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Flight Crew Factors for CTAS/FMS Integration in the Terminal Area

Barry W. Crane, Thomas Prevot, and Everett A. Palmer
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August 2000

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Summary

Center TRACON Automation System (CTAS)/Flight Management System (FMS) integration on the flightdeck implies flight crews flying coupled in highly automated FMS modes [i.e. Vertical Navigation (VNAV) and Lateral Navigation (LNAV)] from top of descent to the final approach phase of flight. Pilots may also have to make FMS route edits and respond to datalink clearances in the Terminal Radar Approach Control (TRACON) airspace. This full mission simulator study addresses how the introduction of these FMS descent procedures affect crew activities, workload, and performance. It also assesses crew acceptance of these procedures. Results indicate that the number of crew activities and workload ratings are significantly reduced below current day levels when FMS procedures can be flown uninterrupted, but that activity numbers increase significantly above current day levels and workload ratings return to current day levels when FMS procedures are interrupted by common ATC interventions and CTAS routing advisories. Crew performance showed some problems with speed control during FMS procedures. Crew acceptance of the FMS procedures and route modification requirements was generally high; a minority of crews expressed concerns about use of VNAV in the TRACON airspace. Suggestions for future study are discussed.

Background

National Airspace System Problems

Increasing congestion at airports

"By the year 2011, aircraft operations at the top 100 airports are projected to increase 32 percent beyond current day (1998) operations. This increase and projected further increases indicate that the busiest U.S. airports are getting busier, which will compound problems of congestion at these key airports unless airport and airspace capacity enhancements are made. Assuring that the capacity of the National Airspace System (NAS) can accommodate the growing demand for aviation services is critical to the Nation's economic future" (FAA Office of System Capacity, 1998).

Current operations in and near the terminal airspace

The current air traffic control system uses analog voice communications, and tactical vectoring for aircraft separation and traffic flow management in the arrival and approach phases of flight. Aircraft in general begin their descent in an Air Route Traffic Control Center (ARTCC or Center) on charted Standard Terminal Arrival Routes (STARs) that include both lateral and vertical constraints for the path of flight. The lateral constraints consist of a path defined by straight line segments between navigational database waypoints that terminate at or near a "corner post" or entry gate into Terminal Radar Approach Control (TRACON) airspace. This lateral path defined on the STAR is generally cleared by Center controllers and flown by pilots as specified on the STAR chart. The vertical constraints of a STAR are specified as speed and altitude restrictions associated with the navigational waypoints on the STAR. When an aircraft nears the termination point of the STAR, it is handed off to TRACON air traffic controllers. TRACON controllers guide the aircraft to an assigned runway by issuing tactical altitude, speed, and heading instructions. Unlike the STAR used in the center airspace, these TRACON routes are not charted. Although nominal paths are usually followed in the TRACON, the aircraft crew is generally only aware of their current instructions (altitude, speed, and heading). As traffic levels increase, both Center and TRACON controllers are forced to direct aircraft on 'radar vectors' that deviate from STARs and the nominal preferred TRACON paths to runways.

Current and forecasted problems

This approach to air traffic management is becoming inefficient in meeting growing air traffic demands. The continued growth of air traffic at major airports has caused increases in air traffic delays and has put considerable stress on both existing air traffic control (ATC) systems and on the air traffic controllers themselves (Davis, et al., 1997). The projected increase in aircraft operations would produce undue strain on the current air traffic management system. A more efficient system is needed in order to accommodate the anticipated growth in operations. These concerns have motivated development of computerized controller aiding tools aimed at helping controllers cope with increased traffic demands.

Problems from the user perspective

The airborne Flight Management System (FMS) is a highly capable present day technology. An estimated 10,000 FMS equipped aircraft exist in the current worldwide fleet. Aircraft FMSs enable airplanes to compute and fly fuel efficient trajectories accurately. However, the FMS is seldom utilized within the TRACON airspace due to the current controlling method of tactical vectoring. This requires aircraft to remain in the air longer and fly less efficient descent profiles than is possible when the FMS is used. The result is significant airspace congestion and major airline costs due to fuel burn and added delays.

Proposed Solutions

Controller aiding

To address these problems, NASA and the FAA have been developing the Center TRACON Automation System (CTAS). CTAS is set of ground-based decision support and aiding tools intended to assist controllers with aircraft sequencing, separation, flow control, scheduling, and trajectory prediction in and around the terminal area (see Erzberger et al., 1993). CTAS is comprised of three primary tools. The first tool is the Traffic Management Advisor (TMA). The TMA computes and plans a landing time and sequence number for every aircraft approaching an airport while that aircraft is still in cruise flight. Next the Enroute Descent Advisor (E/DA), advises a fuel efficient descent which can include a particular routing, profile, or speed, in order to meet the arrival time at the TRACON meter fix computed by the TMA. As the aircraft crosses the meter fix and enters the TRACON airspace, TMA updates the sequencing and arrival time plan and assigns a runway for the aircraft. Next, while the aircraft is in the terminal airspace, the third CTAS tool, the Final Approach Spacing Tool (FAST), advises the controller in order to accurately space and sequence the aircraft in the TRACON airspace. FAST advisories may include speeds or particular routings for the aircraft to fly in order to meet the TMA computed threshold arrival time.

The CTAS tools manage arrival traffic strategically to prevent airspace overload and reduce delays. By assigning each aircraft approaching the airport a "slot" defined by a scheduled arrival time at the runway threshold and various intermediate arrival times along the descent path, CTAS can optimize traffic flow to an airport. CTAS can then aid controllers in implementing this optimal traffic flow by providing strategic routing and speed advisories for aircraft to fly in order to meet their scheduled arrival times (see figure 1).

CTAS/FMS integration

The Enroute Descent Advisor tool has undergone field testing at Denver International Airport in recent years (see Green et al., 1996; Cashion et al., 1995; Palmer et al., 1997). The E/DA implementation utilized in these field tests involved issuance of top of descent point and cruise and descent speed advisories to aircraft. These advisories served to adjust arrival time at the TRACON metering fix while keeping aircraft on conflict free trajectories. A more advanced implementation of the E/DA to aid controllers with arrival time adjustments supports rerouting of the aircraft. This is accomplished with a Trial-

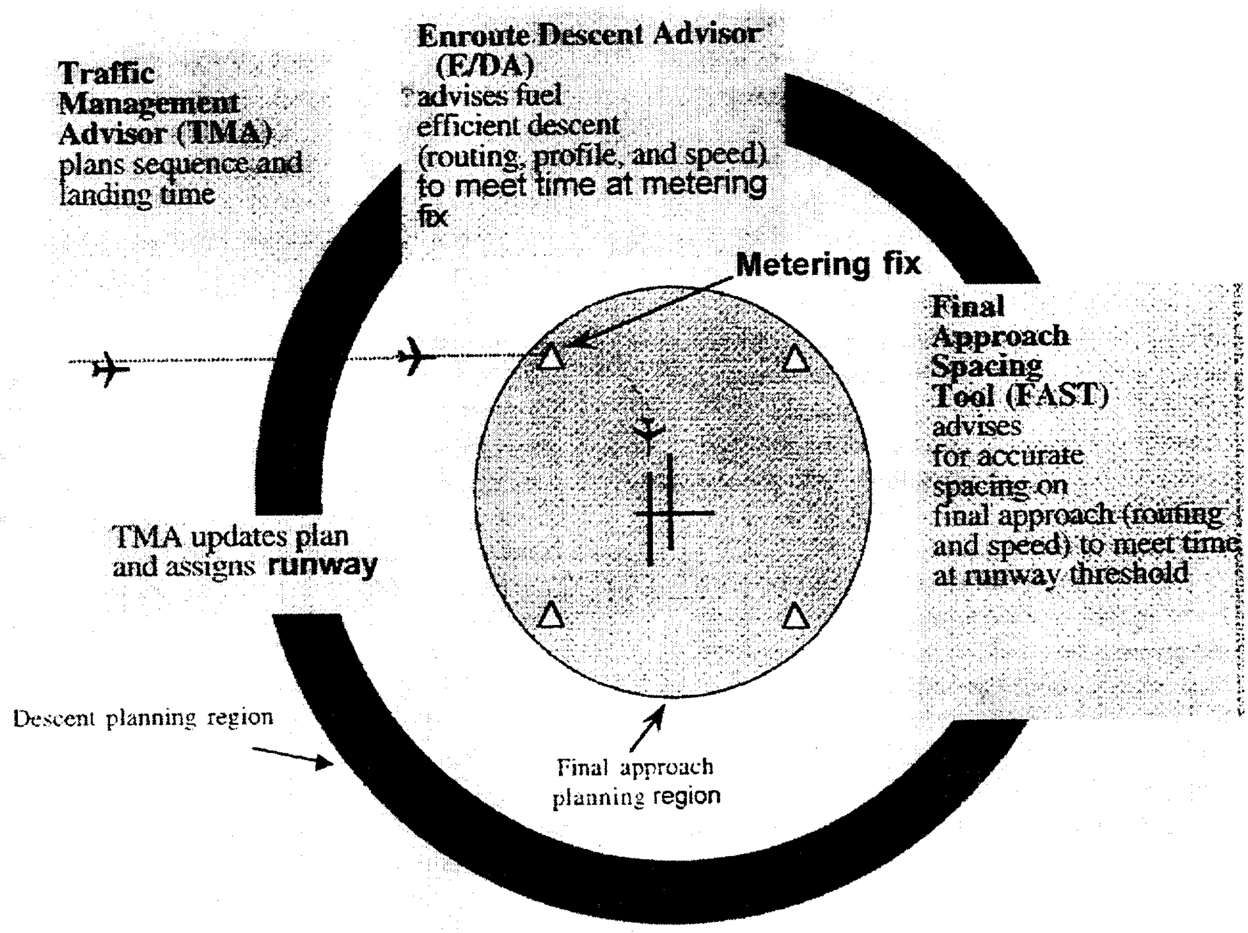

Figure 1. CTAS Tools: Traffic Management Advisor (TMA), Enroute Descent Advisor (E/DA), Final Approach Spacing Tool (FAST).

Planning-Waypoint functionality that allows controllers to propose routings to the E/DA with a movable waypoint to adjust arrival times and avoid conflicts. This new routing, once verified by the E/DA and air traffic controller, can then be communicated to the aircraft by voice or by data link. The data link implementation would allow uplink of this route to Flight Management System (FMS) equipped aircraft. This E/DA functionality is proposed as a possible approach to integrating CTAS with the airborne FMS in the Center airspace. It is hypothesized that the uplink of these routes, to be loaded and then flown by the aircraft FMS, could improve aircraft flightpath accuracy and therefore increase arrival-time accuracy.

The FAST tool can also be utilized to various degrees to aid controllers with scheduling and sequencing aircraft. The *Passive* FAST implementation, which has been under field study for the past few years at the Dallas Fort Worth Metroplex (see Davis et al., 1997), provides controllers with landing sequence and landing runway advisories for all aircraft entering the TRACON airspace. It is left to controllers' discretion whether to heed these advisories.

A more advanced functionality of FAST currently under research is known as TAP FAST. This FAST implementation not only provides the controller with a computed route for each aircraft to fly in the TRACON airspace but provides the capability to uplink this route to Flight Management System (FMS) equipped aircraft. TAP FAST is proposed as a possible approach to integrating CTAS with the airborne FMS in the TRACON airspace. As with the E/DA functionality, it is hypothesized that the uplink of these routes to be flown by FMS aircraft could improve aircraft flightpath accuracy in the TRACON airspace to increase arrival time accuracy. This could allow for closer entrail spacing of aircraft and increase runway throughput at airports. This can also be down with the Active FAST system.

In order to implement these E/DA and FAST route uplink functionalities as described, an air-ground data link capability is necessary. This would entail the implementation of many technologies not currently available to ATC ground stations, aircraft flight decks, and the National Airspace System (NAS) communications infrastructure. Hence, this use of these E/DA and FAST concepts is necessarily intended for more far term implementation.

To permit CTAS/FMS integration in the near term, a concept has been developed that is intended to work with currently available technologies. This concept utilizes the E/DA Trial-Planning-Waypoint and TAP FAST functionalities minus their datalink capability. Thus, the controller is still provided with a route for each aircraft to fly but must communicate this route via the voice channel. Due to the complexity of information contained in even the shortest route segment, voice communication of all this information is not feasible. To make this concept workable, this study proposes configuring the E/DA and TAP FAST to compute nominal default paths from Standard Arrival Routes (STARS) to runway approaches utilizing only speed and path extension degrees of freedom. This permits the loading of these nominal routes in airborne FMS databases as well as charting these routes on cockpit Jeppesen charts. These charted routes are called FMS arrivals and transitions. The controller can clear an aircraft for the FMS arrival and transition and verbally specify any modifications to this route whether they be route modifications, speed change points, or path extension lengths (see Appendix A for a sample FMS arrival and transition chart).

Coordination of automation tools such as E/DA, FAST, and the FMS may enable aircraft to use their FMS computed trajectories from top of descent to final approach. If an aircraft can remain on an FMS trajectory until the final approach, a number of sources of arrival time error are eliminated. This is because aircraft on FMS routes can fly more predictable and precise trajectories, and thus they are more likely to match trajectories and arrival times anticipated by controllers and predicted by the CTAS tools. Placing aircraft on FMS paths can also help reduce excess spacing buffers, and increase the efficiency of the CTAS delay distribution function (Couluris et al., 1997). This could allow for increased capacity, efficiency, and safety in the terminal airspace. Additionally, if controllers are able to clear aircraft for FMS routes in the Center and TRACON airspace, this would reduce the number of clearances required to guide aircraft through this airspace. This could result in a reduction in both pilot and controller communication workload.

FMS Descent Procedures

FMS descent procedures involve descents from cruise altitude to the final approach course intercept without radar vectors or altitude assignments with the aircraft coupled to the FMS in both the lateral and vertical navigation and guidance modes. The lateral and vertical route is specified on paper charts and is coded and selectable in the aircraft FMS electronic database. The route is loaded via the Control and Display Unit (CDU) and can be selected in the approach page database adjacent STAR and runway listings. As of 1999, STARs in the National Airspace System (NAS) generally terminate at the TRACON entry "corner post" after which aircraft are typically issued vectors from ATC to the final approach course. FMS descent procedures vary in the extent of their routing but usually describe a path that includes the current day STAR routing and then extend into TRACON airspace to the point of localizer capture (final approach) at a specified runway or series of runways. FMS descent procedures are distinguished from STARs primarily by this charted transition routing in the TRACON airspace. Another distinguishing feature of FMS descent procedures is that when they are loaded into the flight computer via the CDU, all charted altitude and speed restrictions appear adjacent their corresponding waypoints on the CDU legs page. With STARs, charted crossing restrictions, whether specified as "expect" or "cross at" values, require manual input by the flight crew once the STAR has been loaded. When a STAR is in use, ATC is required to explicitly clear aircraft for all charted restrictions stated as "expect" on the STAR chart. FMS descent procedures do not include "expect" restrictions because all charted values, both speed and altitudes, are "hard" restrictions that must be flown once an aircraft is cleared for the FMS descent procedure.

FMS descent procedures take advantage of the advanced Flight Management System in today's aircraft. They are intended to optimize the lateral and vertical path flown by aircraft in order to reduce fuel consumption and provide a predictable descent path for aircrews and controllers thereby reducing the need for radar vectoring (Transport Canada, 1997). FMS descent procedures are designed to allow maximal utilization of the vertical and lateral navigation and guidance capabilities of automated aircraft. They provide the crew with a well defined predictable path for the aircraft to fly in the descent phase of flight. FMS descent procedures require flightcrews to use their FMS at low altitudes, in the high workload descent phase of flight. In today's operations, crews are accustomed to a lesser degree of automation during this phase of flight that involves active speed, heading, and altitude control via direct autopilot inputs.

FMS descent procedures are proposed as a primary integration step with the E/DA and FAST CTAS controller aiding tools. These have been termed CTAS/FMS procedures. This entails the FMS descent procedures described above with route modification and speed update capabilities added. This involves the flight crew receiving an initial clearance to fly the charted *nominal* FMS routing. While still in Center airspace, the crew may receive an updated routing from ATC, as advised by E/DA, in the form of a descent route modification. When entering the TRACON airspace, the crew is cleared for the remaining TRACON portion of the charted FMS routing. While flying this routing, the crew may receive an amended speed change point and/or a route modification (path extension), to adjust arrival time, spacing, or sequencing of aircraft as advised by FAST. The crew inputs this route modification into the FMS and proceeds to fly the updated routing. This procedure requires crews to fly coupled to the FMS in the Center and TRACON airspace and in addition to make edits to their FMS routes during this phase of flight. In today's vectoring environment, speed amendments and path extension clearances are transparent to flight crews as they are essentially indistinguishable from nominal vectoring procedures and routes.

Flying FMS and CTAS/FMS Descents

Focus of Study

The objective of this research is to determine how a shift from current day (as of 1999) descent procedures (STARs and tactical vectoring in the TRACON) to the proposed FMS and CTAS/FMS descent procedures will impact crew activities, workload, and performance. In addition, the study will elicit pilot perspectives regarding the acceptability and usability of the proposed procedures.

The introduction of FMS descent procedures and CTAS/FMS descent procedures may create substantial changes in the number and nature of the crew's flightdeck activities. Current day descent procedures in the NAS only include routings for the initial descent segment within the Center airspace and require crews to fly the approach segment using discrete tactical clearances from ATC. This allows crews to fly the initial route segment of the descent in a highly automated mode with the autopilot coupled to the FMS, and requires less automated, tactical "Mode Control Panel (MCP) flying", in the non-charted TRACON segment of the descent. FMS descent procedures require crews to fly coupled to the FMS, in a highly automated mode, for the entire descent until turning onto final approach. CTAS/FMS procedures impose the same requirements but also require crews to perform FMS route modifications during descent. These changes in flightdeck activities will be investigated through a full mission simulation of nominal (baseline) and complex descents for the current and proposed descent procedures.

A change in the crew's flight deck activities during the descent phase of flight may impact their workload. Descents are typically very busy periods for the flight crew, and concerns regarding high workload demands during this period are discussed in the literature (Wiener, 1985). This study aims to determine if and how workload is affected by the proposed procedures. If significant shifts in workload levels are found, the goal will be to ascertain the nature of these shifts, whether the shifts maintain workload at acceptable levels, and to identify any potential problems or benefits that may emerge as a result of these shifts. Crew performance is another primary factor to consider with the introduction of new procedures. It is important to determine if crews can maintain acceptable performance when flying the proposed descent procedures. While workload is a metric indicating task difficulty, it is often dissociated from performance measures (Yeh & Wickens, 1988). For example, in a situation where task demands (and thus workload) are already high with a given procedure, and the new procedure imposes even higher demands, performance may degrade but subjective workload measures may not increase. This is because nearly full resources are invested in the first procedure and thus no further resources can be invested into the more demanding procedure producing no subjective increase in task demand. Conversely, if task demands are already very low and increase yet remain low with introduction of the new task, performance will not change but subjective workload will increase (Yeh & Wickens, 1988). This possible dissociation makes it necessary to measure and compare both performance and workload for the new procedures.

Study Approach

The approach for this study was to develop candidate FMS and CTAS/FMS descent procedures for a single arrival, approach, and runway at the Dallas Fort-Worth Metroplex (DFW) that overlay the current day STAR and nominal TRACON vector routing. Then a set of descent scenarios was developed for current day, FMS, and CTAS/FMS operations. A nominal baseline descent scenario was generated for the current day (as of 1999) and FMS operations. A more complex descent scenario was generated for the current day, FMS, and CTAS/FMS operations.

To support the newly developed CTAS/FMS procedures, various interface enhancements were designed and implemented. These are described below. A full-mission simulation was then conducted to track crews' actual descent activities, and to gather workload, performance, and attitudinal measures from crews.

Development of FMS descent procedures

The FMS descent procedures were developed by drafting an experimental Jeppesen chart (see Appendix A) and coding the charted routing in the FMS database of the test simulator. The arrival portion of the procedure overlays the routing of the current day Glen Rose 3 STAR at DFW (see Appendix A). Unlike the STAR, all the crossing restrictions are "hard" restrictions as depicted on the chart and are loaded into the FMS from the database. This means that the restrictions are an integrated element of the procedure and crews must comply with them when cleared for the procedure. The transition portion of the FMS procedure overlays the current nominal vector routing from the Glen Rose 3 STAR to runway 18R at DFW. Like the FMS arrival portion, this routing includes "hard" speed and altitude crossing restrictions up until the final approach course. Crews are required to fly the procedure in Vertical Navigation (VNAV) and Lateral Navigation (LNAV), the FMS guidance modes.

Development of CTAS/FMS descent procedures

The CTAS/FMS descent procedures (see Appendix A) are identical to the FMS descent procedures except for the addition of speed and route modification degrees of freedom as integrated elements of the procedure. Notes on the charted CTAS/FMS procedure advise the crew that they may receive a speed to fly and/or a route modification in the arrival segment of the descent. They are also advised that they may receive a speed amendment and/or a route modification (downwind extension) during the transition segment of the procedure.

Interface enhancements

To support the speed and route modification degrees of freedom required for the CTAS/FMS procedures, three cockpit interface enhancements were prototyped for the current study. The three enhancements represent a continuum from near term to far term technologies.

