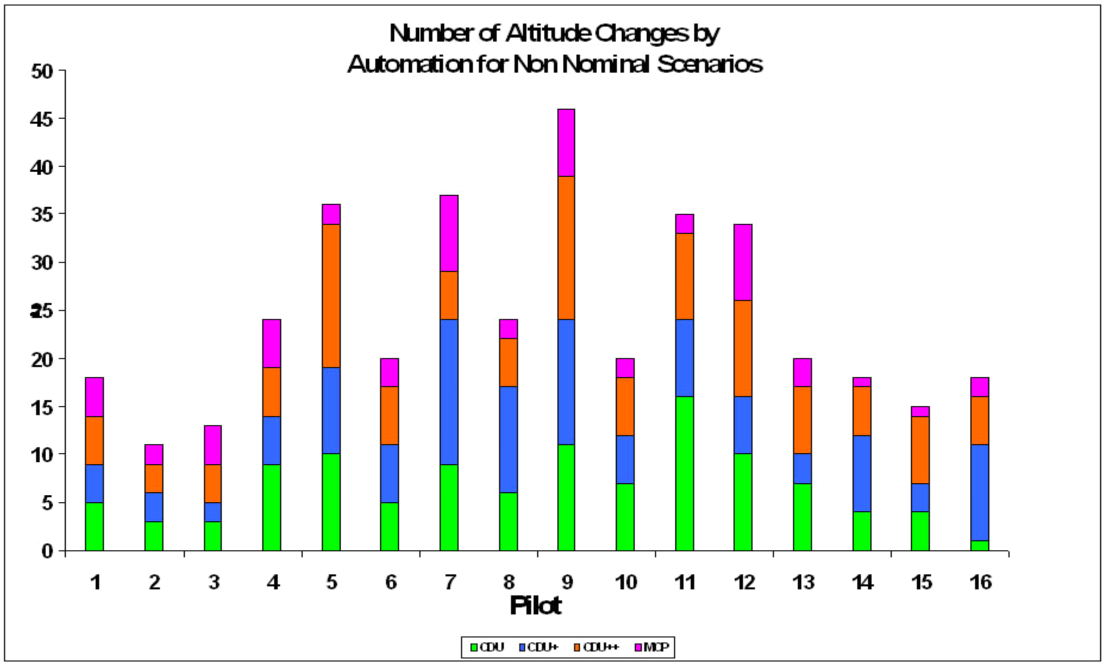


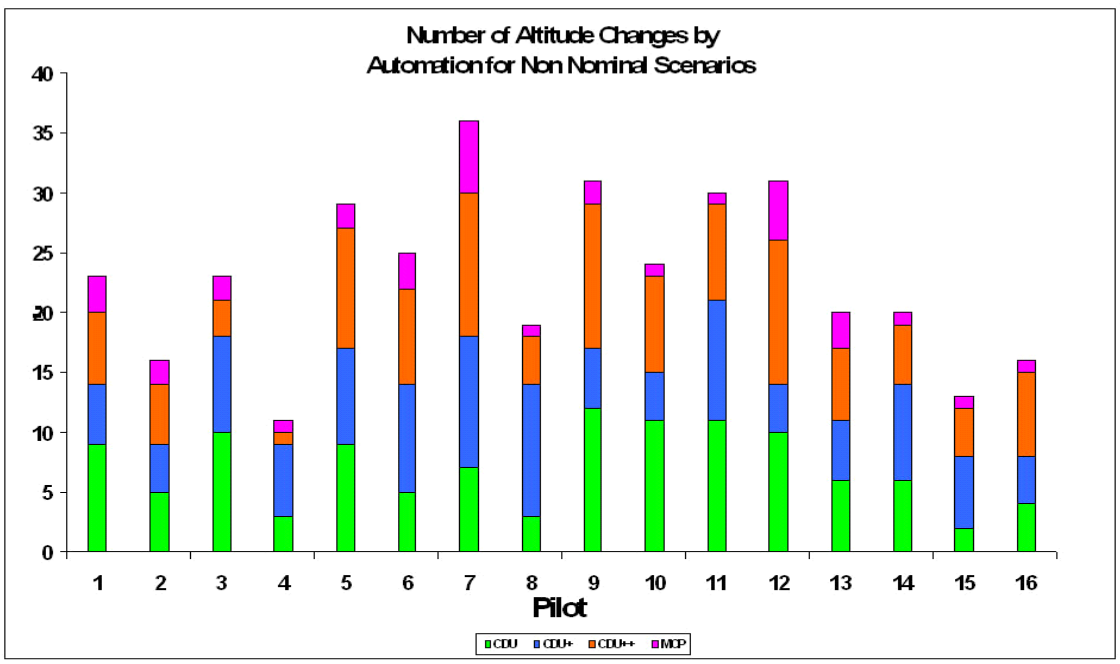
Number of Speed Changes





Number of Altitude Changes





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