NASA Contractor Report 182070

"DIVERTER" DECISION AIDING FOR IN-FLIGHT DIVERSIONS

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P.328

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Contract NAS1-18029
August 1990

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

FOREWORD

This report discusses the feasibility of using artificial intelligence (AI) and algorithm based decision aids to assist pilots in evaluating and selecting route options depicted by in-flight diversions. Phases I and II evaluated the application of AI to diversion planning, while Phase III has extended the evaluation into a limited system prototype. Additional design and evaluation of a pilot vehicle interface and dynamic attribute weighting was included in Phase III. The work reported was performed by the Lockheed Aeronautical Systems Company-Georgia Division (LASC-Georgia) for the National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) at Hampton, Virginia. The project was funded by NASA under Contract Number NAS1-18029, Task 04A. This report is also identified as LG90ER0040 for Lockheed internal control purposes.

Guidance for the program was provided by Cary R. Spitzer, NASA-Langley Technical Representative of the Contracting Officer, and Michael T. Palmer, NASA-Langley Technical Monitor. George A. Sexton directed the Lockheed effort. Major Lockheed contributors were Scott J. Bayles, Terri L. Hall, David A. Homoki, and Frederick M. Rudolph.

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INTRODUCTION AND SUMMARY

New demands are being placed upon pilots to use airspace more effectively, to operate aircraft more efficiently, and to reduce in-flight delays while continuing to operate safely. At the same time, the amount of air traffic is increasing greatly with a relatively small increase in airport facilities. New technologies are being developed which, when properly applied, may help alleviate the overall problem. Artificial Intelligence (AI) is one of those new technologies, and its application to airborne systems was the subject of this study. The specific application of AI addressed was its use in providing the pilot with all of the necessary information upon which to base decisions regarding in-flight diversions. Since the system provides information to the pilot to ensure that the aircraft maneuvers through the in-flight diversion to safely arrive at a destination, it was named "Diverter".

Earlier phases of the program established the feasibility of incorporating artificial intelligence into airborne flight management computers. The AI functions that would be most useful to the pilot are situational assessment, evaluation of systems status, evaluation of outside influences on the contemplated rerouting, flight planning/replanning, and maneuver planning.

Earlier phases used a skeletal planner known as the Knowledge Acquisition Development Tool (KADET) developed by Teknowledge Federal Systems, a combination script-based and rule-based system. Instead, Phase III utilized a Statice database integrated with a rule-base developed using the Joshua expert system development tool. Statice and Joshua are tools developed by Symbolics Corporation to provide greater flexibility by permitting dynamic allocation of weights during the calculation of diversion recommendations. A second prototype of the system was developed which demonstrates the advanced in-flight planning/replanning capability. A prototype interface was also developed to aid in design and permit evaluation of the interface concept and design alternatives.

PROBLEM

Pilots of today's aircraft obtain information pertinent to their proposed flight plan from a variety of sources. Through extensive preflight activities, they assimilate all necessary data and plan the flight so that navigation can be executed in conjunction with other operational procedures. Currently, those flight plans are three dimensional (latitude, longitude, and altitude). In the future, however, the fourth dimension (time) will be added.

When an in-flight diversion is required the data upon which to base decisions concerning diversions must come from many sources, some of which are not readily available. In addition to knowing or obtaining the present position, fuel, and maintenance status of the aircraft, the pilot may need to consult aircraft handbooks, aircraft performance data, en route, terminal area, and instrument approach charts, company's flight operations, flight service personnel, and air traffic controllers. Developing a new flight plan to make efficient use of manpower, fuel, and time, while satisfying all applicable constraints, can be time consuming and labor intensive, particularly when the replanning is during a critical phase of flight. Frequently, there is inadequate time to obtain all data before initiating the diversion, so the pilot bases his decision upon the best information available, which is sometimes incomplete. A system is needed to quickly provide the pilot with complete and accurate information upon which to make decisions, as well as flight planning recommendations, concerning in-flight diversions.