The near term enhancement, termed Manual Path Extension (MPE), enables a route modification to the TRACON portion of the FMS procedure routing via CDU inputs made by the crew. The route modification involves an extension of the downwind and final approach distances of the FMS procedure. This is made possible through an experimental leg type termed a Fix-to-a-Variable-Distance leg. The length of this leg can be altered by the crew as many times as desired by down selecting its reference waypoint (ROSEL for current study) in the CDU scratch pad and entering the new desired distance. This is intended to support the TAP FAST tool which advises controllers with strategic base turn points for aircraft in the TRACON airspace.

The second, medium term interface enhancement, termed CDU DL (Control and Display Unit Data Link), utilized data link route modifications and communications via the CDU. This interface was inspired by the current FANS (Future Air Navigation System) data link implementation in use in the B747-400 aircraft. The CDU DL interface was used to support E/DA and FAST route modifications. Route modifications were uplinked to the aircraft and loadable directly into the FMS by crew CDU actions. This loadable route could be inserted into the current FMS route and thus implemented the specified route modification.

The far term interface implementation, termed DDL (Distributed Data Link), also features an air-ground data link for route modification communications. Unlike the CDU DL interface, data link route messages were displayed directly in the upper center EICAS (Engine Indicating and Crew Alerting System) screen on the flightdeck, and responses to data link messages were made using buttons placed adjacent to the MCP on the flightdeck glareshield. Route modification messages automatically loaded into the FMS 'mod route' upon arrival. Crews reviewed, and if they were acceptable, executed and accepted these route modifications.

Each of these interfaces allows the actual computed CTAS routing to be input into the FMS. Because some of these route modifications occur in the busy TRACON airspace, key questions regarding each of these interfaces are: Will crews successfully perform all the necessary steps required to complete the route modification task for each interface? How much time will be required to complete the route modification tasks? How much total "heads-down" time will be required by each crew member during performance of the tasks? For each interface, what is the average length of time each crew member fixes his or her gaze, or dwells, in the "heads-down" position?

Descent scenarios

Two descent scenarios were developed for the study. The first scenario, termed *baseline,* consisted of ATC clearances to fly charted routings from top-of-descent to final approach with no deviations for vectors, temporary altitudes, or speed amendments. The second scenario, termed *complex*, contained deviations from the charted routings including vectors, intermediate altitude level-offs, and speed amendments. The complex scenario represented likely CTAS advisory clearances from ATC. These two descent scenarios were used in both current day and FMS procedure conditions to facilitate direct comparison between the current day (STAR) and FMS procedure contexts. The complex scenario was also used for the three CTAS/FMS procedure contexts (Manual Path Extension, CDU DL, and DDL.) to test use of these interfaces as a method of dynamically updating FMS routes (see figure 2).

Theoretical Perspective of Crew Activity Analysis

Prior to analysis of crew activities, a short background and theoretical discussion of pilot interaction with aircraft automation is necessary. This will provide a framework for discussion and analysis of crew activities.

Control and management automation descriptions and definitions

Automatic piloting devices have been in use in aircraft since the 1930's. These early autopilots relieved pilots of the manual labor of hand-flying on long flights. They provided inner-loop control to the aircraft in response to direct pilot instructions but left the pilot to perform all navigation and other essential piloting tasks (Billings, 1996). By the 1980's autopiloting advances built on microprocessor technology provided the capability to program complete routes into a flight computer, to couple this computer to an autopilot, and to hand over the navigation, guidance, and control tasks to the computer.

Procedure	Baseline Scenario (no route deviations)	Complex Scenario (CTAS advisories)
Current Day (as of 1999)	X	X
FMS	X	X
Manual Path Extension		X
CDU DL		X
DDL		X

Figure 2. Test matrix.

The crew acts to monitor the computer's "actions", to update the programmed flight route, or make any necessary interventions. These two categories of automation have been termed control automation (e.g. Fadden, 1990) and management automation (e.g. Billings, 1996) respectively (see Billings (1996) for a more complete discussion).

In the aviation domain, control automation entails the use of an autopilot as a tactical controller of the aircraft in response to explicit speed, heading, and altitude command inputs from the pilot. Management automation involves strategic programming of a complete lateral and/or vertical flight plan into a flight management computer which can be coupled to the autopilot to autonomously carry out the aircraft navigation, guidance, and control necessary to follow the programmed route with limited pilot input.

With an aircraft under control automation, the pilot makes discrete tactical inputs commanding immediate output (behavior) from the autopilot. The crew ensures that the autopilot is moving toward and then maintaining this goal (monitoring) until the time for further tactical input arises. For example, the pilot may select a new heading for the aircraft to fly by dialing the value into the autopilot (Mode Control Panel). The autopilot in turn commands the aircraft to turn immediately to this heading and maintain it until the pilot makes further tactical inputs. Thus, control automation is characterized by the pilot specifying a discrete goal state to the autopilot and the autopilot proceeding immediately to satisfy and maintain that goal.

With an aircraft under management automation, the pilot makes primarily strategic inputs to a flight management computer (FMC). The pilot can then couple the FMC to the autopilot so that it carries out the programmed inputs. The pilot then must verify that the aircraft is behaving as programmed (monitoring). For example, the pilot may input a series of waypoints that define a route from one airport to another, couple the autopilot to the FMC via the lateral navigation mode (LNAV), and then monitor the aircraft behavior as it flies the programmed routing. Thus, management automation is characterized by the pilot specifying a series of goal states to the FMC in one programming cycle, and the FMC commanding the autopilot to carry out these goals without further pilot input. Unlike control automation, in management automation the aircraft does not necessarily proceed immediately with programmed goals. The aircraft can only pursue one goal (in each control axis) at a time and thus a latency often exists between goal specification and goal execution (aircraft behavior).

For ease of discussion the phrase "tactical input" or "tactical activity" will be used interchangeably with the phrase "use of control automation", and the phrase "strategic input" or "strategic activity" will be used interchangeably with the phrase "use of management automation".

Expected crew activity changes

Based on activity models developed with subject matter experts prior to the simulation study, it is anticipated that compared to current day descent procedures, crews flying FMS descent procedures during the *baseline* scenario will show [hypothesis (1)] a marked reduction in the number of observable crew activities (physical inputs into aircraft automation) that results from [hypothesis (2)] performance of significantly fewer tactical activities (use of control automation), and therefore, performance of primarily strategic activities (use of management automation). However, when flying FMS descent procedures during the *complex* scenario, it is anticipated that [hypothesis (3)] the number of crew activities will be roughly equal to that of current day descent procedures.

The anticipated changes in crew activities with the FMS procedure *baseline* scenario will alter crew flight deck *monitoring* behavior by requiring intermittent and continuous monitoring of multiple latent aircraft behaviors typical of management automation use rather than immediate monitoring of immediate aircraft behaviors as is seen with use of control automation. Also, with the FMS procedures, crews will be entrusting automation guidance to comply with programmed altitude restrictions, rather than meeting charted restrictions tactically, and crews are expected to utilize the LNAV and VNAV automated flight modes in the TRACON airspace. These modes are not available with current day (as of 1999) STAR procedures. This study investigates the workload and performance impact of these procedural changes in the number and character of flight deck activities, and the acceptance of these changes by crews.

The CTAS/FMS descent procedures are adjuncts to the FMS descent procedure designed to better accommodate the dynamic advisories generated by the E/DA and FAST controller aiding tools. Aside from the assigned descent speed in the CTAS/FMS procedures, the *complex* scenario events are identical between the FMS and CTAS/FMS procedures. The primary difference is that the CTAS/FMS procedures permit crews to modify an existing FMS routing in a *strategic* fashion thereby retaining accurate FMS guidance of the flight. This is made possible in this study by the three interface enhancements previously discussed.

The primary differences among the three CTAS/FMS procedures are the manner in which FMS route modifications are made. The interface enhancements provided in the CTAS/FMS procedures explore alternative methods for responding to the ATC prompting events. In this study, the acceptability and performance by flight crews of these route modifications and their interfaces is explored. A description of each CTAS/FMS procedure interface is provided below.

The first CTAS/FMS interface, Manual Path Extension (MPE), involves manipulation of the existing FMS transition procedure base turn point via the CDU LEGS page. There are six tasks necessary to complete the activity. The crew member must (1) acknowledge and readback the ATC cleared base turn distance, (2) line select the reference waypoint ROSEL into the CDU scratchpad, (3) enter a backslash (/) and the new base turn point value, (4) reselect the waypoint into the flightplan, (5) review the modification on the CDU and Navigation display, and (6) execute the modification by pressing the execute button on the CDU. Observe that this activity requires the crew to make entries of numerical data by hand in a specified entry format (i.e. /X.X) making it potentially error prone and subject to forgetting (Billings, 1996). In addition, this is a CDU task that requires the non-flying crew member to go "heads-down" in the busy TRACON airspace. The MPE interface does not support E/DA route modifications issued in the Center airspace.

The second CTAS/FMS interface, CDU DL, involves loading, executing, and accepting, via the CDU, an ATC data link message that contains an E/DA rerouting of the FMS Arrival or a FAST base turn point extension routing. This activity contains seven tasks. Upon receipt of the data link message (indicated by a chime, and an EICAS and CDU message), the non-flying crew member must (1) press the ATC key on the CDU, (2) read the message text on the CDU page aloud to the other crew member, (3) receive confirmation from the other crew member, (4) load the new route by pressing a LOAD prompt, (5) the flying crew member reviews and verifies the loaded message on the LEGS page (this is necessary because the non-flying crew member is on the ATC page) and Navigation display, (6) the non-flying crew member accepts the message by pressing the ACCEPT prompt, and (7) the flying crew member executes the new route. The CDU DL activity requires both crew members to go "heads-down" in the TRACON airspace.

The third CTAS/FMS interface, DDL, involves executing and accepting an ATC data link message through use of a "heads-forward" interface. This activity contains five tasks. Upon receipt of the data link message (indicated by a chime, and an EICAS and CDU message) the non-flying crew member must (1) read the message text *on the EICAS display* aloud to the other crew member, (2) receive confirmation from the other crew member, (3) review and verify the automatically loaded message on the LEGS page and Navigation display, (4) execute the new route by pressing the execute button on the CDU, and (5) accept the message by pressing the accept button *on the glareshield.* Unlike all the tasks in the previous two activities, only task (4) requires the non-flying crew member to go "heads-down" in this activity. Furthermore, when the message arrives, the text is immediately displayed on the EICAS screen, and the route modification is automatically loaded. This eliminates the access and loading steps required with the CDU DL activity. Both the CDU DL and DDL activities eliminate the requirement to manually enter new route data as in the MPE condition.

It is important to note a distinction between the MPE and data link conditions. With the MPE path extension, crews manually modify only the base turn point. In the data link conditions, the FAST uplink may contain other changes to the route in addition to the base turn point extension such as a modified speed schedule or new crossing restriction parameters.

Activity models generated with subject matter experts reveal a modest reduction in the number of required crew activities with the introduction of the data link interfaces only. The reduced number of activities for the CDU DL and the DDL procedures result from the uplink of CTAS route segments that provide modifications to the FMS descent procedure routing. This permits crews to remain coupled to their FMS routing, and thus to continue strategic flying, through most of the descent. The number of crew activities for the MPE procedure is nearly identical to the complex FMS procedure scenario for the initial descent segment. Differences in activities arise in the TRACON airspace. The MPE interface supports strategic modification of the base turn point distance. This prevents the need to revert to control automation as in the FMS procedure when the base turn point is extended by ATC.

Relationship to previous research

Since the advent of automation technology in commercial aircraft, a steady stream of research has emerged that addresses the impact of automation on flight crews (Wiener & Curry, 1980; Wiener, 1985; Curry, 1985; Wiener, 1989; Tsang & Vidulich, 1989; Billings, 1996). Two main assertions appear repeatedly in this body of literature. First is the assertion that the human is poorly suited as a system monitor. And second is the claim that increased automation on the flight deck may not reduce crew workload but will merely shift its nature from physical operations (e.g. button presses, etc.) to more mental operations (e.g. monitoring, etc.). Billings (1996) discusses issues of monitoring and workload of management automation specifically. He remarks that use of management automation means *management by exception*. This means the automation is given the authority to carry out all programmed tasks and performs them unless the crew takes exception. He comments that this may lighten physical workload, but may increase the cognitive burden on the crew as they are required to anticipate and confirm correct automation behavior. Also, Billings warns that use of this type of automation may decrease the crew's involvement with the flying task and the mission as a whole. He remarks that even the most motivated and capable pilot can fatigue and lose vigilance when activity demands are so dramatically reduced. While the claims in this literature hold theoretical and intuitive merit, empirical study is needed to support or oppose these assertions. This study is intended to provide such empirical data. The workload and performance measures to be gathered are intended as an initial examination into the effects on pilots of increased automation in the descent phase of flight. The assertions that pilots are poorly suited as system monitors and that greater use of management automation may decrease pilot involvement in the flying task are not directly addressed in this study. However, performance results may be able to provide hints as to possible problems brought on by increased use of management automation during the descent phase of flight.

Method

Participants

Twelve flight crews who fly for commercial air carriers were recruited to participate in the study. Participants were recruited by the Raytheon Corporation and were paid for their time and compensated for travel and accommodation expenses. Crew participation requirements included: a type rating on the Boeing 757, 767, 737-500, or 777 aircraft and no prior data link experience.

Equipment

Crews flew in the Advanced Concepts Flight Simulator (ACFS) at NASA Ames Research Center (see Blake, 1996). This simulator is a full-mission type with a "generic" glass cockpit layout. It resembles the B757 aircraft in its avionics layout and functionality. Additions to the cockpit avionics are four interface enhancements: a vertical situation display (see Prevot, et. al. 1998); a variable-fix-to-a-distance leg type in the FMS database; a FANS data link functionality; and an advanced "heads-forward" data link interface.

Design and Procedure

After reading and signing a consent form (see Appendix B), each crew flew seven descents (due to time constraints, four current day and six FMS descents were not flown) from the descent procedures and scenarios previously discussed (see figure 2 and Appendices A and C). Twelve unique random orders were arranged for the seven descents with the condition that no descent appear first more than twice. Crew members alternated as pilot-flying (PF) and pilot-not-flying (PNF) for each descent. Two pseudo controllers acted as confederates and provided ATC clearances to the crews from an ATC laboratory at the simulator facility. A pseudo pilot acted as a confederate and interacted with the pseudo controllers to simulate background chatter during the descent runs.

Crew training

Crews underwent a training session prior to beginning each descent procedure. The training session included presentation and explanation of procedure charts and activities on overhead slides and crew performance of activities in the ACFS with the simulator in "flight freeze". The training criterion was that the crews successfully performed procedure interface activities (e.g. MPE, CDU DL, and DDL) once before the data collection runs were flown. In addition to the procedure-specific training sessions, crews received a background briefing on the CTAS/FMS integration concept. Also, six of the twelve crews received training that allowed them to use the VSD during the study.

Dependent Measures

Crew activity analysis

The number and type of crew activities performed during descents within each procedure condition and scenario type were gathered using the Crew Activity Tracking System (CATS) (Callantine, et. al., 1999). Comparisons were made between the baseline and complex scenarios of the current day and FMS procedures and complex scenario of the FMS and CTAS/FMS procedure scenarios.

Crew workload measure

Following each descent crews were asked to fill out the NASA-TLX subjective workload rating sheet (see Appendix D). Crews were briefed on use of this instrument prior to flying the descents. Subjective crew workload is a dependent measure in the study.

Workload definition and measure description

Crew workload is a measure used in the aviation domain to assess the level of difficulty of required cockpit tasks and procedures. The difficulty of a task can be inferred from the interaction between an operator and the assigned task. Workload refers to the "cost" imposed on the operator as the task is performed (Gopher & Donchin, 1986). This implies that the operator has a limited information processing capacity with a given level of available resources (Kahneman, 1973) and that a given task has variable demands on those resources. Hence, workload can be thought of as the relationship between resource supply and task demand (Wickens, 1992). The more operator resources are imposed on by a task, the less the resource supply will be, resulting in higher workload.

Subjective workload measurement is aimed at capturing task demand and amount of operator resources expended (operator output) through operator self-report. Hart and Staveland (1988) developed the NASA Task Load Index (NASA-TLX), a multi-dimensional subjective workload measure that assesses perceived task demands across three dimensions and perceived operator outputs across three dimensions. The task demand dimensions are Mental Demand, Physical Demand, and Temporal Demand. The operator output dimensions are Performance, Effort, and Frustration. Descriptions of these workload dimensions are found in Appendix D.

Crew performance criteria

Crew performance was evaluated on each descent based on crew compliance with procedural and ATC requirements. All requirements were enumerated during crew training sessions. A list of the specific performance criteria for each procedure can be found in Appendix E. This is a dependent measure in the study.

Video and digital data

To aid with crew performance data collection, crews were videotaped during performance of the descent procedures using an overall cockpit view and a "face" view tracking crew gazing behavior. The "face" view was used to track heads-down and dwell times during route modification activities. Additional cameras were placed on the MCP, CDUs, Primary Flight Display (PFD), and Navigation Display to collect crew activity data. Digital flight data was also recorded.

Crew questionnaire

Crew acceptance of the proposed procedures was evaluated with a post-experiment questionnaire and debriefing session. After flying the seven descent scenarios, crews were presented with the post-experiment questionnaire. Following completion of the questionnaire crews were interviewed and debriefed and allowed to ask any questions regarding the study. Results of the questionnaire are another dependent measure in the study. The crew questionnaire is shown in Appendix F.

Results and Discussion

In order to address the hypotheses described earlier, this section begins with analyses that make direct comparisons between the current day and FMS procedures in both the baseline and complex scenario conditions. The first analysis focuses on the changes in the number and type of crew activities. Activity changes between current day and FMS procedures in both the baseline and complex scenarios will be analyzed. This initial analysis will investigate the hypothesized activity changes previously mentioned. These are: (1) The expected reduction in the number of observable crew activities (physical inputs into aircraft automation) when crews fly FMS descent procedures during the *baseline* scenario as compared to current day descent procedures. (2) This reduction is expected to result from significantly fewer tactical activities, and therefore, use of primarily strategic activities. (3) During the *complex* scenario, the number of crew activities in the FMS procedure will be roughly equal to that of current day descent procedures. Following the activity analysis, subjective workload ratings will be analyzed with the same comparisons used in the activity analysis. Next, two categories of crew performance will be assessed. The first category will address crew compliance with procedural elements such as automation use requirements and speed and altitude crossing restrictions. The second category will address crew performance during the CTAS/FMS procedure (complex) scenarios using the interface enhancements to perform TRACON route modifications during descent. Finally, selected elements from the post experiment questionnaire will be discussed.

Crew Activities: Current Day vs. FMS for Baseline and Complex Scenarios

Planned comparisons

In order to determine the shift in the number and type of crew activities (automation inputs) with the introduction of FMS procedures, analyses were conducted using the Crew Activity Tracking System (Callantine, 1997). Of particular interest was the shift in activities with the introduction of FMS procedures as compared to current day procedures in both the baseline and complex descent scenarios used in the study.

Number of activities

To determine the differences in the total number of crew activities between the FMS and current day procedures and the baseline and current day scenarios, a 2 (Procedures) X 2 (scenarios) analysis of variance (ANOVA) was conducted and revealed no significant main effect for procedure $F\ (1,11) = 1.7$, $p > .05$, but a significant main effect for scenario $F\ (1,11) = 217.3$, $p < .05$, such that crews performed more activities overall during the complex scenario, $M = 37$ (S.E. = 1.1), than during the baseline scenario, $M = 19$ (S.E. = 1.3). The Procedure x Scenario interaction was statistically significant, $F\ (1,11) = 39.7$, $p < .05$, such that the pattern of activity count differences between the FMS and current day procedures depended on which scenario crews were flying. To further investigate this interaction and test the stated hypotheses, simple comparisons were performed between the procedures within each scenario. A one-way ANOVA between the FMS and current day procedures in the baseline scenario revealed, as expected [hypothesis (1)], that based on activity model predictions, crews performed significantly fewer activities on average when flying the baseline FMS procedure scenario, $M = 14$ (S.E. = 1.2) as compared to the baseline current day procedure scenario, $M = 24$ (S.E. = 1.4), $F\ (1,11) = 42.6$, $p < .05$ (see figure 3). However contrary to activity model predictions [hypothesis (3)] stating that activity counts would be roughly equal between current day and FMS procedures in the *complex* scenario, a one-way ANOVA in the complex scenario showed that crews performed significantly more activities during the FMS procedure, $M = 41$ (S.E. = 1.8), than during the current day procedure, $M = 34$ (S.E. = 1.6), $F\ (1,11) = 14$, $p < .05$.

This interaction reveals that when flying FMS descent procedures crews tend to make fewer automation inputs than in current day flying [hypothesis (1)] when the procedure can be flown uninterrupted. If interruptions to the FMS procedure are made, such as off-route vectors, intermediate altitude level-offs, and speed amendments, then crews tend to make more automation inputs when flying FMS procedures than with current day procedures. This is due to the necessity to shift back and forth between strategic and tactical automation modes when flying the FMS procedure. This finding is consistent with debriefing comments made by pilots who stated that FMS procedures are most desirable and require less automation interaction when ATC does not intervene with the charted routing. The changes in the number of specific activity types and the effects on workload of FMS procedures in both the baseline and complex scenarios are discussed below.

Activity types

Activity types used for this analysis were the strategic (management automation) and tactical (control automation) categories described above. Strategic inputs imply use of higher levels of automation that enable the aircraft to carryout future behaviors autonomously. For example, using the LNAV mode for lateral navigation. Tactical activities imply use of lower levels of automation with no autonomy granted to the automation other than to maintain the current tactical target. For example, using heading select mode for lateral navigation.

To investigate differences in tactical activity counts between the FMS and current day

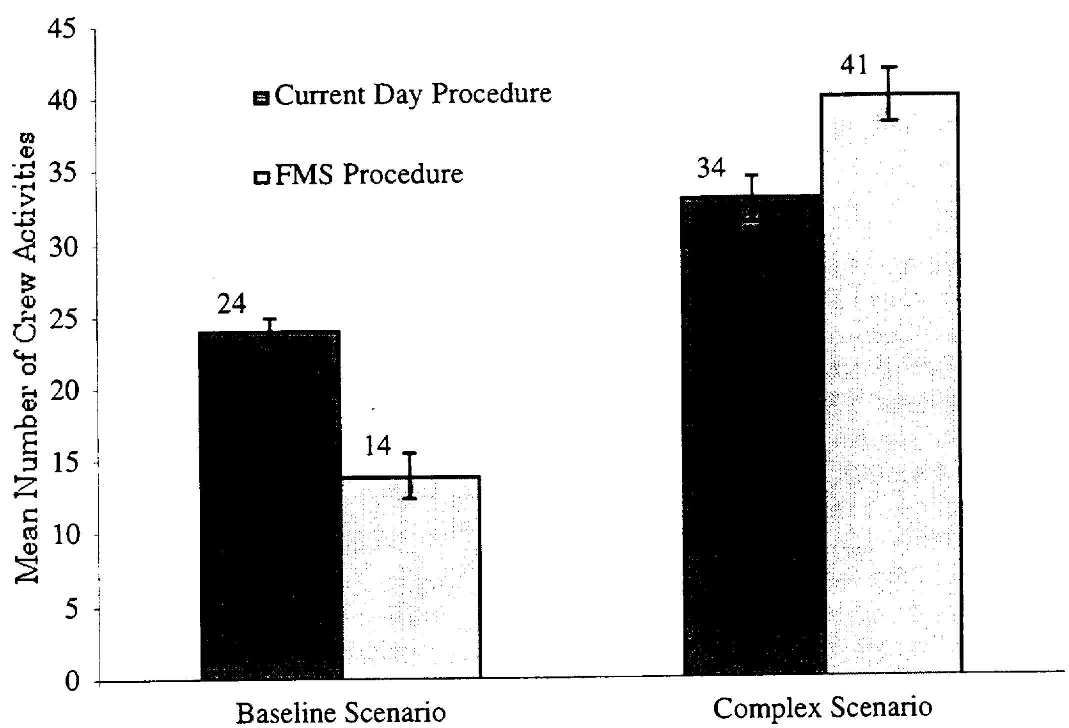

Figure 3. Mean number of crew activities (+/- SE) in Current Day and FMS procedures for baseline and complex scenarios.

procedures during the baseline and complex scenarios and to test hypothesis (2), a 2 (Procedures) X 2 (scenarios) analysis of variance (ANOVA) was conducted and revealed a significant main effect for procedure, F (1,11) = 22.4, p < .05, with crews performing significantly more tactical activities during the current day procedure, M = 16 (S.E. = 0.9), over the FMS procedure, M = 13 (S.E. = 1.5), a significant main effect for scenario, F (1,11) = 143.6, p < .05, such that crews performed significantly more tactical activities during the complex scenario, M = 20 (S.E. = 0.5) over the baseline scenario, M = 10 (S.E. = 0.9), and a significant interaction, F (1,11) = 18.0, p < .05, such that the pattern in the number of tactical activities performed between the two procedures depended on which scenario was being flown (see figure 4). To investigate this interaction further one-way ANOVAs were conducted between the two procedures within each scenario condition. As expected in the baseline scenario [hypothesis (2)], a one-way ANOVA showed that crews made significantly fewer tactical inputs in the FMS procedure, M = 6 (S.E. = 0.8), as compared to the current day procedure, M =13 (S.E. = 0.8), F (1,11) = 31.8, p < .05, but in the complex scenario, there were no significant differences, p > .05, in the number of tactical activities between the current day, M = 20 (S. E. = 0.7), and FMS, M = 20 (S.E. = 0.7), procedures. The drop in tactical activity count for the FMS procedure in the baseline scenario is congruent with the overall activity count pattern for the baseline scenario, but the equal procedure activity count means in the complex scenario does not reflect the rise in the number of FMS activities in this scenario in the overall activity count. A look at the strategic activity counts should clear up this discrepancy and complete the picture.

To investigate the differences in the strategic activity counts between the FMS and current day procedures during the baseline and complex scenarios, a 2 (Procedures) X 2 (scenarios) analysis of variance (ANOVA) was conducted and revealed significant main effects for procedure, F (1,11) = 8.5, p < .05, with crews performing significantly more strategic activities during the FMS procedure, M = 14 (S.E. = 1.5), over the current day procedures, M = 13 (S.E. = 0.5), a significant main effect for scenario, F (1,11) = 142.3, p < .05, with crews performing significantly more strategic activities during the complex scenario, M = 17 (S.E. = 1.0), than during the baseline scenario, M = 10 (S.E. = 0.6), and a significant interaction, F (1,11) = 46.0, p < .05, such that the number of strategic activities performed between the two procedures depended on the type of scenario being flown (see figure 5). To investigate this interaction, a one-way ANOVA of the number of strategic inputs made during the baseline scenario was conducted which revealed that crews made significantly fewer strategic inputs with the FMS procedure, M = 8 (S.E. = 0.8), than in the current day procedure, M =11 (S.E. = 0.7), F (1,11) = 24.7, p < .05. However, the trend reversed in the complex scenario, where a one-way ANOVA revealed that crews made significantly *more* strategic inputs during the FMS procedure, M = 21 (S.E. = 1.2), than in the current day procedure, M =14 (S.E. = 0.5), F (1,11) =, p < .05. This rise in the number of strategic FMS activities in the complex scenario, not found in the tactical activity counts, accounts for the overall activity interaction previously discussed. (see figure 3).

These results highlight the expected large decline in tactical inputs during descent in the baseline scenario with the introduction of FMS procedures. There was also a drop in the number of strategic inputs in the baseline

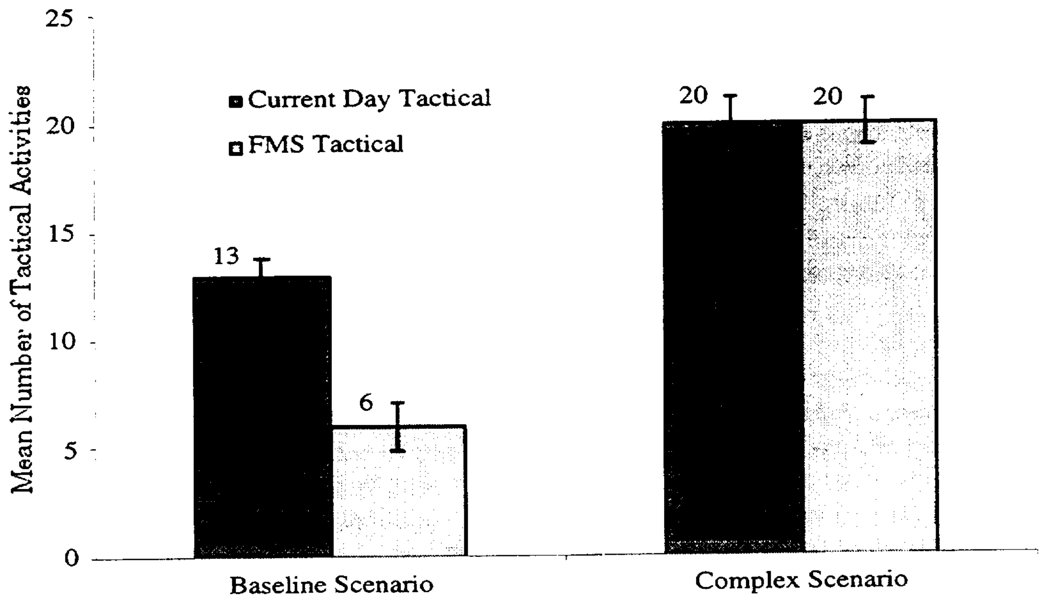

Figure 4. Mean number of strategic crew activities in Current Day and FMS procedures for baseline and complex scenarios.

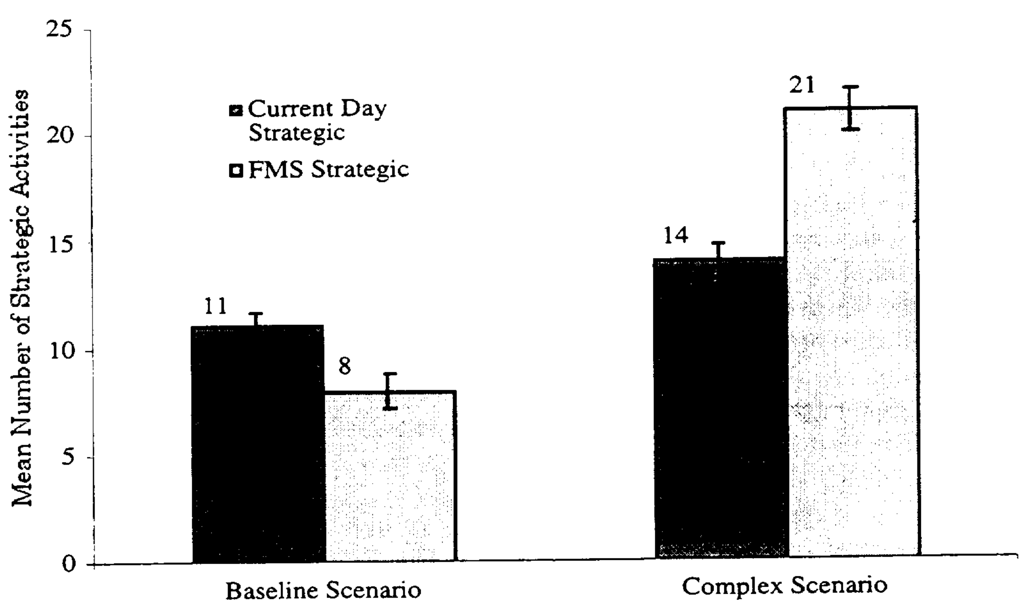

Figure 5. Mean number of tactical crew activities in Current Day and FMS procedures for baseline and complex scenarios.

scenario with the introduction of FMS procedures. With this drop in the number of inputs comes an increase in the number of latent behaviors that are relegated to the automation. Both these decreases led to a reduction in perceived workload in the baseline FMS scenario, but they raise questions as to the implications of increased automation. These issues are discussed below.

The results also indicate that when crews are forced to deviate from and rejoin FMS procedures to comply with ATC constraints as in the complex scenario, the number of tactical activities required rises dramatically (from a mean of six to a mean of twenty) but matches current day procedure levels (twenty) for the same complex scenario. This dramatic rise for the FMS procedure is also found in the strategic activity counts. During the FMS procedure crews performed an average of eight strategic activities in the baseline scenario and an average of twenty-one in the complex scenario. However, unlike the pattern found in the tactical activity analysis, strategic activity levels in current day scenario do not rise so dramatically between the baseline and complex scenarios (from 11 to 14). This finding confirms the notion that during the complex scenario, where there are multiple interruptions to the FMS procedure, crews are required to make frequent strategic inputs, such as re-engaging LNAV and VNAV modes, in order to resume the procedure. This illustrates that because of the strategic nature of FMS procedures, any deviations from the planned and programmed trajectory can lead to a precipitous rise in the required crew activities, both tactical and strategic. This brings into question of the utility of continuing FMS procedures when deviations are required. This issue and the effects on workload of these activity changes is discussed below.

Subjective Workload: Current Day vs. FMS for Baseline and Complex Scenarios

Overall workload ratings were in the low range with a grand mean of 4.8 (S.E. = .4) over a one to twenty point range. Crews reported that lack of out-the-window traffic, no TCAS display, no adverse weather, minimal radio chatter, no company communications requirements, and no interruptions from the passenger cabin during the simulation to be the major factors influencing the lower workload ratings. Crews also commented that the lack of these factors detracted from the realism of the simulation.

To determine workload differences between the two procedures within the two scenarios, a 2 (procedure) X 2 (scenario) ANOVA was conducted which revealed no main effect for procedure, $F(1,23) = 1.1$, $p > .05$, a main effect for scenario, $F(1,23) = 5.0$, $p < .05$, such that crews reported higher workload during the complex scenario, $M = 5.1$ (S.E. = 0.3), than during the baseline scenario, $M = 4.4$ (S.E. = 0.3), and a significant interaction, $F(1,23) = 6.0$, $p < .05$, such that the pattern of workload differences between procedures depended on the which scenario was being flown (see figure 6).

Planned comparisons

To investigate the nature of the interaction, the following workload comparisons were conducted based on comparisons of particular procedure scenarios from the activity analyses above.

Baseline current day procedure scenario vs. baseline FMS procedure scenario

A one-way ANOVA revealed that pilots reported significantly lower mean workload scores in the baseline FMS procedure scenario, $M = 3.9$ (S.E. = 0.5), than in the baseline current day procedure scenario, $M = 5.0$ (S.E. = 0.5), $F(1,23) = 6.0$, $p < .05$ (see figure 6).

Complex current day procedure scenario vs. complex FMS procedure scenario

A one-way ANOVA showed that pilots reported a non-significant difference in mean workload scores in the complex FMS condition, $M = 5.2$ (S.E. = 0.5), than in the complex current day condition, M = 4.9 (S.E. = 0.5). $F(1,23) = .18$, $p > .05$ (see figure 6).

For the baseline scenario, the lower mean activity count corresponds to the lower reported workload in the FMS procedure as compared to the current day procedure. But the higher mean activity count for the FMS procedure complex scenario does not show a corresponding significant increase in workload over the complex current day procedure scenario.

These results indicate that use of FMS procedures during the descent phase of flight leads to reduced flight crew subjective workload ratings when these procedures can be flown uninterrupted. These procedures include significantly fewer crew automation inputs than current day procedures, and more use of management automation. The use of management automation includes use of the VNAV and LNAV modes throughout the descent up until glideslope capture. This is evidence that higher levels of automation use can lead to lower crew subjective workload.

When FMS procedures are interrupted by common ATC clearance amendments, forcing crews to switch between high and low levels of automation multiple times, the average number of crew activities nearly triples (from a mean of 14 to a mean of 41) as compared to the current day rise from 24 to 34 activities. However, workload does not rise significantly above current day levels. This indicates that the requirement to shift between automation levels during descent does not necessarily increase the workload burden on flightcrews. During the debriefing sessions, many crews remarked that they are accustomed to making transitions between higher and lower levels of automation in their current day environment.

The conclusion that workload is not increased when crews are required to frequently switch between management and control automation is made with caution due to the artificially low workload levels experienced by crews overall during the study. These findings need further validation from studies with more realistic task loading on flightcrews during the descent phase of flight. It should also be noted that a

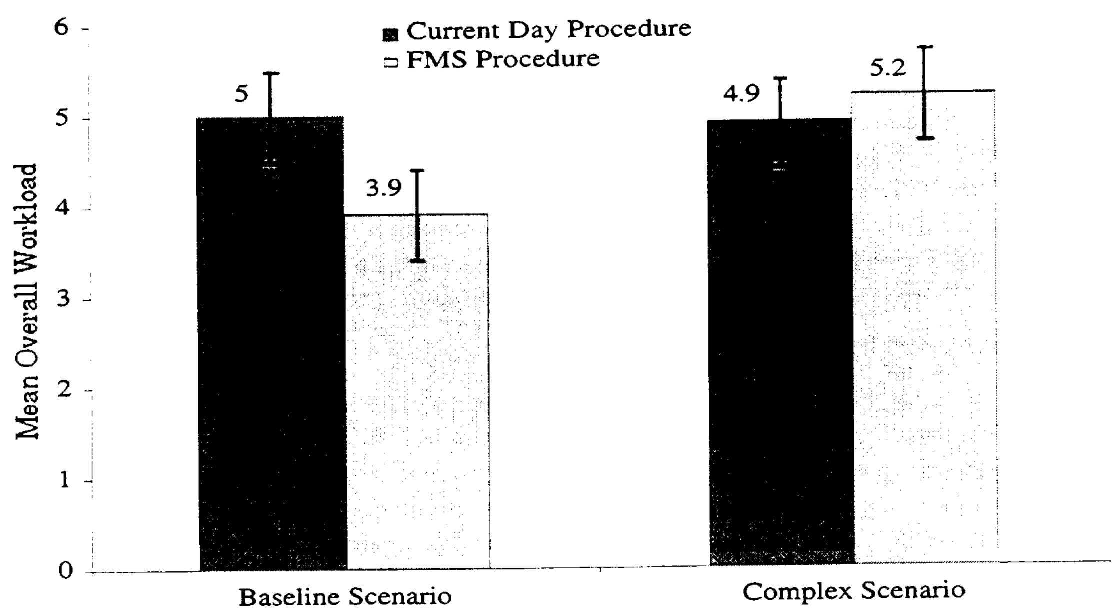

Figure 6. Mean subjective workload ratings (+/- SE) for Current Day and FMS procedures in the baseline and complex scenarios.

reduction in workload is not necessarily the goal of these procedures. The objective was to ensure that with the introduction of FMS procedures, workload remains at manageable levels. These results suggest that this is the case.

The current results indicate that if FMS procedures are implemented, then greater use of management automation in the descent phase of flight will result. The drop in workload levels during the baseline FMS procedures as compared to baseline current day procedures raises questions about the possibility of introducing excessively low workload levels during FMS procedures. The use of management automation assigns most flying tasks to the autopilot after the flight crew loads the FMS procedure and sets up the automation to carry-out the procedure parameters. The flight crew then acts primarily as a system monitor. This calls on concerns raised by Billings (1996) that greater use of management automation may decrease crew involvement in the flying task. This study does not directly address this issue. Performance results discussed below address how well crews comply with FMS procedure requirements, but give no indication of changes in crew vigilance due to increased monitoring demands imposed by FMS procedures. This issue requires the use of specific techniques to test crew vigilance such as the inclusion of automation errors or failures during use of these procedures.

Crew Performance: Compliance with Procedural Elements

The first set of performance results refers to how well crews complied with the requirements and constraints of the procedures flown. This includes compliance with speed and altitude constraints prescribed by each procedure. Also included are the operational requirements in the FMS (and CTAS/FMS) procedures to use VNAV and LNAV during the descent.

Speed and altitude compliance

In two of the seventy-four descents (2.7%), crews were more than ten knots fast at the TRACON boundary crossing restriction waypoint, FEVER. In two of the seventy-four descents (2.7%), one crew was more than 300 feet high at the FEVER restriction and another crew was more than 300 feet low. In four of the seventy-four descents (5.4%), crews were at least ten knots fast at the DELMO waypoint along the TRACON routing. In 30 of the 54 FMS procedure descents (56%), crews were at least ten knots fast as they flew the downwind approach routing during the FMS procedure. In 9 of the 74 descents flown (12.2%) crews were at least ten knots slow at the assigned final approach fix crossing speed.

The high number of crew overspeeds (56%) observed during the downwind approach routing of the FMS procedure may be due to multiple factors. First, the charted vertical routing for the downwind leg of the FMS procedure requires a relatively steep angle of descent in order to comply with altitude crossing restrictions along the route. Second, when the aircraft is in the VNAV vertical mode, the automation prioritizes tracking of the computed path and does not track the programmed speed. These two factors combine so that, without pilot actions, the aircraft tends to overspeed during this segment. Crews had the option to extend flaps and/or speed brakes to keep the aircraft at required speeds. They were slow to use these controls in the overspeed cases. This may indicate that pilots are willing to sacrifice precision in flying charted speeds in order to meet altitude restrictions, save fuel, or maintain passenger comfort. Also, this portion of the routing may not be considered as speed constrained by pilots, because speed constraints are only specified at waypoint crossings. It is important for the accuracy of the CTAS system and the ATC advisories it computes that crews comply as closely as possible with charted and cleared speeds at and between waypoints. Therefore, the high number of crew overspeeds while on the FMS procedure during this portion of the flight is a concern. It brings into question the utility of requiring use of VNAV to descend on the

FMS procedure. The FLCH and V/S modes are alternative ways of descending the aircraft that puts more priority on speed tracking and thus may serve the needs of the CTAS system better than the VNAV descent mode.