APPROACH

This program was divided into four phases: (I) concept feasibility and software tools requirements, (II) stand-alone demonstrations, (III) evaluation in NASA Langley's Advanced Concepts Simulator, and (IV) Validation in NASA Langley's B-737 Transport Systems Research Vehicle (TSRV) aircraft. This report covers that portion of phase three up until actual installation in the simulator.

This phase has developed the concepts of the first two phases to more fully design the software and Pilot Vehicle Interface (PVI) for implementation and evaluation in the Advanced Concepts Simulator. Phase I addressed the feasibility of the application of artificial intelligence (AI) and algorithm based decision aids to evaluate and recommend in-flight diversions. This included the definition of diversion types, as well as functional analysis of current procedures involved with diversion planning and execution. Phase III has used and augmented this previous information. A more detailed functional flow analysis was completed to provide an in depth analysis of a pilot's in-flight diversion planning process. The results of the functional analysis were subsequently adapted and combined with the results of an information analysis which listed both the types and sources of required information for diversion planning. The information analysis permitted the allocation of flight planning processes to either the pilot, Diverter, or both. In this way, information display and control requirements for the system were identified.

An analysis of display requirements identified the need for both graphical and alphanumeric (text) displays. These represent the display of spatial information necessary for situation awareness as well as alphanumeric information required for diversion planning, evaluation, and execution. Since concurrent display of both spatial and textual information was found to be necessary, two separate output devices were selected to display this information.

A similar analysis of control requirements identified text (alpha-numeric), spatial, and system control (e.g., menu selection) requirements. The available technologies were surveyed with the resultant selection of a combined Control/Display Unit (CDU) for entry and display of alphanumeric information; and a touch screen/graphical display for entry and manipulation of spatial information as well as system control.

Once analyses of control and display requirements and evaluation of available technologies were completed, display formats were designed to provide the pilot with the information found necessary from the aforementioned information analysis. The large amount of information mandated that the design of display formats maximize the amount of information available while minimizing the complexity and clutter of individual displays. Additionally, development of a system architecture required the application of a structure to display formatting. This structure determined display format requirements and directly influenced the efficacy with which available information could be retrieved. A correctly applied structure should reduce information complexity and clutter, enhance integration of multiple sources of information, maximize the amount of information presented and its usefulness, and minimize workload associated with the access, integration and interpretation of information. A hybrid menu format was designed which provides highly processed categorical information at higher menu levels with decreasing processing at lower levels. The lowest menu level presents source level information processed only to facilitate pilot retrieval. The information at this level represents the basis of logic-based decisions and presents information normally available only during preflight planning in a manner consistent with original sources, but highly retrievable.

Integration of text and graphical information was accomplished in reference to the information analysis described above. Redundant display of spatial information was presented in a format integrated with current onboard weather radar display information. This integration provides both graphical route information and display of radar images corresponding to current weather in the operational area. Integrated information also provides for a more meaningful display of current aircraft flight status. Additional graphical depiction of airspace and terrain conflicts, integrated with the aforementioned weather and route information provides the pilot with comprehensive information as to the current aircraft flight profile.

Similar redundancy of textual clearance information with graphical route depiction presents the information in a format familiar to the pilot, readily achievable and transferable to other onboard systems, as well as spatially congruent with navigational objectives. This redundancy minimizes the manipulation of mental representations that depict the aircraft's situation. Additionally, such integration facilitates evaluation of information used to represent the aircraft's situation, providing greater situational awareness, reduced work load, and fewer errors.

DIVERSIONS

Phases I and II considered both the feasibility and essential functional requirements of the application of an AI based decision aiding system to diversion planning and execution. This information was utilized in developing more detailed and extensive functional requirements for the Diverter system. As discussed in the previous report, diversions were placed into six categories: different departure route, en route change to the same destination, delaying vectors, holding, different arrival route, and alternate destination.

These were reduced to three general types of diversions: destination, route, and delay diversions. Compound diversions could be developed which combine each of these general types. For example, a diversion due to weather might involve both a destination change and a delay, in the form of holding at an en route fix, delay vectors, or course change from an optimal direct route. This could be the scenario if weather conditions at a planned destination fall below minimums and traffic congestion to viable alternates requires en route holding to permit flow control of traffic into a terminal area.