Nine of seventy-four crews (12.2%) crossed the final approach fix more than ten knots slower than the charted and cleared speed of 170 knots. This speed is set for the CTAS system to precisely control an aircraft's arrival time at the runway threshold. During the post experiment debriefings crews that failed to comply with this speed restriction mentioned two reasons for doing so. First these crews mentioned that they habitually set their approach reference speed into the autopilot upon receipt of the approach clearance by ATC. They also mentioned the requirement to be "stabilized on the approach" by the final approach fix when flying in instrument conditions. This means that they have the aircraft fully configured and that airspeed is equal to the approach reference speed. Given this requirement, crews said that they felt uncomfortable crossing this point at the higher assigned speed and preferred to be slowed down to their reference speed by this point.

VNAV and LNAV use

When flying the FMS procedures, crews were required to use the VNAV and LNAV autopilot modes. During particular parts of the complex scenario, use of these modes was prevented by ATC clearances that diverted the aircraft from the charted FMS procedure. Crews were eventually cleared to resume the FMS procedure following the diversions which reinstated the VNAV and LNAV requirements. In 11 of the 54 (20.4%) FMS descents flown, crews used autopilot modes other than VNAV (i.e. FLCH or V/S) to descend after being diverted from and then re-cleared for the FMS procedure. All crews used the LNAV autopilot mode during all 54 of the FMS procedures. These results indicate some crew resistance to use of VNAV, or preference for the FLCH and/or V/S modes, during the descent phase of flight. Crew responses on the post-experiment questionnaire indicate some crew discomfort with the VNAV mode in the TRACON airspace. This issue if discussed at length below.

All crews used the VNAV top of descent point when required during the FMS procedures.

Crew Performance: CTAS/FMS Procedures Used During Complex Scenarios

In this section, the analysis shifts and addresses crew performance using the interface enhancements during the complex scenarios. Recall that these procedures are termed CTAS/FMS procedures.

TRACON route modifications

Crew performance of the CTAS route modifications was evaluated for the TRACON route modifications only. This approach was chosen to facilitate comparison among the three interface concepts (MPE, CDU DL, and DDL) in which crews flew the complex scenarios and were able to respond to ATC route modifications using these technologies. Recall that MPE was not used for the Center route modification, and that it was the most progressive procedure proposal in the study. To evaluate crew performance of the CTAS TRACON route modification interface activities, a number of measures were collected. First, an evaluation of crew performance of the particular elements of each activity was performed. This entailed viewing the videotape data to record the elements of each activity that crews performed and comparing this with the expected performance based on how crews were briefed and trained for each interface activity. This analysis also included the recording of any entry errors by crews. Second, the total time to complete the route modification activity was recorded. Third, the total heads down time for each crew member was determined by viewing the "face" cameras from the videotape data. Heads down time is defined here as the total amount of time that a crew member spends with his/her gaze on the CDU during the route modification activity. Fourth, the total heads down time for each observation was broken down into a collection of dwell times. Dwell time is defined here as the duration of a single fixation on the CDU during performance of the route modification activity. The sum of these dwell times equals the total heads down time. Note that dwell time was so large compared to travel time that travel time was ignored in this analysis.

Performance of activity elements

All crews in the MPE interface condition performed the activity without any errors or element omissions. In the CDU DL interface condition, four of twelve pilots not flying (PNFs) (33%) omitted the step of reading the clearance text aloud upon receiving the data link message. Five of twelve crews (42%) executed the route modification before reviewing the newly loaded route. No entry errors were made. In the DDL interface condition, three of twelve PNFs (25%) failed to read the message text aloud upon receipt of the data link message, and three of twelve crews (25%) failed to review the route modification before executing and accepting it. One of the twelve DDL crews (8%) failed to both read the message text aloud and to review the route modification before executing and accepting it. No entry errors were made in the DDL interface condition.

The cases in which the PNFs failed to read the data link message text aloud and where crews failed to review the message may indicate task shedding due to crew occupation with other tasks. This possibility cannot be evaluated in this study because continuous crew task tracking data was not collected. However the low workload study environment that crews reported is not congruent with the notion that crews were saturated with other tasks. This issue of task omissions may be addressed in future studies by introducing errors or unforeseen elements in route clearance messages. It should be noted that these omitted tasks were checking and monitoring tasks and were not essential for successful completion of the route modifications activities. This means that the system can work properly when pilots do not perform these tasks. This is true with most procedural aspects of flying, such as use of checklists. It emphasizes the necessity to make checking and monitoring during data link operations a required standard operating procedure for crews.

Total activity time

The mean total activity times in seconds for the three route modification interfaces were, $\underline{M} = 24.1$ ($\underline{S.E.} = 2.3$) for MPE, $\underline{M} = 26.7$ ($\underline{S.E.} = 2.7$) for CDU DL, and $\underline{M} = 20.3$ ($\underline{S.E.} = 2.1$) for DDL. Although DDL took the shortest amount of time on average, a one-way ANOVA revealed that mean total activity time differences among the three interfaces were not statistically significant, $\underline{F}\ (2,22) = 2.04$, $\underline{p} > .05$.

These route modification activities resulted in activity times in the range of twenty to twenty-seven seconds. This raises the question as to what amount of time to complete this activity is operationally acceptable. To the author's knowledge, no objective standard has been set. Crews frequently comment that they prefer to minimize time programming their FMS in the terminal area because it distracts from the vital tasks of instrument and out-the-window monitoring required in this airspace. All participants in the current study found these interfaces to be operationally acceptable for route modifications in the terminal area. The only crew concerns focused on the MPE interface which crews felt produced excessive heads-down time. This will be discussed below with the heads-down time and dwell time results. As mentioned before, crew operational acceptance of these interfaces and activities based on this study should be taken with caution. It is necessary to further validate the use of these interfaces and activities in flight conditions that more closely match those found at busy airports. This includes simulations with out-the-window traffic, TCAS traffic, and likely distractions encountered during descent into the terminal area.

Total heads down time

Mean total heads down times for the PNFs (crew member who performed that majority of elements for each route modification) were, M = 15.3 (S.E. = 1.8) for MPE, M = 18.2 (S.E. = 1.8) for CDU DL, and M = 6.3 (S.E. = 1.7) for DDL (see figure 7). The DDL interface required less than half the heads down time than did the MPE interface and roughly one-third the heads down time than did the CDU DL interface. A one-way ANOVA of heads-down time revealed significant differences among the three interfaces, F (2,22) = 13.3, $p < .05$. Simple comparison ANOVAs revealed that the DDL interface heads-down time was significantly shorter than both the MPE (F (1,11) = 16.9 , $p < .05$) and CDU DL (F (1,11) = 21.6, $p < .05$) interfaces. There was no significant difference between the MPE and CDU DL heads down times, F (1,11) = 1.4, $p > .05$

Mean total heads down time for the Pilots flying (PFs) were, M = 5.2 (S.E. = 1.2) for MPE, M = 9.7 (S.E. = 1.4) for CDU DL, and M = 4.1 (S.E. = 1.2) for DDL (see figure 8). The DDL required the least amount of heads down time for the PF, a little more than a second less than the MPE interface, but more than five-and-a-half seconds less than the CDU DL interface. A one-way ANOVA of heads-down time revealed significant differences among the three interfaces, F (2,22) = 9.27, $p < .05$. Simple comparison ANOVAs revealed that the CDU DL interface heads-down time was significantly longer than both the MPE (F (1,11) = 17.9, $p < .05$) and the DDL (F (1,11) = 17.7, $p < .05$) interfaces. There was no significant difference in heads-down time for the PF between the MPE and DDL interfaces, F (1,11) = .42 , $p > .05$.

Dwell time

PNFs had the shortest mean dwell times while using the DDL interface M = 2.2 (S.E. = .4), followed by the CDU DL interface M = 8.3 (S.E. = 2.4). The longest dwell times for PNFs occurred with the MPE interface, M = 10.7 (S.E. = 2.1) (see figure 7). A one-way ANOVA of dwell time revealed significant differences among the three interfaces, F (2,22) = 7.30, $p < .05$. Simple comparison ANOVAs revealed that the DDL interface had a significantly shorter mean dwell time than both the MPE (F (1,11) = 15.1, $p < .05$) and CDU DL (F (1,11) = 5.9, $p < .05$) interfaces. There was no significant difference in mean dwell time for the PNF between the MPE and CDU DL interfaces, F (1,11) = 1.2, $p > .05$

The mean dwell times for the PFs were less varied than for the PNFs: M = 2.8 (S.E. = 0.9) for MPE, M = 2.5 (S.E. = 0.3) for CDU DL, and 2.0 (S.E. = 0.5) for DDL (see figure 8). A one-way ANOVA of dwell time revealed non-significant differences among the three interfaces, F (2,22) = .39, $p > .05$.

The results indicate that the DDL route modification interface required the least amount of heads-down time for both PNFs and PFs among the three interfaces. As with task time, the question remains as to what amount of heads-down time is operationally acceptable. While it is difficult to establish an objective standard for what is acceptable, pilot comments point to the common sense answer of "the less heads-down time in the TRACON, the better". Perhaps a more operationally significant measure of time taken away from instrument and out-the-window scan is dwell time, because it represents the duration of a fixation on the CDU. If dwell times are short despite long cumulative heads-down times, this may indicate that pilots are time sharing, or have the opportunity to time share the route modification task with instrument and out-the-window scanning tasks. To validate this assumption, a higher resolution analysis of crew gaze and fixation behavior is required. In the current study, the PNFs average dwell time was considerably shorter with the DDL interface in addition to the considerably shorter total heads-down time found with this interface. These results indicate that the DDL

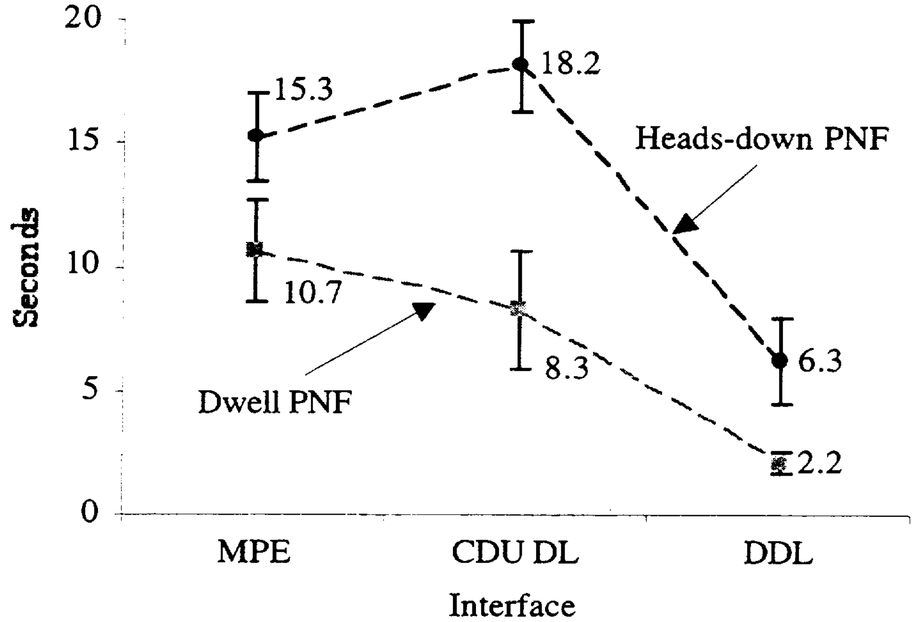

Figure 7. Mean total heads-down time and dwell time (+/- SE) for pilots not flying.

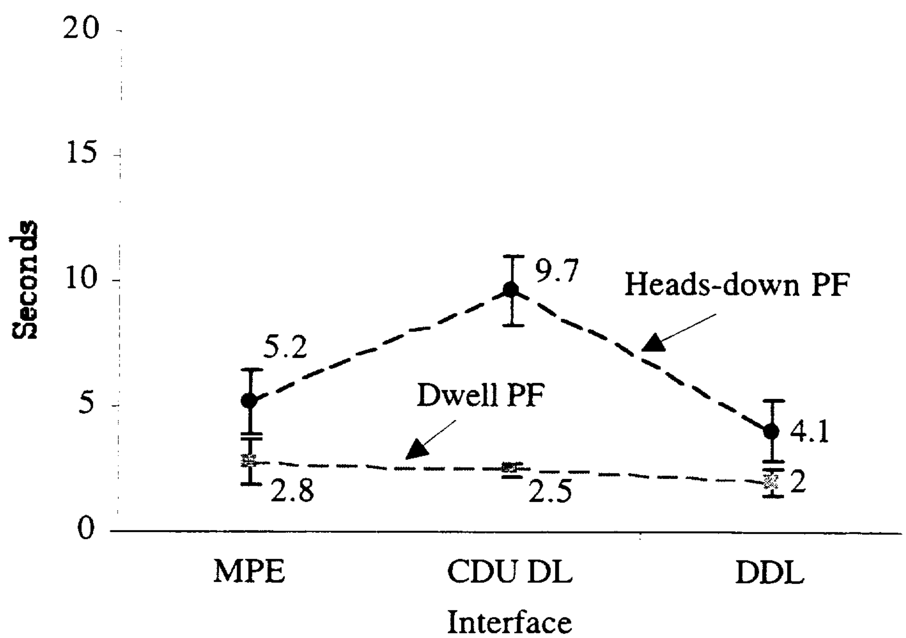

Figure 8. Mean total heads-down time and dwell time (+/- SE) for pilots flying.

interface accomplished the objective of keeping the PNF more heads-forward during the route modification activity. For the PFs average dwell times for all interfaces were around two seconds indicating a tendency for the PF to include observation of the route modification activity into the flight deck scan. However, average total heads-down time for the PFs was significantly longer with the CDU DL interface than with the others indicating a tendency for the PF to dwell more frequently on the CDU during the route modification activity.

Post Experiment Questionnaire

The following results cover only selected items from the post-experiment questionnaire. A full listing of all pilot responses to the yes or no and Likert scale questions is listed in Appendix G

Acceptability of FMS procedure

Crews were asked to respond to a series of questions regarding the acceptability of the Glenn Rose FMS Arrival and Delmo FMS Transition Procedure. The following are the results from selected items.

In response to the question: "Was any portion of the Glenn Rose FMS Arrival and Delmo FMS Transition Procedure unclear or confusing?", four of the twenty-four pilots answered yes. The stated reasons for this confusion were , (1) "speed assignments and alterations were confusing at first, then after re-reading the notes it became clear." (This comment refers to note #2 on the chart that states speed and downpath routing amendments do not cancel the FMS procedure, which is contrary to current procedures), (2) "The ... procedure notes were too long. Chart should be read quickly and not have to be studied.", and (3) "(it was unclear) at what point to abandon the LNAV transition and switch to localizer for approach."

In response to the question: "How acceptable or unacceptable was the requirement to Use LNAV during The Delmo FMS Transition?", seventeen crew members responded that it was very acceptable, six responded that it was somewhat acceptable, and one responded that it was borderline. In response to the question: "How comfortable or uncomfortable were you using LNAV during the Delmo FMS Transition?", nineteen pilots responded that they were very comfortable and five responded that they were somewhat comfortable (see figures 9 and 10). In response to the question: "How acceptable or unacceptable was the

requirement to use VNAV during the Delmo FMS Transition?", eleven pilots said this was very acceptable, six said it was somewhat acceptable, three pilots said it was borderline, three said it was somewhat unacceptable, and one pilot said it was very. In response to the airspace, approximately one-quarter of the twenty-four pilots felt that use of VNAV in the question: "How comfortable or uncomfortable were you using VNAV during the Delmo FMS Transition?", eleven pilots responded that they were very comfortable, six said they were somewhat comfortable, two said they were borderline comfortable, three responded that they were somewhat uncomfortable, and two said that they very uncomfortable (see figures 11 and 12).

These results reveal that while pilots had no objections to use of LNAV in the TRACON airspace, approximately one-quarter of the twenty-four pilots felt that use of VNAV in the TRACON was unacceptable and that they were uncomfortable with it in some way. Pilots confirmed these views during post experiment debriefings. All pilots mentioned that use of LNAV was fine within the TRACON. Those pilots who found the use of VNAV in the TRACON unacceptable or problematic stated a number of reasons listed here: (1) Use of VNAV below 10,000 feet lowers workload too much which may produce complacency and make the crew feel out of the loop; (2) Use of VNAV requires increased monitoring and constant asking of the question: "Is it going to do it?"; (3) Use of VNAV is made difficult when changes are made to the charted routing, forcing interaction with the CDU resulting in heads-down in the TRACON; (4) There are too many speed and altitude crossing restrictions requiring constant cross checking with charts, the CDU, and aircraft performance increasing workload and heads-down time; (5) Using FLCH or V/S makes it easier to get what you want out of the airplane; (6) (I) feel more assured MCP flying in the TRACON, (7)

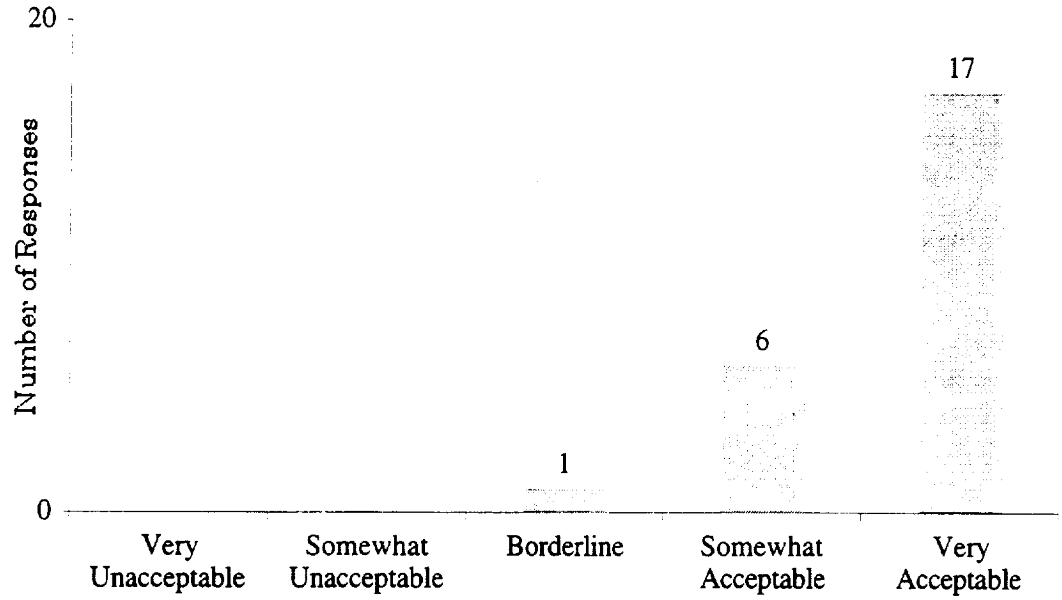

Figure 9. Pilot questionnaire responses to the question: How acceptable or unacceptable was the requirement to use LNAV in the TRACON airspace?

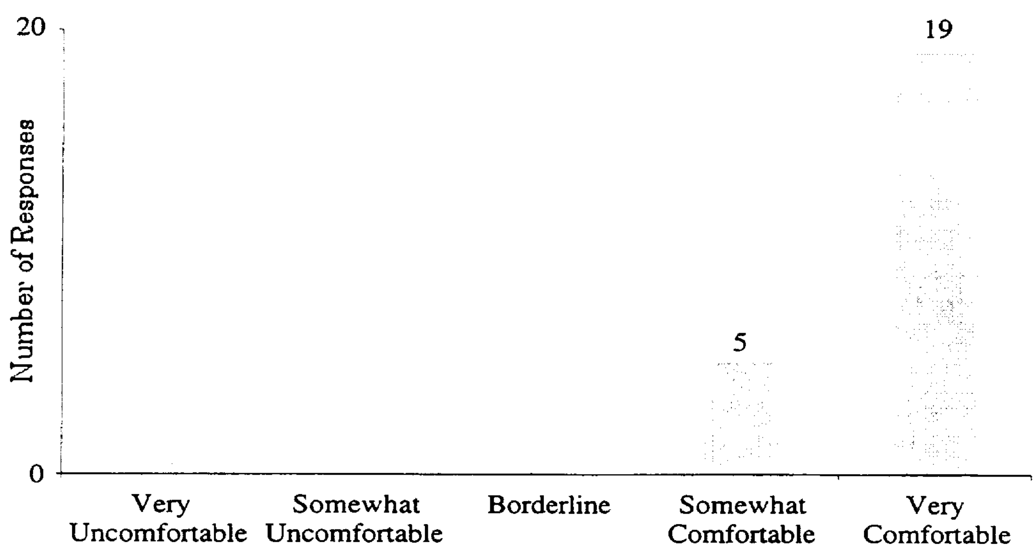

Figure 10. Pilot questionnaire responses to the question: How comfortable or uncomfortable were you using LNAV in the TRACON airspace?

VNAV "jerks" the a/c around and does not provide smooth transitions between crossing restrictions; (8) the wind model in the FMS must match the actual winds to get good performance from VNAV, they usually do not match; and (9) anti-ice changes the descent profile and FMS performance.

These complaints about use of VNAV in the TRACON airspace are varied. Comments (1) and (2) seem to address the baseline scenario condition in which the crew is cleared for the entire vertical FMS routing without deviation. This minority of crews reported feeling out of the loop and complacent when they delegated full vertical guidance to the automation which required vigilant monitoring to ensure the VNAV function meets all the charted restrictions. These comments echo Billings (1996) statements regarding use of management automation as increasing cognitive (monitoring) load and potentially decreasing crews involvement in the flying task.

Comments (3) and (4) refer to increases in workload and heads-down time with VNAV usage when the route is complex or altered by ATC. This suggests the need to keep charted routes simple and quickly and easily decipherable, and to create effective route modification interfaces that minimize heads-down time and clearly and efficiently highlight changes to the FMS routing.

Comments (5) and (6) refer to pilot preferences for the less automated vertical modes FLCH and V/S. Pilots report that these modes provide more precise speed control than VNAV and also provide the current speed target in the MCP speed window for quick heads-up reference and manipulation.

Comments (7) through (9) refer to side-effects of VNAV use that degrade its performance and precision.

In response to the question: "In General, how was your workload affected when flying the Glenn Rose FMS Arrival and Delmo FMS Transition as compared to your current day descent procedures", four pilots responded that their workload was greatly decreased, nine pilots responded that their workload was somewhat decreased, five said that their workload was unaffected, and four responded that their workload was somewhat increased. In response to the question: "In general, how was you monitoring behavior affected when flying the Glenn Rose FMS Arrival and Delmo FMS Transition procedure as compared to your current day descent procedures?", three pilots said that their monitoring was greatly increased, nine said that it was somewhat increased, eight said that their monitoring behavior was unaffected, and three said that their monitoring behavior was somewhat decreased (see figures 13 and 14).

Pilot responses to these two questions indicate that the FMS procedures generally reduce workload while increasing monitoring demands. This dissociation between workload and monitoring reports indicates that pilots perceive an increase in monitoring demands to create a decrease in workload. This explains the complacency and out-of-the-loop experienced by crews during the FMS procedures.

In response to the question: "How acceptable or unacceptable was the Glenn Rose FMS Arrival and Delmo FMS transition procedure as a whole?" , ten pilots said it was very acceptable, eleven said it was somewhat acceptable, two said it was borderline, and one said it was somewhat unacceptable (see figure 15).

The following are typical favorable comments made about the FMS procedure: "Procedure was easy and straight forward. Any confusion or difficulties had to do with the airspeed and altitude requirements which required a different cockpit scan"; "The FMS procedure made situational awareness much better. Planning ahead was much simpler. It was very easy to plan speed changes and flap/gear extension". The following are typical cautionary or negative comments made about the FMS procedure: "...was not comfortable with the VNAV descent in the transition phase of flight"; "Using VNAV to fly the FMS transition was a bad idea"; "This procedure

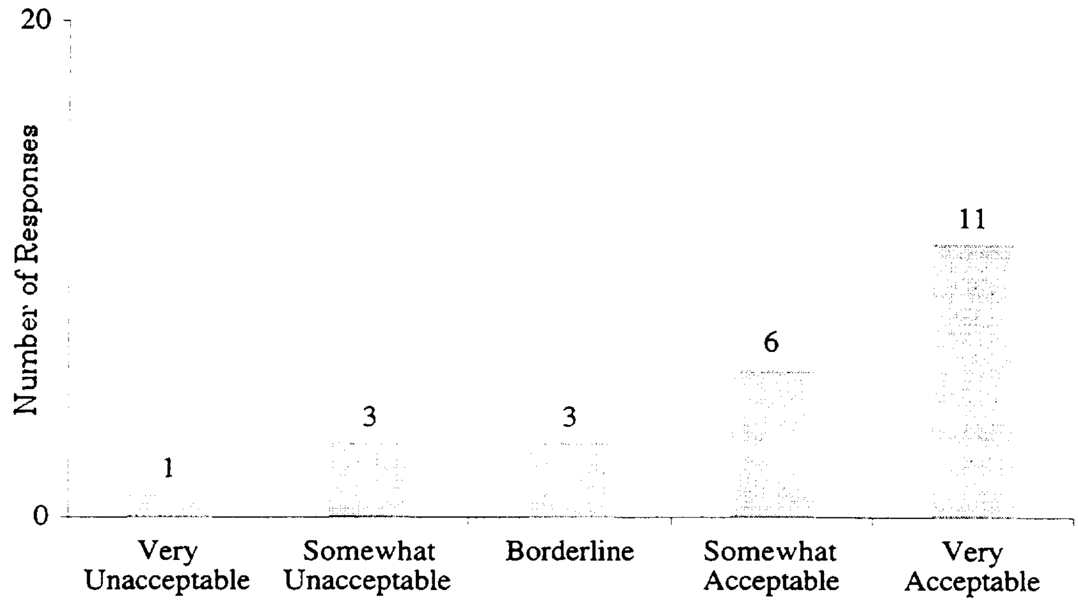

Figure 11. Pilot questionnaire responses to the question: How acceptable or unacceptable was the requirement to use VNAV in the TRACON airspace?

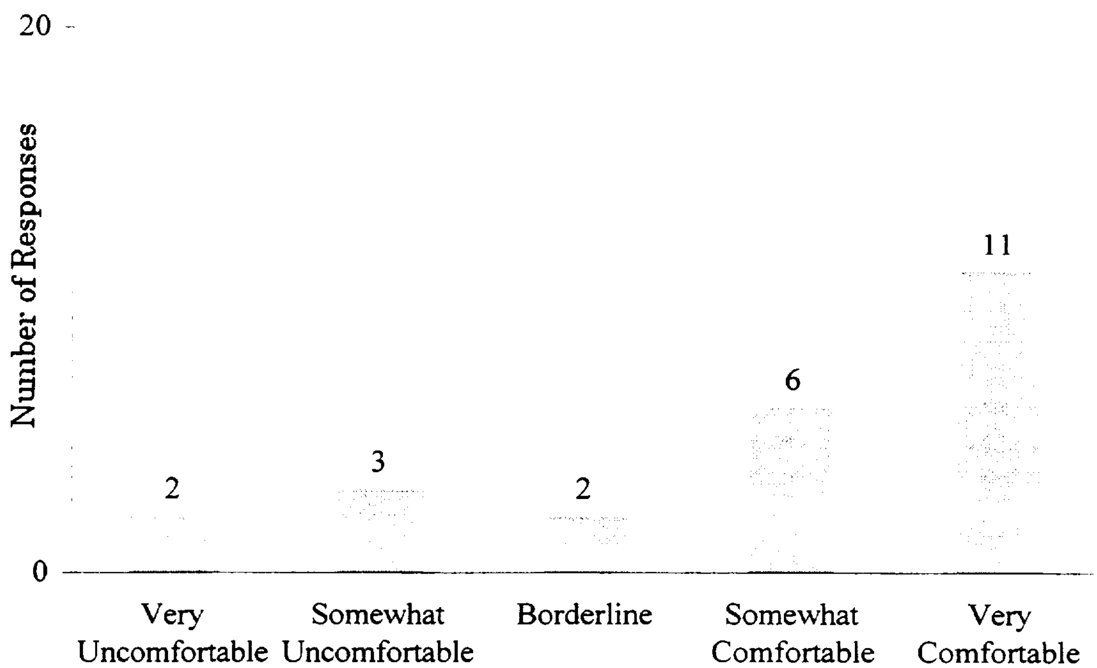

Figure 12. Pilot questionnaire responses to the question: How comfortable or uncomfortable were you using VNAV in the TRACON airspace

was not difficult or task overloaded. It required a little more concentration in terms of monitoring the automation to ensure it is doing what it is commanded. Setting the altitude down to the final cleared altitude

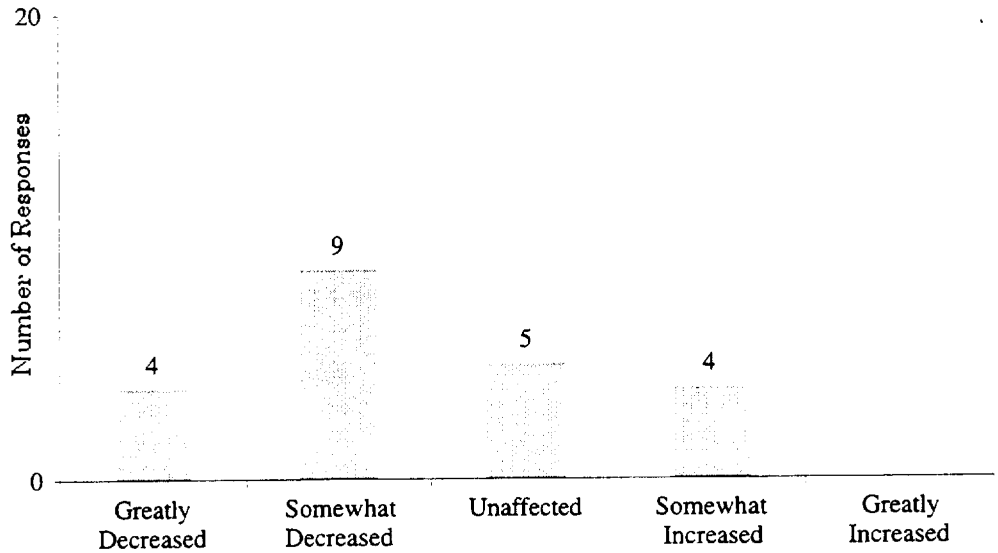

Figure 13. Pilot questionnaire responses to the question: In General, how was your workload affected when flying the Glenn Rose FMS Arrival and Delmo FMS Transition as compared to your current day descent procedures?

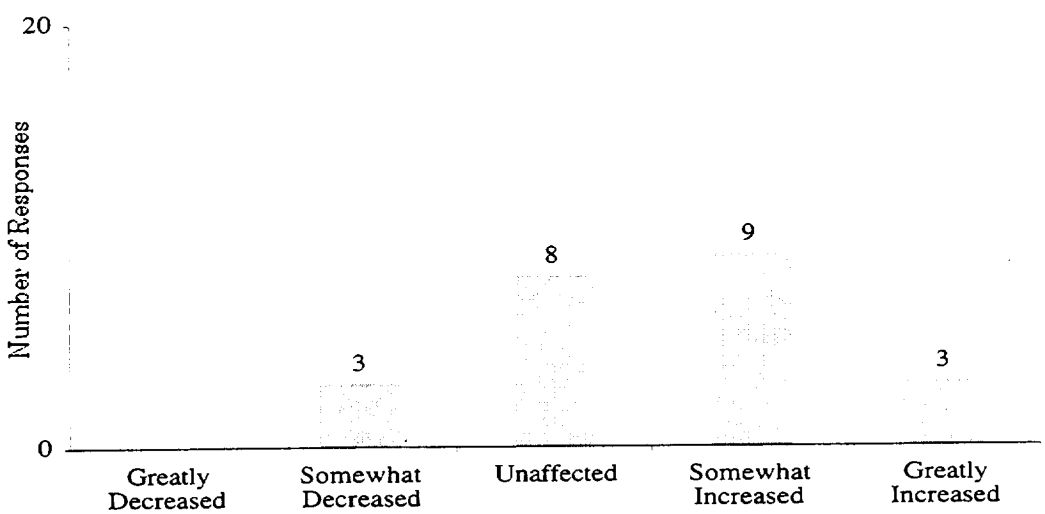

Figure 14. Pilot questionnaire responses to the question: In general, how was you monitoring behavior affected when flying the Glenn Rose FMS Arrival and Delmo FMS Transition procedure as compared to your current day descent procedures?

could pose some problems with crews descending before "authorized" if they change to descent modes other than VNAV, or if descent mode changes automatically"; "Everything was okay. I still don't completely trust VNAV in tight situations. LNAV is okay though"; "Too many speed restrictions and waypoints."

Acceptability of CTAS/FMS procedures

The pilots were asked to respond to a series of questions to assess their acceptance and opinion of the CTAS/FMS procedures that they performed during the study. The following are the results from selected questionnaire items.

In response to the question: "How acceptable or unacceptable was the requirement to use data link for route modifications while in cruise near the top of descent?", eighteen pilots said it was very acceptable and six said that it was somewhat acceptable. In response to the question: "How acceptable or unacceptable was the requirement to use data link for route modifications while in the TRACON?", Twelve responded that it was very acceptable, nine said it was somewhat acceptable, two that it was borderline, and one pilot responded that it was somewhat unacceptable (see figure 16). This indicates that while all pilots felt comfortable with use of datalink before top of descent, three of twelve (25%) of pilots felt that use of datalink in the TRACON airspace was either borderline or somewhat unacceptable. Debriefing comments regarding this issue focused on the increased heads-down time required when processing datalink messages that pulled the PNF out of the instrument and traffic scanning tasks during a critical phase of flight. Pilots were asked to state the FMS route modification interface they most preferred. Fifteen said the DDL, seven the CDU DL interface, and one the MPE interface (see figure 16). The strong preference for the DDL is congruent with the shorter heads-down and dwell times required with this interface and pilot concerns about excessive heads-down time in the TRACON airspace.

Conclusions and Future Work

This study investigated the impact of FMS and CTAS/FMS descent procedures on crew activities, workload, and performance. It also assessed crew acceptance of these procedures.

The findings can be summarized as follows: (1) The study demonstrated that use of FMS descent procedures can significantly reduce both crew activity load and workload below current day flying levels in situations where the charted procedure can be flown uninterrupted. However, activity loads significantly increase beyond current day levels and workload returns to current day levels when FMS descent procedures are interrupted by common ATC interventions and CTAS routing advisories. Further study is required to validate these conclusions and investigate issues that were not addressed in the current study. (2) Crew performance during use of FMS procedures was generally acceptable but suffered in a few key areas. More than half of the crews demonstrated poor speed control between waypoints in the TRACON airspace, and about one in ten crews did not comply with charted and cleared speeds at the final approach fix. (3) Pilots were very comfortable with the use of LNAV in the TRACON airspace, but at least one in four pilots expressed discomfort with or non-acceptance of the use of VNAV in the TRACON airspace for safety, performance, and/or situation awareness reasons. (4) One in five crews demonstrated that once taken off of the FMS procedure and then re-cleared for it, that they were reluctant to re-engage the VNAV mode. (5) Crews in general liked the FMS and CTAS/FMS procedures and found them acceptable. Crews mentioned the ability to look ahead and plan energy management as a primary positive contribution of the procedures. (6) Crews were comfortable with the use of datalink for route modifications in both the Center and TRACON airspace and expressed concern mainly for interfaces that produce excessive heads-down time or require manual entry of alpha-numeric information. (7) Crews demonstrated the best overall performance in terms of minimizing heads-down and dwell times using the DDL interface as compared to the CDU DL and MPE interfaces.

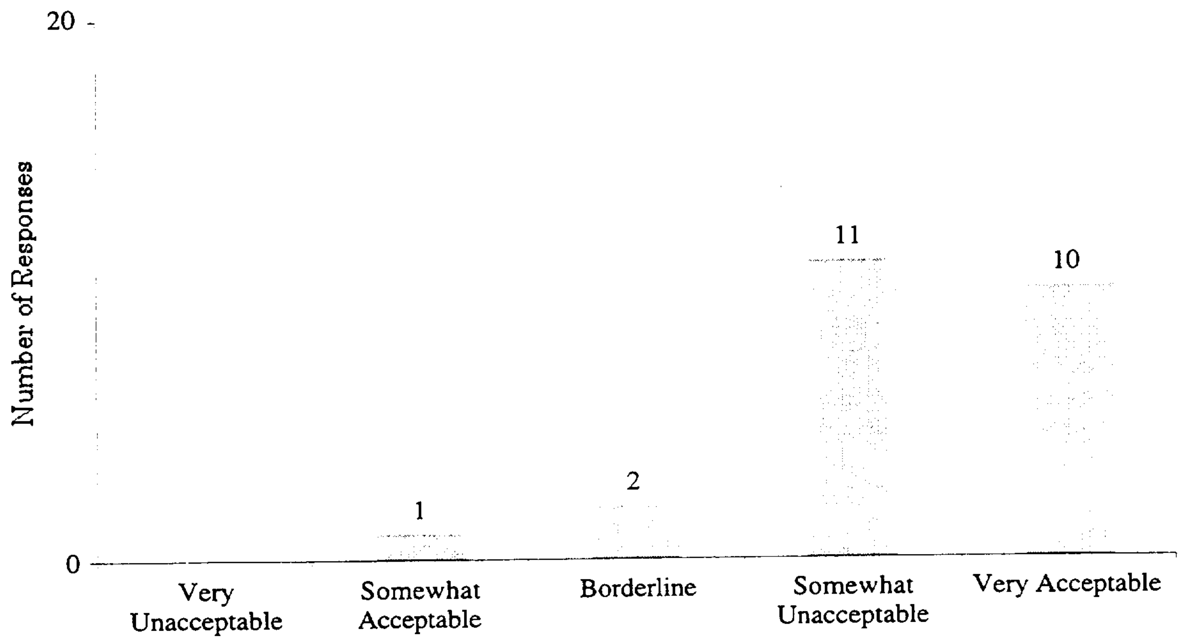

Figure 15. Pilot questionnaire responses to the question: How acceptable or unacceptable was the Glenn Rose FMS Arrival and Delmo FMS transition procedure as a whole?

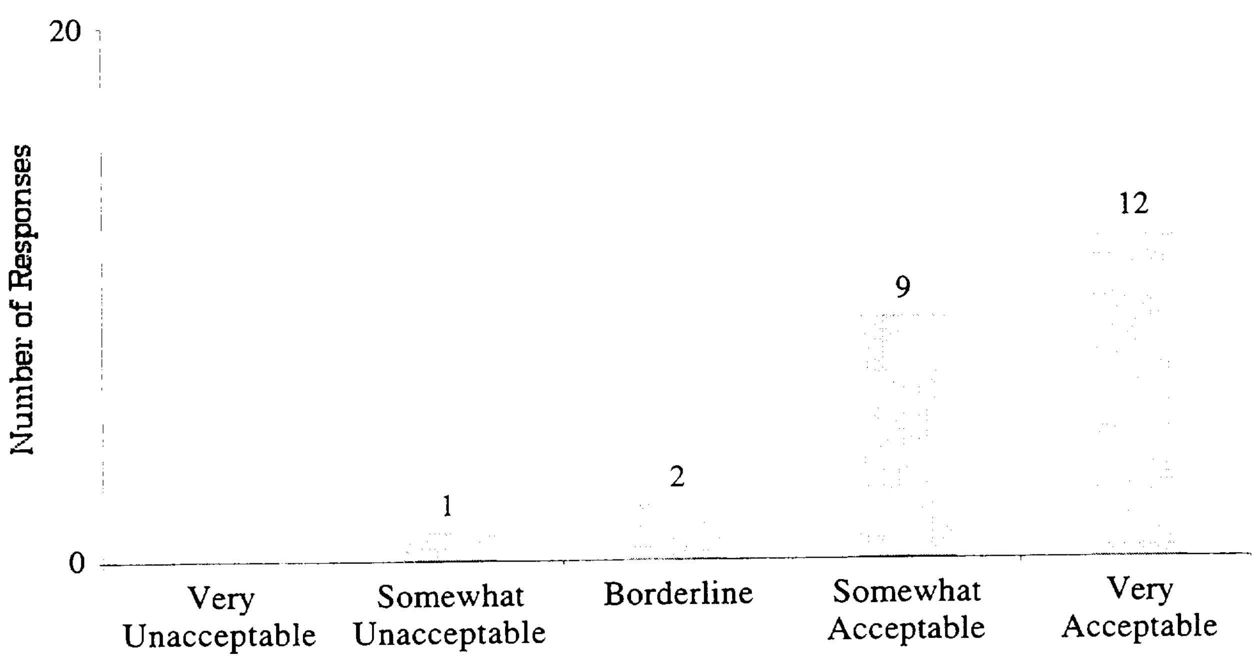

Figure 16. Pilot questionnaire responses to the question: How acceptable or unacceptable was the requirement to use data link for route modifications while in the TRACON?

To validate the workload results gathered in this study, future simulation studies should include contexts that more closely match real-world operations. While creating this environment in a simulation setting is difficult, pilot recommendations gathered in the current study helped produce a list of practical steps for accomplishing this goal. Pilots reported that out-the-window (visual) traffic, a TCAS display, realistic radio chatter, adverse or unpredictable winds and weather, requirements for company communications, and cabin interruptions were the most conspicuous real-world elements missing from the current study.

The drop in workload found in the baseline FMS procedure scenario runs raised the issue of possible *under* stimulation of pilots creating the potential for automation-induced complacency on the flight deck. As the air traffic system evolves, and FMS descent procedures become more commonplace, studies addressing this issue become necessary. While performance problems were more common in this study when crews were flying FMS procedures (e.g. poor speed control), this cannot be attributed directly to crew automation complacency as other factors previously mentioned likely played a role. An experimental design, well controlled and geared specifically toward the question of complacency is required.

Because of the resistance by a few of the pilots to the use of VNAV in the TRACON, and the inherent speed control problems this mode introduces, the requirement to use VNAV in FMS procedures should be carefully considered. This is especially true for CTAS/FMS integration where speed control is vital to operational success. The question of what benefits are derived with the use of VNAV in the TRACON seems appropriate. Based on the results in this study, the VNAV requirement has been removed from the planned follow-up study on CTAS/FMS integration.

Crew performance and acceptance of the TRACON route modifications required for CTAS/FMS integration is an encouraging finding. As with the FMS procedure workload findings, these results also need further study and validation in the more realistic simulation context outlined above. Also, the introduction of message errors and equipment malfunctions in future studies would provide a measure of crew error trapping capabilities with these interfaces. The fact that some crews failed to read the initial datalink message text and/or failed to review the loaded route raises concerns of crew complacency with this communication format.