The goal was to develop a system independent from specific diversion scenarios. Scenarios do provide a vehicle for analysis of the application of the decision aiding system. However, compliance to scenarios limits the "generalization" of rule bases to the intricacies and complexity of real life situations. The use of general rules resulted in a functional analysis useful in designing a rule base applicable to any type of diversion.

SYSTEM DEFINITION

While Phase II of the program provided a general functional analysis detailing a general diversion planning process, Phase III expanded and enhanced this previous work. A functional flow diagram was completed illustrating the analysis (see Appendix A). This functional analysis of pilot planning processes provided increased delineation of the processes which comprise diversion planning, as well as the structure necessary for the development of an intelligent system which models human information processing activities.

The goal of this application of artificial intelligence (AI) and algorithm based decision aiding has been to replicate a pilot's information processing and application of logic principles during in - flight diversion planning. Since the Diverter system will recommend a course of action to the pilot, the data used, as well as the rule base and system logic applied to determine a recommended action, must be understood, available, acceptable, and congruent with a pilot's normal cognitive activity in planning a diversion. Only under these conditions will the recommendation be considered reliable and acceptable to the pilot.

Diverter was designed to closely resemble the cognitive and information processing functions used by pilots during diversion planning. Congruence between pilot and machine information processing was accomplished by obtaining information from domain experts (pilots) as to the methods and logic used during diversion planning. The resultant information was represented in the functional flow analyses. This information, in conjunction with information from sources such as Federal Aviation Regulations (FARs) and the Airman's Information Manual (AIM), was used in the expansion and further definition of the functional flow analysis referenced above. Since current planning practice often limits the number of alternatives and breadth of information a pilot might incorporate in his planning strategy, participating knowledge experts were encouraged to describe not only current practices, sources, and methods of planning a diversion, but also to indicate where limitations might be alleviated with the application of AI technology. Further, information about suggested system architecture, display and control types, display formats, and system integration into both current generation flight decks and expected future flight decks was also solicited.

It was assumed that Diverter will be an "invisible", although continuously active, system until a situation arises requiring planning, display, and execution of a diversion. This background activity will consist of constant system database updates from onboard systems as well as from ground based systems through datalink communications. Due to the relative rarity of diversion planning, the system need not use cockpit displays for this activity; hence data display will not occur until the system is activated.

Activation will be initiated by either the pilot or the Diverter system. In the former case, system activation would be provided through a menu option on a flight data CDU. Current generation aircraft have moved away from separate switches for activation of subsystems and annunciation of systems status or failure, utilizing instead menu driven displays. It is assumed that a "Diverter option" would be available from such a CDU.

Similarly, system activation could occur automatically when the reason for the diversion is due either to a change in onboard aircraft system status or information from datalink communications with ground based sources. In this case, annunciation of the activation would occur through the aircraft's integrated fault/system status annunciation system. Increasingly, aircraft are centralizing advisory and system status messages in an integrated display which prioritizes the message, thus reducing the number of separate warning displays. Diverter activation would be displayed through such a system. This would provide the pilot with control over activation of the system's pilot vehicle interface and the display of system data, preventing automatic display swapping associated with Diverter's information displays. Automatic display swapping could be detrimental to pilot performance and could provide a hazardous situation if information needed for aircraft control or situation awareness was lost.

Once annunciated, in a electronic cockpit, the pilot could select the placement of displays according to his own individual preferences and task requirements. Again, this is more a function of cockpit system architecture than a Diverter function. As such, the exact placement of displays is essentially beyond the scope of this work; in a flexible glass display cockpit, it might be ultimately determined by pilot preference. However, the design of the PVI was completed to permit the incorporation of the Diverter system into aircraft lacking this flexibility. In this case, a multi-mode graphical moving map display and a text supporting CDU were selected.

FUNCTIONAL ANALYSIS

A pilot's top level diversion planning functions, as illustrated in Appendix A, are to monitor systems for changes, assess the impact of any changes, assess response options given sufficient impact, and/or concomitantly allow for the execution of emergency procedures should the situation require such action. After response options have been assessed, the pilot determines what requirements will determine the course of diversion planning. These requirements will serve to some degree as constraints in the generation of a plan of action. Once diversion options have been planned, the pilot evaluates and possibly executes the option. Thereafter, the pilot returns to other duties, including monitoring system status and progression of the flight.