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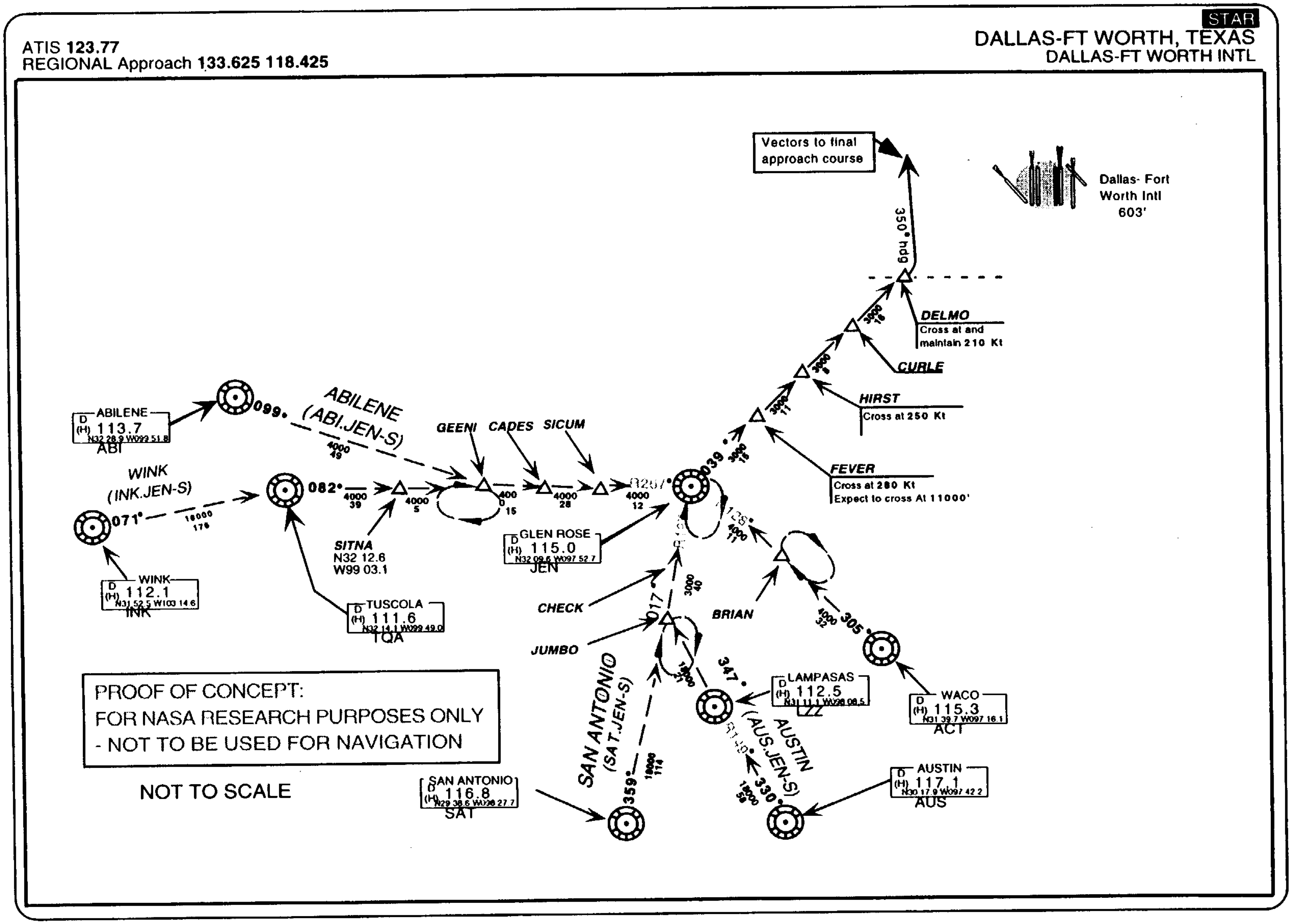
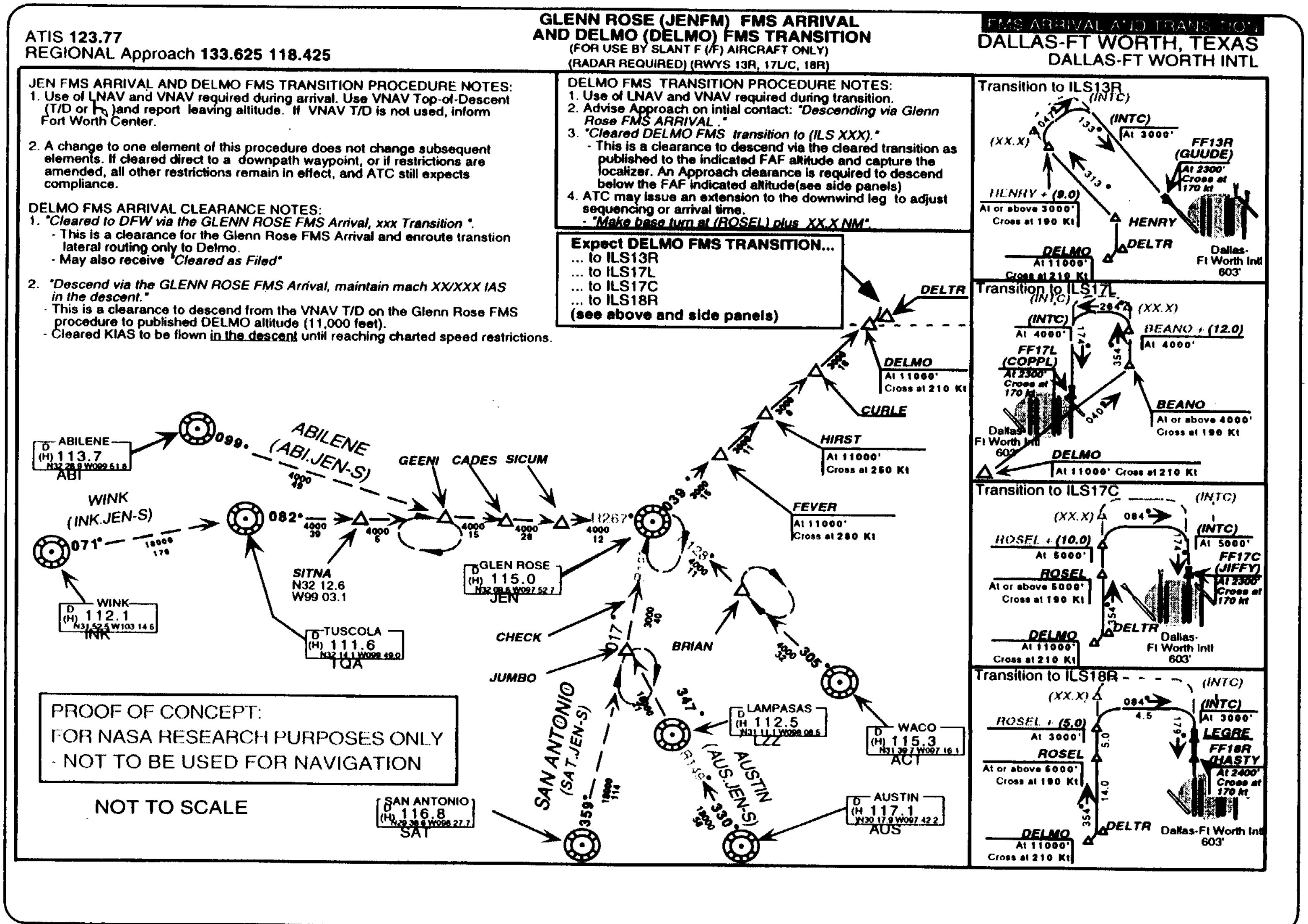
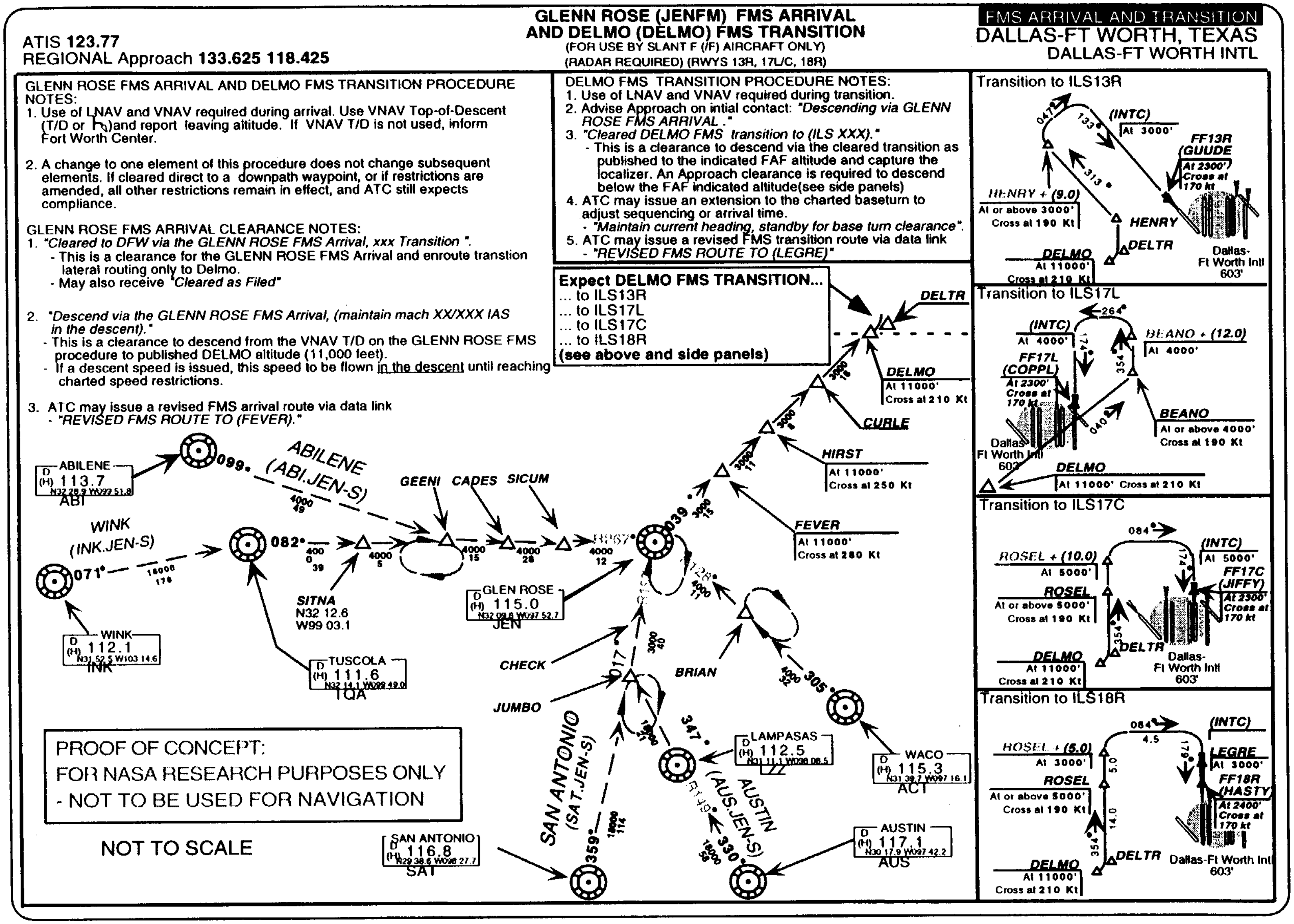
Appendix A

STAR, FMS, and CTAS/FMS Charts



STAR
DALLAS-FT WORTH, TEXAS
DALLAS-FT WORTH INTL
ATIS 123.77
REGIONAL Approach 133.625 118.425
Vectors to final approach course
Dallas- Fort Worth Intl 603'
350° hdg
DELMO
Cross at and maintain 210 Kt
CURLE
HIRST
Cross at 250 Kt
FEVER
Cross at 280 Kt
Expect to cross At 11000'
ABILENE 113.7 ABI
ABILENE (ABI.JEN-S)
WINK (INK.JEN-S)
WINK 112.1 INK
GEENI
CADES
SICUM
SITNA N32 12.6 W99 03.1
TUSCOLA 111.6 TQA
GLEN ROSE 115.0 JEN
CHECK
JUMBO
BRIAN
LAMPASAS 112.5 LZZ
WACO 115.3 ACT
AUSTIN 117.1 AUS
AUSTIN (AUS.JEN-S)
SAN ANTONIO (SAT.JEN-S)
SAN ANTONIO 116.8 SAT
099°
071°
082°
039°
305°
347°
330°
359°
017
PROOF OF CONCEPT:
FOR NASA RESEARCH PURPOSES ONLY
- NOT TO BE USED FOR NAVIGATION
NOT TO SCALE


ATIS 123.77
REGIONAL Approach 133.625 118.425
GLENN ROSE (JENFM) FMS ARRIVAL
AND DELMO (DELMO) FMS TRANSITION
(FOR USE BY SLANT F (/F) AIRCRAFT ONLY)
(RADAR REQUIRED) (RWYS 13R, 17L/C, 18R)
DALLAS-FT WORTH, TEXAS
DALLAS-FT WORTH INTL
JEN FMS ARRIVAL AND DELMO FMS TRANSITION PROCEDURE NOTES:
1. Use of LNAV and VNAV required during arrival. Use VNAV Top-of-Descent (T/D or) and report leaving altitude. If VNAV T/D is not used, inform Fort Worth Center.
2. A change to one element of this procedure does not change subsequent elements. If cleared direct to a downpath waypoint, or if restrictions are amended, all other restrictions remain in effect, and ATC still expects compliance.
DELMO FMS ARRIVAL CLEARANCE NOTES:
1. "Cleared to DFW via the GLENN ROSE FMS Arrival, xxx Transition ".
- This is a clearance for the Glenn Rose FMS Arrival and enroute transtion lateral routing only to Delmo.
- May also receive "Cleared as Filed"
2. "Descend via the GLENN ROSE FMS Arrival, maintain mach XX/XXX IAS in the descent."
- This is a clearance to descend from the VNAV T/D on the Glenn Rose FMS procedure to published DELMO altitude (11,000 feet).
- Cleared KIAS to be flown in the descent until reaching charted speed restrictions.
DELMO FMS TRANSITION PROCEDURE NOTES:
1. Use of LNAV and VNAV required during transition.
2. Advise Approach on intial contact: "Descending via Glenn Rose FMS ARRIVAL ."
3. "Cleared DELMO FMS transition to (ILS XXX)."
- This is a clearance to descend via the cleared transition as published to the indicated FAF altitude and capture the localizer. An Approach clearance is required to descend below the FAF indicated altitude(see side panels)
4. ATC may issue an extension to the downwind leg to adjust sequencing or arrival time.
- "Make base turn at (ROSEL) plus XX.X NM".
Expect DELMO FMS TRANSITION...
... to ILS13R
... to ILS17L
... to ILS17C
... to ILS18R
(see above and side panels)
ABILENE 113.7 ABI
ABILENE (ABI.JEN-S)
WINK (INK.JEN-S)
WINK 112.1 INK
GEENI
CADES
SICUM
SITNA N32 12.6 W99 03.1
TUSCOLA 111.6 TQA
GLEN ROSE 115.0 JEN
CHECK
JUMBO
BRIAN
FEVER At 11000' Cross at 280 Kt
HIRST At 11000' Cross at 250 Kt
CURLE
DELMO At 11000' Cross at 210 Kt
DELTR
SAN ANTONIO (SAT.JEN-S)
SAN ANTONIO 116.8 SAT
AUSTIN (AUS.JEN-S)
AUSTIN 117.1 AUS
LAMPASAS 112.5 LZZ
WACO 115.3 ACT
PROOF OF CONCEPT:
FOR NASA RESEARCH PURPOSES ONLY
- NOT TO BE USED FOR NAVIGATION
NOT TO SCALE
Transition to ILS13R
HENRY + (9.0) At or above 3000' Cross at 190 Kt
HENRY
FF13R (GUUDE) At 2300' Cross at 170 Kt
Dallas-Ft Worth Intl 603'
Transition to ILS17L
BEANO + (12.0) At 4000'
BEANO At or above 4000' Cross at 190 Kt
FF17L (COPPL) At 2300' Cross at 170 Kt
Transition to ILS17C
ROSEL + (10.0) At 5000'
ROSEL At or above 5000' Cross at 190 Kt
FF17C (JIFFY) At 2300' Cross at 170 Kt
Transition to ILS18R
ROSEL + (5.0) At 3000'
ROSEL At or above 5000' Cross at 190 Kt
LEGRE
FF18R (HASTY) At 2400' Cross at 170 Kt


ATIS 123.77
REGIONAL Approach 133.625 118.425
GLENN ROSE (JENFM) FMS ARRIVAL
AND DELMO (DELMO) FMS TRANSITION
(FOR USE BY SLANT F (/F) AIRCRAFT ONLY)
(RADAR REQUIRED) (RWYS 13R, 17L/C, 18R)
FMS ARRIVAL AND TRANSITION
DALLAS-FT WORTH, TEXAS
DALLAS-FT WORTH INTL
GLENN ROSE FMS ARRIVAL AND DELMO FMS TRANSITION PROCEDURE NOTES:
1. Use of LNAV and VNAV required during arrival. Use VNAV Top-of-Descent (T/D or) and report leaving altitude. If VNAV T/D is not used, inform Fort Worth Center.
2. A change to one element of this procedure does not change subsequent elements. If cleared direct to a downpath waypoint, or if restrictions are amended, all other restrictions remain in effect, and ATC still expects compliance.
GLENN ROSE FMS ARRIVAL CLEARANCE NOTES:
1. "Cleared to DFW via the GLENN ROSE FMS Arrival, xxx Transition ".
- This is a clearance for the GLENN ROSE FMS Arrival and enroute transtion lateral routing only to Delmo.
- May also receive "Cleared as Filed"
2. "Descend via the GLENN ROSE FMS Arrival, (maintain mach XX/XXX IAS in the descent)."
- This is a clearance to descend from the VNAV T/D on the GLENN ROSE FMS procedure to published DELMO altitude (11,000 feet).
- If a descent speed is issued, this speed to be flown in the descent until reaching charted speed restrictions.
3. ATC may issue a revised FMS arrival route via data link
- "REVISED FMS ROUTE TO (FEVER)."
DELMO FMS TRANSITION PROCEDURE NOTES:
1. Use of LNAV and VNAV required during transition.
2. Advise Approach on intial contact: "Descending via GLENN ROSE FMS ARRIVAL ."
3. "Cleared DELMO FMS transition to (ILS XXX)."
- This is a clearance to descend via the cleared transition as published to the indicated FAF altitude and capture the localizer. An Approach clearance is required to descend below the FAF indicated altitude(see side panels)
4. ATC may issue an extension to the charted baseturn to adjust sequencing or arrival time.
- "Maintain current heading, standby for base turn clearance".
5. ATC may issue a revised FMS transition route via data link
- "REVISED FMS ROUTE TO (LEGRE)"
Expect DELMO FMS TRANSITION...
... to ILS13R
... to ILS17L
... to ILS17C
... to ILS18R
(see above and side panels)
Transition to ILS13R
(INTC)
At 3000'
FF13R
(GUUDE
At 2300'
Cross at 170 kt
HENRY + (9.0)
At or above 3000'
Cross at 190 Kt
HENRY
DELTR
DELMO
At 11000'
Cross at 210 Kt
Dallas-Ft Worth Intl 603'
Transition to ILS17L
(INTC)
At 4000'
FF17L
(COPPL)
At 2300'
Cross at 170 kt
BEANO + (12.0)
At 4000'
BEANO
At or above 4000'
Cross at 190 Kt
DELMO
At 11000' Cross at 210 Kt
Dallas-Ft Worth Intl 603'
Transition to ILS17C
ROSEL + (10.0)
At 5000'
ROSEL
At or above 5000'
Cross at 190 Kt
(INTC)
At 5000'
FF17C
(JIFFY)
At 2300'
Cross at 170 kt
DELTR
DELMO
At 11000'
Cross at 210 Kt
Dallas-Ft Worth Intl 603'
Transition to ILS18R
ROSEL + (5.0)
At 3000'
ROSEL
At or above 5000'
Cross at 190 Kt
(INTC)
LEGRE
At 3000'
FF18R
(HASTY)
At 2400'
Cross at 170 kt
DELTR
DELMO
At 11000'
Cross at 210 Kt
Dallas-Ft Worth Intl 603'
DELTR
DELMO
At 11000'
Cross at 210 Kt
CURLE
HIRST
At 11000'
Cross at 250 Kt
FEVER
At 11000'
Cross at 280 Kt
ABILENE 113.7 ABI
WINK 112.1 INK
TUSCOLA 111.6 TQA
GLEN ROSE 115.0 JEN
LAMPASAS 112.5 LZZ
WACO 115.3 ACT
AUSTIN 117.1 AUS
SAN ANTONIO 116.8 SAT
ABILENE (ABI.JEN-S)
WINK (INK.JEN-S)
SAN ANTONIO (SAT.JEN-S)
AUSTIN (AUS.JEN-S)
GEENI
CADES
SICUM
SITNA
N32 12.6
W99 03.1
CHECK
JUMBO
BRIAN
PROOF OF CONCEPT:
FOR NASA RESEARCH PURPOSES ONLY
- NOT TO BE USED FOR NAVIGATION
NOT TO SCALE

Appendix B

Participant Consent Form

NASA Ames Research Center

Human Research Minimal Risk Consent

To the Test Subject: Please read this consent form and the attached protocol and/or subject instructions carefully. Make sure all questions have been answered to your satisfaction before signing.

I agree to participate as a subject in CTAS/FMS Integration Crew Factors research experiment as described in the attached protocol or subject instructions. I understand that I am employed by Raytheon Corporation who can be contacted at (650) 604-2118.

I understand that my participation could cause me minimal risk*, inconvenience, or discomfort. The purpose and procedures have been explained to me and I understand the risks and discomforts as described in the attached research protocol.

To my knowledge, I have no medical conditions, including pregnancy, that will prevent my participation in this study. I understand that if my medical status should change while a participant in the research experiment that there may be unforeseeable risks to me (or the embryo or fetus if applicable). I agree to notify the Principal Investigator (P.I.) or medical monitor of any known changes in my condition for safety purposes

My consent to participate as a subject has been freely given. I may withdraw my consent, and thereby withdraw from the study at any time without pearly or loss of benefits to which I am entitled. I understand that the P.I. may request my withdrawal or the study may be terminated for any reason. I agree to follow procedures for orderly and safe termination.

I am not releasing NASA from liability for any injury arising as a result from my participation in this study.

I hereby agree that all records collected by NASA in the course of this study are available to the research study investigators, support staff, and any duly authorized research review committee. I grant NASA permission to reproduce and publish all recorded, notes, or data collected from my participation, provided there is no association of my name with the collected data and that confidentiality is maintained, unless specifically waived by me.

I have had the opportunity to ask questions and have received satisfactory answers to all my questions. I understand the P.I. for the study is the person responsible for this activity and that any pertinent questions regarding the research will be addressed to him/her during the course of the study. I have read the above agreement, the attached protocol and/or subject instructions prior to signature, and understand the contents.

**Minimal risk means that the probability and magnitude of harm or discomfort anticipated in the research are not greater, in and of themselves, than those ordinarily encountered in daily life or during performance of routine physical or psychological examinations or tests.*

Signature of Test Subject Date	Signature of Principal Investigator
Printed name of test subject	Printed name of Principal Investigator
Address	Telephone Number of Principal Investigator
City, State, Zip Code	Subject Signature: Authorization for videotape
Telephone Number of Test Subject	Subject Signature: Authorization for release of information to Non-NASA Source

For Questions regarding this study contact:
Serena Stanford at SJSU (408) 924 2480
Everett Palmer at NASA (650) 604 0673
Barry Crane at SJSU (650) 604 2011

Appendix C

Descent Scenarios

Appendix C

Descent Scenarios

Baseline Current Day Procedure Scenario

AIRCRAFT POSITION	CLEARANCE PHRASEOLOGY
CENTER: 127.15	
•IP: 10 miles southeast of Abilene on JEN3 Arrival	("NASA 21, cleared to DFW via the GLENN ROSE 3 Arrival, Abilene transition.")
• Following IP	"NASA 21, descend via the GLENN ROSE 3 Arrival, cross FEVER at and maintain 11,000 feet."
• A/C at Glenn Rose	"NASA 21, contact Regional Approach 133.62."
FEEDER: 133.62	
• A/C at Glenn Rose	"NASA 21, After FEVER, Maintain 11,000 feet, comply with speeds on STAR, expect vectors to ILS18R."
• A/C before DELMO	"NASA 21, Contact Regional Approach 118.42."
FINAL: 118.42	
• A/C at DELMO	"NASA 21, fly heading 350 vectors to ILS18R, descend and maintain 5000'."
• A/C between two miles before ROSEL	"NASA 21, Reduce speed to 190, descend and maintain 3000."
• A/C ~six miles beyond ROSEL	"NASA 21, turn right heading 090."
• A/C on base	"NASA 21, turn right heading 140, intercept ILS18R localizer.
• A/C on final	"NASA 21, cleared for ILS18R approach, cross Final Approach Fix at 170 knots."
• A/C on final	"NASA 21, contact DFW tower 124.15"
TOWER: 124.15	
• A/C on final	"NASA 21, cleared to land runway 18R

Baseline FMS Procedure Scenario

AIRCRAFT POSITION	PHRASEOLOGY
CENTER: 127.15	
• IP: 10 miles southeast of Abilene on JEN FMS Arrival	("NASA 21, cleared to DFW via GLENN ROSE FMS Arrival, Abilene transition.")
• Following IP	"NASA 21, descend via GLENN ROSE FMS Arrival"
• A/C at Glenn Rose	NASA 21, Contact Regional Approach 133.62

FEEDER: 133.62	
• A/C at Glenn Rose	"NASA 21, Roger, cleared for DELMO FMS Transition to ILS18R"
• A/C before DELMO	"NASA 21, Contact Regional Approach 118.42"
FINAL: 118.42	
• A/C before DELMO	"NASA 21 Roger"
• A/C on base	"NASA 21, cleared for ILS18R approach."
• A/C on final	"NASA 21, Contact DFW tower 124.15"
TOWER: 124.15	
• A/C on final	"NASA 21, cleared to land runway 18R"

Complex Current Day Procedure Scenario

AIRCRAFT POSITION	CLEARANCE PHRASEOLOGY
CENTER: 127.15	
•IP: 10 miles southeast of Abilene on JEN3 Arrival	("NASA 21, cleared to DFW via the GLENN ROSE 3 Arrival, Abilene transition.")
• Following IP	"NASA 21, fly heading 080, descend pilots discretion, maintain FL240, expect to cross FEVER at 11,000 feet."
• A/C level at FL240 for 25 secs.	"NASA 21 traffic 2 o' clock, five miles, northbound, 2000 below you." "NASA 21, traffic no factor, cleared direct FEVER, cross FEVER at and maintain 11,000 feet."
• A/C abeam Glenn Rose	"NASA 21, contact Regional Approach 133.62."
FEEDER: 133.62	
• A/C abeam Glenn Rose	"NASA 21, After FEVER, Maintain 11,000 feet, comply with speeds on the STAR, expect vectors to runway 18R."
• A/C before DELMO	"NASA 21, Contact Regional Approach 118.42"
FINAL: 118.42	
• A/C at DELMO	"NASA 21, fly heading 350 vectors to ILS18R, descend and maintain 5000'."
• A/C between six miles before ROSEL	"NASA 21, Reduce speed to 190, descend and maintain 3000."
• A/C ~six miles beyond ROSEL	"NASA 21, turn right heading 090."
• A/C on base	"NASA 21, turn right heading 140, intercept ILS18R localizer.
• A/C on final	"NASA 21, cleared for ILS18R approach, cross Final Approach

	Fix at 170 knots."
• A/C on final	"NASA 21, Contact DFW tower 124.15"
TOWER: 124.15	
• A/C on final	"NASA 21, Cleared to land runway 18R"

Complex FMS Procedure Scenario

AIRCRAFT POSITION	PHRASEOLOGY
CENTER: 127.15	
• IP: 10 miles southeast of Abilene on JEN FMS Arrival	("NASA 21, cleared to DFW via GLENN ROSE FMS Arrival, Abilene transition.")
• Following IP	"NASA 21, fly heading 080, descend at pilots discretion, maintain FL240, expect direct FEVER to rejoin GLENN ROSE FMS Arrival"
• A/C at FL240 for 25 secs.	"NASA 21 traffic 4 o' clock, five miles, northwestbound, 2000 below you." "NASA 21, clear of traffic, cleared direct FEVER, resume GLENN ROSE FMS Arrival."
• A/C abeam Glenn Rose	NASA 21, Contact Regional Approach 133.62
FEEDER: 133.62	
• A/C abeam Glenn Rose	"NASA 21, Roger, after crossing FEVER, cleared for DELMO FMS transition to ILS18R"
• A/C before DELMO	"NASA 21, Contact Regional Approach 118.42"
FINAL: 118.42	
• A/C before DELMO	"NASA 21 Roger"
• A/C six miles prior to ROSEL	"NASA 21, Slow to 190 knots."
• A/C just past ROSEL	"NASA 21, Maintain current heading, standby for base turn clearance."
• A/C seven miles beyond ROSEL	"NASA 21, turn right heading 090."
• A/C on base	"NASA 21, turn right heading 140, intercept ILS18R localizer
• A/C on final	cleared for ILS18R approach, cross Final Approach Fix at 170 knots"
• A/C on final	"NASA 21, Contact DFW tower 124.15"
TOWER: 124.15	
• A/C on final	"NASA 21, cleared to land runway 18R"

Manual Path Extension Procedure Scenario

AIRCRAFT POSITION	PHRASEOLOGY
CENTER: 127.15	
• IP: 10 miles southeast of Abilene on JEN FMS Arrival	("NASA 21, cleared to DFW via the GLENN ROSE FMS Arrival, Abilene transition.")
• Following IP	"NASA 21, fly heading 080, descend pilots discretion at 300 knots, maintain FL240, expect direct FEVER to rejoin GLENN ROSE FMS Arrival"
• A/C at FL240 for 25 secs.	"NASA 21 traffic 5 o' clock, five miles, northeastbound, 2000 below you." "NASA 21, clear of traffic, resume descent at 300 knots, cleared direct FEVER, resume GLENN ROSE FMS Arrival."
• A/C abeam Glenn Rose	NASA 21, Contact Regional Approach 133.62
FEEDER: 133.62	
• A/C abeam Glenn Rose	"NASA 21, Roger, cleared for DELMO FMS transition to ILS18R"
• A/C before DELMO	"NASA 21, Contact Regional Approach 118.42"
FINAL: 118.42	
• A/C before DELMO	"NASA 21, Roger"
•A/C just past DELMO	"NASA 21, make base turn at ROSEL plus x.x nautical miles."
• A/C six miles prior to ROSEL	"NASA 21, Slow to 190 knots."
• A/C on base	"NASA 21, cleared for ILS18R approach."
• A/C on final	"NASA 21, Contact DFW tower 124.15"
TOWER: 124.15	
• A/C on final	"NASA 21, cleared to land runway 18R"

CDU DL and DDL Procedure Scenarios

AIRCRAFT POSITION	PHRASEOLOGY
CENTER: 127.15	
• IP: 10 miles southeast of Abilene on JEN FMS Arrival	("NASA 21, cleared to DFW via the GLENN ROSE FMS Arrival, Abilene transition.")
• Following IP	"NASA 21, Expect route uplink."
• Following IP	Data link message: NASA 21 ------ROUTE MODIFICATION------ REVISED FMS RTE TO FEVER
• Following data link clearance	"NASA 21, descend via revised FMS route to FEVER at 300 knots."
•A/C at ~FL260	"NASA 21, maintain FL240 for traffic"
• A/C at FL240 for 25 secs.	"NASA 21 traffic 3 o' clock, five miles, northbound, 2000 below you." "NASA 21, clear of traffic, resume FMS descent at 300 knots."
• A/C abeam Glenn Rose	NASA 21, Contact Regional Approach 133.62
FEEDER: 133.62	
• A/C abeam Glenn Rose	"NASA 21, Roger, cleared for DELMO FMS Transition to ILS18R"
• A/C before DELMO	"NASA 21, Contact Regional Approach 118.42"
FINAL: 118.42	
• A/C before DELMO	"NASA 21, Roger, expect route modification uplink."
•A/C just past DELMO	Data link message: NASA 21 --ROUTE MODIFICATION— REVISED FMS RTE TO LEGRE
• A/C six miles prior to ROSEL	"NASA 21, Slow to 190 knots."
• A/C on base	"NASA 21, cleared for ILS18R approach."
• A/C on final	"NASA 21, Contact DFW tower 124.15"
TOWER: 124.15	
• A/C on final	"NASA 21, cleared to land runway 18R"

Appendix D

Workload Dimension Descriptions and Workload Rating Sheet

Appendix D

Workload Dimension Descriptions and Workload Rating Sheet

Workload Dimension	Endpoints	Description
MENTAL DEMAND	Low/High	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, monitoring, looking, searching, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	Low/High	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	Low/High	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 frantic?
PERFORMANCE	Good/Poor	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
EFFORT	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Appendix E

Procedure Performance Criteria

Appendix E

Procedure Performance Criteria

General criteria that apply to all procedures:

Altitudes

Comply with all charted and ATC specified altitude restrictions within plus or minus 300 feet as measured when passing over location (e.g. waypoint, navaid, etc.) of specified restriction. If compliance is not possible due to limitations in aircraft performance or other reason, inform ATC.

Speeds

Comply with all charted and ATC specified speed restriction within plus or minus 10 KIAS as measured when passing over location (e.g. waypoint, navaid, etc.) of specified restriction or when in phase of flight where a speed restriction has been specified (e.g. descent speed). If compliance is not possible due to limitations in aircraft performance or other reason, inform ATC.

Criteria specific to FMS and CTAS/FMS procedures:

Use of LNAV

Unless given a heading vector by ATC, fly the entire FMS or CTAS/FMS procedure in the LNAV guidance mode until the point of Localizer capture .

Use of VNAV

When flying the DELMO FMS Transition, remain in the VNAV guidance mode until the point of Glideslope capture.

Use of VNAV top of descent

Unless given a heading vector by ATC, when flying the Glen Rose FMS Arrival, begin descent within plus or minus 5 miles of the VNAV calculated top of descent point. If compliance is not possible, inform ATC.

Responding to, loading, and executing DELMO FMS Transition

When cleared for the DELMO FMS Transition to ILS18R, correctly perform this activity. Correct performance of this activity is as follows: (1) Readback clearance to ATC, (2) access the DEP/ARR page, (3) select ILS18R on the runway menu, (4) select DELMO on the transition menu, (5) press Execute on the CDU, (6) select 2400 in the MCP altitude window.

Responding to, loading and executing a Manual Path Extension clearance

Upon receipt of a Manual Path Extension clearance, correctly perform this activity. Correct performance of this activity is as follows: the PNF must (1) acknowledge and readback the ATC cleared base turn distance, (2) line select the reference waypoint ROSEL into the CDU scratchpad, (3) enter a backslash (/) and the new base turn point value, (4) reselect the waypoint into the flightplan, (5) review the modification on the CDU and Navigation display, and (6) execute the modification by pressing the execute button on the CDU.

Responding to, loading and executing a CDU DL clearance

Upon receipt of a CDU DL clearance, correctly perform this activity. Correct performance of this activity is as follows: the PNF must (1) press the ATC key on the CDU, (2) read the message text on the CDU page aloud to the other crew member, (3) receive confirmation from the other crew member, (4) load the new route by pressing a LOAD prompt, (5) press the LEGS key on the CDU, (6) review and verify the loaded message on the LEGS page and Navigation display, (7) execute the new route by pressing the execute button on the CDU, (8) press the ATC key on the CDU, and (9) accept the message by pressing the ACCEPT prompt.

Responding to, loading and executing a DDL clearance

Upon receipt of a DDL clearance, correctly perform this activity. Correct performance of this activity is as follows: the PNF must (1) read the message text *on the EICAS display* aloud to the other crew member, (2) receive confirmation from the other crew member, (3) review and verify the loaded message on the LEGS page and Navigation display, (4) execute the new route by pressing the execute button on the CDU, and (5) accept the message by pressing the accept button *on the glareshield.*

Appendix F

Crew Questionnaire

CTAS/FMS Integration Evaluation: ACFS Crew Factors Study -- Fall 1998

Pilot Questionnaire

BACKGROUND INFORMATION

Date: ____________________ Crew Position: ____________________

Approximate total hours: ______

Approximate total hours flying "glass" aircraft: __________________

Please specify approximate total hours in each type aircraft 727 ______ DC-9 ______

737- 200 ________ DC –10 _______ L10-11 _________ 747-200/300 ________

MD-80 _______ 737-300/500 ________ 747-400 _________ 757 __________

767 __________ 777 _________ A300 _______ A310 _______ A320 _______

A340 ________

Other type aircraft (please specify)
____
______

Estimated number of times you have flown into DFW in the past 3 years _________

Estimated number of times you have flown the Glen Rose 3 Arrival into DFW in the past 3 years _________

Instructions: Please circle the tick mark on each scale that best fits your response to the following questions or statements. Please also provide answers to the yes/no questions and comments or explanations where indicated. Please consider your responses carefully. Your responses will play an important role in the evaluation being conducted

FMS ARRIVAL AND TRANSITION CHARTS

How clear or unclear was the information presented on the Glenn Rose FMS Arrival and Delmo FMS Transition charts used in this study?

Very Unclear	Somewhat Unclear	Borderline	Somewhat Clear	Very Clear

How organized or unorganized was the information presented on the Glenn Rose FMS Arrival and Delmo FMS Transition charts used in this study?

Very	Somewhat	Borderline	Somewhat	Very

Unorganized Unorganized **Organized** **Organized**

How adequate or inadequate were the Glenn Rose FMS Arrival and Delmo FMS Transition charts in helping you perform the procedures?

Very Inadequate	Somewhat Inadequate	Borderline	Somewhat Adequate	Very Adequate

Was there any information missing from the FMS Arrival and Transition charts that you would have liked to see?

Yes ________ No ________

If yes, please explain

____

____

____

____

____

Do you think the FMS Arrival and Transition charts should have contained less information, or less detailed information?

Yes ________ No ________

If yes, please explain

____

____

____

How acceptable or unacceptable were the Glenn Rose FMS Arrival and Delmo FMS Transition charts as a whole?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

FMS ARRIVAL AND TRANSITION CLEARANCE PHRASEOLOGY

Initial FMS Arrival Descent Clearance
"NASA 21, Descend via the Glenn Rose FMS Arrival, maintain XXX Knots in the descent"

Was any portion of this clearance phraseology unclear or confusing the first time you heard it?

Yes ________ No ________

Please explain

____

When you first received this clearance, was it clear to you what to do?

Yes ________ No ________

Please explain

____

Delmo FMS Transition Clearance
"NASA 21, Cleared for the Delmo FMS Transition to ILS18R"

Was any portion of this clearance phraseology unclear or confusing the first time you heard it?

Yes ________ No ________

Please explain

____

When you first received this clearance, was it clear to you what to do?

Yes ________ No ________

Please explain

____

How acceptable or unacceptable was the Glenn Rose FMS Arrival and Delmo FMS Transition phraseology as a whole?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

PROCEDURE ACCEPTABILITY

FMS Procedure: Questions in this section refer specifically to the Glenn Rose FMS Arrival and Delmo FMS Transition procedure without regard to the adjunct route modification procedures (i.e. Manual Path Extension, CDU DL, and DDR).

Was any portion of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure unclear or confusing?

Yes ________ No ________

Please explain

____

____

How acceptable or unacceptable was the requirement to set your MCP altitude window to the last crossing restriction on the routing of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

How acceptable or unacceptable was the requirement to use LNAV during the Arrival portion (at and above 11,000) of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

How comfortable or uncomfortable were you using LNAV during the Arrival portion of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

Very Uncomfortable	Somewhat Uncomfortable	Borderline	Somewhat Comfortable	Very Comfortable

How acceptable or unacceptable was the requirement to use VNAV during the Arrival portion of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

Very Unacceptable | **Somewhat Unacceptable** | **Borderline** | **Somewhat Acceptable** | **Very Acceptable**

How comfortable or uncomfortable were you using VNAV during the Arrival portion of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

Very Uncomfortable | **Somewhat Uncomfortable** | **Borderline** | **Somewhat Comfortable** | **Very Comfortable**

How acceptable or unacceptable was the requirement to use LNAV during the Delmo Transition portion (below 11,000) of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

Very Unacceptable | **Somewhat Unacceptable** | **Borderline** | **Somewhat Acceptable** | **Very Acceptable**

How comfortable or uncomfortable were you using LNAV during the Delmo Transition portion of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

Very Uncomfortable | **Somewhat Uncomfortable** | **Borderline** | **Somewhat Comfortable** | **Very Comfortable**

How acceptable or unacceptable was the requirement to use VNAV during the Delmo Transition portion of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

Very Unacceptable | **Somewhat Unacceptable** | **Borderline** | **Somewhat Acceptable** | **Very Acceptable**

How comfortable or uncomfortable were you using VNAV during the Delmo Transition portion of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

Very Uncomfortable | **Somewhat Uncomfortable** | **Borderline** | **Somewhat Comfortable** | **Very Comfortable**

"Nasa 21, fly heading 080, descend at pilot's discretion, maintain FL240, expect direct

FEVER to rejoin Glenn Rose FMS Arrival"....
"Nasa 21, clear of traffic, cleared direct FEVER, resume Glenn Rose FMS Arrival."
How acceptable or unacceptable were the above set of clearances that vectored you off the Glenn Rose FMS Arrival and then had you resume it?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

"Nasa 21, Maintain current heading, standby for base turn clearance."
How acceptable or unacceptable was the above clearance given during the Delmo FMS Transition procedure?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

Did you feel rushed at any time during the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

Yes ________ No ________

Please explain

____

In general, how was your workload affected when flying the Glenn Rose FMS Arrival and Delmo FMS Transition procedure as compared to your current day descent procedures:

Greatly Decreased	Somewhat Decreased	Unaffected	Somewhat Increased	Greatly Increased

In general, how was your monitoring behavior affected when flying the Glenn Rose FMS Arrival and Delmo FMS Transition procedure as compared to your current day descent procedures:

Greatly Decreased	Somewhat Decreased	Unaffected	Somewhat Increased	Greatly Increased

The Glenn Rose FMS Arrival and Delmo FMS Transition procedure made flying the descent:

Very Easy	Somewhat Easy	Borderline	Somewhat Difficult	Very Difficult

Compared to current day descent procedures, the Glenn Rose FMS Arrival and Delmo FMS Transition procedure was:

Very Undesirable	Somewhat Undesirable	Borderline	Somewhat Desirable	Very Desirable

How acceptable or unacceptable was the Glenn Rose FMS Arrival and Delmo FMS Transition procedure as a whole?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

Please provide any comments you have regarding the Glenn Rose FMS Arrival and Delmo FMS Transition Procedure:

____

____

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____

CTAS/FMS PROCEDURES

General

How acceptable or unacceptable was the requirement to use data link for route modifications while in cruise near the top-of-descent (i.e. *"Revised FMS route to FEVER"*)?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

....while in the TRACON?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

How acceptable or unacceptable was the issuance of a descent speed in the Glenn Rose FMS Arrival?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

In general, how acceptable or unacceptable was the requirement to make FMS edits to the Delmo FMS transition routing while on downwind in the TRACON airspace?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

General Data link

How acceptable or unacceptable was the data link phraseology used in the Center airspace (i.e. *"Revised FMS route to FEVER"*)?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

How acceptable or unacceptable was the data link phraseology used in the TRACON airspace (i.e. *"Revised FMS route to LEGRE"*)?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

Manual Path Extension Procedure

How acceptable or unacceptable was the Manual Path Extension procedure requirement to manually enter the modified base turn point into the CDU during the Delmo FMS Transition procedure?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

How acceptable or unacceptable were the tasks required to complete the Manual Path

Extension procedure?

Very Unacceptable | **Somewhat Unacceptable** | **Borderline** | **Somewhat Acceptable** | **Very Acceptable**

Did you feel rushed at any time during the Manual Path Extension procedure?

Yes ________ No ________

Please explain ____

How acceptable or unacceptable was the Manual Path Extension procedure phraseology (*"Make base turn at Rosel +X.X miles"*)?

Very Unacceptable | **Somewhat Unacceptable** | **Borderline** | **Somewhat Acceptable** | **Very Acceptable**

How acceptable or unacceptable was the Manual Path Extension procedure as a whole?

Very Unacceptable | **Somewhat Unacceptable** | **Borderline** | **Somewhat Acceptable** | **Very Acceptable**

Please provide any comments you have regarding the Manual Path Extension procedure:

____

____

____

____

____

____

CDU DL Procedures

How acceptable or unacceptable were the tasks required to complete the CDU DL procedure?

Very | **Somewhat** | **Borderline** | **Somewhat** | **Very**

Unacceptable Unacceptable **Acceptable Acceptable**

How acceptable or unacceptable was the CDU DL interface for route modifications received in the Center airspace (*"Revised route to EFVER"*)?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

Did you have any trouble understanding the CDU DL data link message you received in the Center airspace once it was loaded
(i.e. *"Revised FMS route to FEVER"*)?

Yes ___________ No ______________

Please explain

____

____

____

How acceptable or unacceptable was the CDU DL interface for route modifications received in the TRACON airspace (*"Revised route to LEGRE"*)?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

Did you have any trouble Understanding the CDU DL data link message you received in the TRACON airspace once it was loaded
(i.e. *"Revised FMS route to LEGRE"*)?

Yes ___________ No ______________

If yes, please explain

____

____

____

Did you feel rushed at any time when completing the CDU DL procedure in the Center airspace?

Yes ________ No ________

If yes, please explain

____

____

Did you feel rushed at any time when completing the <u>CDU DL procedure</u> in the <u>TRACON</u> airspace?

Yes ________ No ________

If yes, please explain

____

____

How acceptable or unacceptable was the <u>CDU DL Interface</u> as a whole?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

How acceptable or unacceptable was the <u>CDU DL Procedure</u> as a whole?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

Please provide any comments you have regarding the <u>CDU DL procedure</u>:

____

<u>DDR Procedures</u>

How acceptable or unacceptable were the <u>tasks</u> required to complete the <u>DDR procedure</u>?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

How acceptable or unacceptable was the <u>DDR interface</u> for route modifications received in the <u>Center</u> airspace (*"Revised route to FEVER"*)?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

Did you have any trouble understanding the DDR data link message you received in the Center airspace (i.e. *"Revised FMS route to FEVER"*)?

Yes __________ No ____________

Please explain

____

How acceptable or unacceptable was the DDR interface for route modifications received in the TRACON airspace (*"Revised route to LEGRE"*)?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

Did you have any trouble deciphering the DDR data link message you received in the TRACON airspace (i.e. *"Revised FMS route to LEGRE"*)?

Yes __________ No ____________

Please explain

____

Did you feel rushed at any time when completing the DDR procedure in the Center airspace?

Yes _______ No _______

Please explain

____

Did you feel rushed at any time when completing the DDR procedure in the TRACON airspace?

Yes _______ No _______

Please explain

____

How acceptable or unacceptable was the DDR Interface as a whole?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

How acceptable or unacceptable was the DDR Procedure as a whole?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable

Please provide any comments you have regarding the DDR procedure:

____

Please state the FMS route modification interface (e.g. MPE, DDR, CDU DL) that you most preferred.

____

Why?
____

Which interface(s) do you foresee as most likely to be used in day to day operations?

____

AUTOMATION

Indicate the degree to which you feel you were able to anticipate automation behavior while flying the descents

Never	Not Often	Sometimes	Usually	Always

Were you ever confused by the automation behavior during any of the descents flown?

Yes __________ No __________

If yes, please explain
____

Were you ever surprised by the automation behavior during any of the descents flown?

Yes __________ No __________

If yes, please explain
____

____

Did you feel "ahead" of the aircraft when flying the FMS and CTAS/FMS procedures?

Never	Not Often	Sometimes	Usually	Always

Did the increased use of high level automation with the FMS and CTAS/FMS procedures impact your crew coordination activities in any way?

Yes ____________ No ____________

If yes, please explain the impact they had?

____

Did the increased use of high level automation with the FMS and CTAS/FMS procedures allow you more or less time to look out the window?

Much Less Time	Somewhat Less Time	Borderline	Somewhat More Time	Much More Time

With the FMS and CTAS/FMS procedures, how adequately or inadequately do you feel you were able to picture the vertical situation of the descent given the current displays?

Very Inadequately	Somewhat Inadequately	Borderline	Somewhat Adequately	Very Adequately

ADEQUACY OF BRIEFING AND TRAINING

Did the Glenn Rose FMS Arrival and Delmo FMS Transition briefing you received prepare you sufficiently for this procedure?

Yes _____ No _____

(please elaborate)

____

____

Did the Manual Path Extension briefing and training you received prepare you sufficiently for this procedure?

Yes _____ No _____

(please elaborate)

____

Did the CDU DL briefing and training you received prepare you sufficiently for this procedure?

Yes _____ No _____

(please elaborate)

____

Did the DDR briefing and training you received prepare you sufficiently for this procedure?

Yes _____ No _____

(please elaborate)

____

Do you think simulator training is needed for introduction of the Glenn Rose FMS Arrival and Delmo FMS Transition Procedure?

Yes _____ No _____

(if so, why?)

____

OTHER

How many descents did it take for the Glenn Rose FMS Arrival and Delmo FMS Transition to become comfortable, or routine?

____

Describe any techniques you may have developed for flying the Glenn Rose FMS Arrival and Delmo FMS Transition.

____

____

____

Appendix G

Crew Questionnaire Responses

Pilot Questionnaire Responses to Likert scale and yes or no questions

FMS ARRIVAL AND TRANSITION CHARTS

How clear or unclear was the information presented on the Glenn Rose FMS Arrival and Delmo FMS Transition charts used in this study?

0	0	0	7	16
Very Unclear	**Somewhat Unclear**	**Borderline**	**Somewhat Clear**	**Very Clear**

How organized or unorganized was the information presented on the Glenn Rose FMS Arrival and Delmo FMS Transition charts used in this study?

0	0	0	9	14
Very Unorganized	**Somewhat Unorganized**	**Borderline**	**Somewhat Organized**	**Very Organized**

How adequate or inadequate were the Glenn Rose FMS Arrival and Delmo FMS Transition charts in helping you perform the procedures?

0	0	1	6	17
Very Inadequate	**Somewhat Inadequate**	**Borderline**	**Somewhat Adequate**	**Very Adequate**

Was there any information missing from the FMS Arrival and Transition charts that you would have liked to see?

Yes 2 No 21

Do you think the FMS Arrival and Transition charts should have contained less information, or less detailed information?

Yes 6 No 18

How acceptable or unacceptable were the Glenn Rose FMS Arrival and Delmo FMS Transition charts as a whole?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable
0	0	1	8	15

FMS ARRIVAL AND TRANSITION CLEARANCE PHRASEOLOGY

Initial FMS Arrival Descent Clearance
"NASA 21, Descend via the Glenn Rose FMS Arrival, maintain XXX Knots in the descent"

Was any portion of this clearance phraseology unclear or confusing the first time you heard it?

Yes 5 No 19

When you first received this clearance, was it clear to you what to do?

Yes 20 No 4

Delmo FMS Transition Clearance
"NASA 21, Cleared for the Delmo FMS Transition to ILS18R"

Was any portion of this clearance phraseology unclear or confusing the first time you heard it?

Yes 4 No 20

When you first received this clearance, was it clear to you what to do?

Yes 21 No 4

How acceptable or unacceptable was the Glenn Rose FMS Arrival and Delmo FMS Transition phraseology as a whole?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable
0	2	0	7	15

PROCEDURE ACCEPTABILITY

FMS Procedure: Questions in this section refer specifically to the Glenn Rose FMS Arrival and Delmo FMS Transition procedure without regard to the adjunct route modification procedures (i.e. Manual Path Extension, CDU DL, and DDR).

Was any portion of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure unclear or confusing?

Yes 4 No 20

How acceptable or unacceptable was the requirement to set your MCP altitude window to the last crossing restriction on the routing of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

1	1	4	10	8
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

How acceptable or unacceptable was the requirement to use LNAV during the Arrival portion (at and above 11,000) of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

0	0	0	5	19
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

How comfortable or uncomfortable were you using LNAV during the Arrival portion of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

0	0	0	6	18
Very Uncomfortable	**Somewhat Uncomfortable**	**Borderline**	**Somewhat Comfortable**	**Very Comfortable**

How acceptable or unacceptable was the requirement to use VNAV during the Arrival portion of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

0	1	3	6	13
Very	**Somewhat**	**Borderline**	**Somewhat**	**Very**

Unacceptable	**Unacceptable**		**Acceptable**	**Acceptable**

How comfortable or uncomfortable were you using VNAV during the Arrival portion of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

2	1	1	8	12
Very Uncomfortable	**Somewhat Uncomfortable**	**Borderline**	**Somewhat Comfortable**	**Very Comfortable**

How acceptable or unacceptable was the requirement to use LNAV during the Delmo Transition portion (below 11,000) of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

0	0	1	6	17
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

How comfortable or uncomfortable were you using LNAV during the Delmo Transition portion of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

0	0	0	4	19
Very Uncomfortable	**Somewhat Uncomfortable**	**Borderline**	**Somewhat Comfortable**	**Very Comfortable**

How acceptable or unacceptable was the requirement to use VNAV during the Delmo Transition portion of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

1	3	3	6	11
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

How comfortable or uncomfortable were you using VNAV during the Delmo Transition portion of the Glenn Rose FMS Arrival and Delmo FMS Transition procedure?

2	3	2	6	11
Very	**Somewhat**	**Borderline**	**Somewhat**	**Very**

UncomfortableUncomfortable **ComfortableComfortable**

"Nasa 21, fly heading 080, descend at pilot's discretion, maintain FL240, expect direct FEVER to rejoin Glenn Rose FMS Arrival"....
"Nasa 21, clear of traffic, cleared direct FEVER, resume Glenn Rose FMS Arrival."
How acceptable or unacceptable were the above set of clearances that vectored you off the Glenn Rose FMS Arrival and then had you resume it?

0	1	1	11	10
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

"Nasa 21, Maintain current heading, standby for base turn clearance."
How acceptable or unacceptable was the above clearance given during the Delmo FMS Transition procedure?

0	0	1	6	16
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

Did you feel rushed at any time during the Glenn Rose FMS Arrival and Delmo FMS Transition <u>procedure</u>?

Yes <u>2</u> No <u>21</u>

In general, how was your <u>workload</u> affected when flying the Glenn Rose FMS Arrival and Delmo FMS Transition <u>procedure</u> as compared to your current day descent procedures:

4	9	5	5	0
Greatly Decreased	**Somewhat Decreased**	**Unaffected**	**Somewhat Increased**	**Greatly Increased**

In general, how was your <u>monitoring behavior</u> affected when flying the Glenn Rose FMS Arrival and Delmo FMS Transition <u>procedure</u> as compared to your current day descent procedures:

0	3	8	9	3
Greatly Decreased	**Somewhat Decreased**	**Unaffected**	**Somewhat Increased**	**Greatly Increased**

The Glenn Rose FMS Arrival and Delmo FMS Transition procedure made flying the descent:

Very Easy	Somewhat Easy	Borderline	Somewhat Difficult	Very Difficult
8	11	3	2	0

Compared to current day descent procedures, the Glenn Rose FMS Arrival and Delmo FMS Transition procedure was:

Very Undesirable	Somewhat Undesirable	Borderline	Somewhat Desirable	Very Desirable
0	2	1	10	11

How acceptable or unacceptable was the Glenn Rose FMS Arrival and Delmo FMS Transition procedure as a whole?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable
0	1	2	11	10

CTAS/FMS PROCEDURES

General

How acceptable or unacceptable was the requirement to use data link for route modifications while in cruise near the top-of-descent (i.e. *"Revised FMS route to FEVER"*)?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable
2	0	0	6	16

....while in the TRACON?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable
0	3	2	7	12

How acceptable or unacceptable was the issuance of a descent speed in the Glenn Rose FMS Arrival?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable
0	0	1	10	13

In general, how acceptable or unacceptable was the requirement to make FMS edits to the Delmo FMS transition routing while on downwind in the TRACON airspace?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable
0	4	3	10	7

General Data link

How acceptable or unacceptable was the data link phraseology used in the Center airspace (i.e. *"Revised FMS route to FEVER"*)?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable
0	0	1	4	19

How acceptable or unacceptable was the data link phraseology used in the TRACON airspace (i.e. *"Revised FMS route to LEGRE"*)?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable
0	0	0	3	21

Manual Path Extension Procedure

How acceptable or unacceptable was the Manual Path Extension procedure requirement to manually enter the modified base turn point into the CDU during the Delmo FMS Transition procedure?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable
0	1	3	12	8

How acceptable or unacceptable were the tasks required to complete the Manual Path Extension procedure?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable
0	1	2	10	11

Did you feel rushed at any time during the Manual Path Extension procedure?

Yes 1   No 22

How acceptable or unacceptable was the Manual Path Extension procedure phraseology (*"Make base turn at Rosel +X.X miles"*)?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable
0	0	1	7	16

How acceptable or unacceptable was the Manual Path Extension procedure as a whole?

Very Unacceptable	Somewhat Unacceptable	Borderline	Somewhat Acceptable	Very Acceptable
0	1	2	8	13

CDU DL Procedures

How acceptable or unacceptable were the tasks required to complete the CDU DL procedure?

0	0	0	8	15
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

How acceptable or unacceptable was the CDU DL interface for route modifications received in the Center airspace (*"Revised route to EFVER"*)?

0	0	0	8	15
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

Did you have any trouble understanding the CDU DL data link message you received in the Center airspace once it was loaded
(i.e. *"Revised FMS route to FEVER"*)?

Yes 0 No 24

How acceptable or unacceptable was the CDU DL interface for route modifications received in the TRACON airspace (*"Revised route to LEGRE"*)?

0	1	4	8	11
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

Did you have any trouble Understanding the CDU DL data link message you received in the TRACON airspace once it was loaded
(i.e. *"Revised FMS route to LEGRE"*)?

Yes 0 No 24

Did you feel rushed at any time when completing the CDU DL procedure in the Center airspace?

Yes 0 No 24

Did you feel rushed at any time when completing the CDU DL procedure in the TRACON airspace?

Yes 2 No 22

How acceptable or unacceptable was the CDU DL Interface as a whole?

0	0	0	12	12
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

How acceptable or unacceptable was the CDU DL Procedure as a whole?

0	0	1	12	11
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

DDR Procedures

How acceptable or unacceptable were the tasks required to complete the DDR procedure?

0	0	1	6	17
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

How acceptable or unacceptable was the DDR interface for route modifications received in the Center airspace (*"Revised route to FEVER"*)?

0	0	2	6	16
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

Did you have any trouble understanding the DDR data link message you received in the Center airspace (i.e. *"Revised FMS route to FEVER"*)?

Yes 0 No 24

How acceptable or unacceptable was the DDR interface for route modifications received in the TRACON airspace (*"Revised route to LEGRE"*)?

0	0	3	6	15
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

Did you have any trouble deciphering the DDR data link message you received in the TRACON airspace (i.e.*"Revised FMS route to LEGRE"*)?

Yes 0   No 24

Did you feel rushed at any time when completing the DDR procedure in the Center airspace?

Yes 0   No 24

Did you feel rushed at any time when completing the DDR procedure in the TRACON airspace?

Yes 2   No 22

How acceptable or unacceptable was the DDR Interface as a whole?

0	0	3	7	14
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

How acceptable or unacceptable was the DDR Procedure as a whole?

0	0	1	8	15
Very Unacceptable	**Somewhat Unacceptable**	**Borderline**	**Somewhat Acceptable**	**Very Acceptable**

AUTOMATION

Indicate the degree to which you feel you were able to anticipate automation behavior while flying the descents

Never	Not Often	Sometimes	Usually	Always
0	0	3	18	1

Were you ever confused by the automation behavior during any of the descents flown?

Yes 15 No 9

Were you ever surprised by the automation behavior during any of the descents flown?

Yes 12 No 12

Did you feel "ahead" of the aircraft when flying the FMS and CTAS/FMS procedures?

Never	Not Often	Sometimes	Usually	Always
0	0	3	12	9

Did the increased use of high level automation with the FMS and CTAS/FMS procedures impact your crew coordination activities in any way?

Yes 8 No 16

Did the increased use of high level automation with the FMS and CTAS/FMS procedures allow you more or less time to look out the window?

Much Less Time	Somewhat Less Time	Borderline	Somewhat More Time	Much More Time
2	6	4	9	3

With the FMS and CTAS/FMS procedures, how adequately or inadequately do you feel you were able to picture the vertical situation of the descent given the current displays?

0	2	0	6	16
Very Inadequately	**Somewhat Inadequately**	**Borderline**	**Somewhat Adequately**	**Very Adequately**

ADEQUACY OF BRIEFING AND TRAINING

Did the Glenn Rose FMS Arrival and Delmo FMS Transition briefing you received prepare you sufficiently for this procedure?

Yes 24 No 0

Did the Manual Path Extension briefing and training you received prepare you sufficiently for this procedure?

Yes 24 No 0

Did the CDU DL briefing and training you received prepare you sufficiently for this procedure?

Yes 24 No 0

Did the DDR briefing and training you received prepare you sufficiently for this procedure?

Yes 24 No 0

Do you think simulator training is needed for introduction of the Glenn Rose FMS Arrival and Delmo FMS Transition Procedure?

Yes 9 No 15

OTHER

Did you ever feel bored when flying any of the FMS or CTAS/FMS descents?

Yes 14 No 10

If you were to fly these procedures regularly, do you think boredom would become an issue?

Yes 5 No 14

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12A. DISTRIBUTION/AVAILABILITY STATEMENT

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13. ABSTRACT *(Maximum 200 words)*

Center TRACON Automation System (CTAS)/Flight Management System (FMS) integration on the flightdeck implies flight crews flying coupled in highly automated FMS modes [i.e. Vertical Navigation (VNAV) and Lateral Navigation (LNAV)] from top of descent to the final approach phase of flight. Pilots may also have to make FMS route edits and respond to datalink clearances in the Terminal Radar Approach Control (TRACON) airspace. This full mission simulator study addresses how the introduction of these FMS descent procedures affect crew activities, workload, and performance. It also assesses crew acceptance of these procedures. Results indicate that the number of crew activities and workload ratings are significantly reduced below current day levels when FMS procedures can be flown uninterrupted, but that activity numbers increase significantly above current day levels and workload ratings return to current day levels when FMS procedures are interrupted by common ATC interventions and CTAS routing advisories. Crew performance showed some problems with speed control during FMS procedures. Crew acceptance of the FMS procedures and route modification requirements was generally high; a minority of crews expressed concerns about use of VNAV in the TRACON airspace. Suggestions for future study are discussed.

14. SUBJECT TERMS

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