The diversion planning process, illustrated in Appendix A, involves much more detailed analysis and decision making than that used in Phases I and II. This appendix illustrates the increasingly detailed nature of the functions involved in pilot planning of an in-flight diversion. As an example, the monitoring of system status can be broken down into several areas: aircraft status, air traffic constraints, weather, and route or navigation progress. While the assessment of aircraft status might seem simple, this involves a comparison of system operability and status to defined norms of performance. Certain systems are monitored in a binary manner, with a simple determination as to the presence of a fault. More common, however, is a continuous monitoring of systems for trends indicative of impending fault. This continual monitoring is used to provide a diagnosis of impending fault as early as possible so as to minimize the possibility of forced operation of the aircraft with a complete failure.

Similar monitoring of air traffic status occurs through maintenance of situational awareness of the airspace. "See-and-avoid" measures are augmented by traffic advisories from controllers and monitoring of radio traffic between other pilots and controllers in the general area. Weather status is also monitored in a physical sense, through the use of visual indications as well as through onboard radar, ground-based observations from en route air traffic controllers, en route controller's advisories of weather encountered by other aircraft along the same route, and communications with flight service personnel and company meteorologists.

Finally, aircraft route progress is continually monitored as part of the navigation process. Fixes are cross checked against radio aids and, when possible, visual landmarks. Progress might also be displayed in modern cockpits through the use a moving map display. Similar updates in navigation and route progress are made through ATC reports, or are a part of the normal duties involved with pilotage and navigation.

Since it is expected that diversion planning will possibly be occurring during a phase of flight that is highly workload intensive, it would be advantageous to include automated direct data communications with as many sources of information needed by an intelligent system as possible. Such increased numbers of communications connections would reduce pilot data entry requirements which are often not feasible during high workload conditions. Therefore, the incorporation of automatic datalink communications should provide the greatest bulk of the information to the Diverter system. Communication links with air traffic control, flight service and/or company weather centers, and company dispatchers would minimally be necessary. Further, source differentiation would also be required when information is provided through datalink.

Due to these requirements, the datalink will be assumed to consist of several components. First, the data relevant to a particular aircraft would have to be provided in a manner sufficient to provide directive control. In essence, the datalink would have to provide a means of direct communications between ATC and a specific aircraft to which flight directives are sent. This would require one of several systems. Either the onboard data system would have to be "intelligent" enough to acknowledge and respond to an aircraft specific identifier, or the datalink would have to provide a facility for direct communications with only one recipient of the directive. The latter is preferred as it would most probably result in the lowest probability of fault associated with incomplete transfer or reception of flight directives.

Similarly, datalink must provide information about the general nature of the flight environment. In essence, Diverter must receive general information which, for pilots, would normally be considered to provide awareness of the global situational environment in which the aircraft is operating. This would replicate the pilot's filtering of information which is not specific to his aircraft but which aids his ability to make informed and complete decisions. So, for instance, when a pilot sees a line of thunderstorms, the cells of which might be circumnavigated, he seeks information as to the nature of the storm as well as its impact on other aircraft operating closer to it. This information might formally be presented in pilot reports (PIREPS) requested from flight service. More often than not, however, the additional information is obtained in part through the monitoring of communications between the en route controller and other aircraft closer to the storm. In this way, information regarding the status of the environment is collected and evaluated prior to any diversion planning.

For Diverter to operate effectively, these communications must be replicated through the datalink, or alternatively, entered by the pilot. Since manual entry dramatically increases work load, that approach was not selected. Instead, a dual mode datalink system was selected. One channel would provide advisory and flight directives relevant to the particular aircraft. The other channel would provide information about other communications between aircraft and ATC. Similarly, any information provided by flight service in response to a direct request would be provided through direct communication. Information relevant to a particular area, such as the update of a Notice to Airmen (NOTAM), would be provided through the general channel.

For example, if a flight was planned between La Guardia, New York (LGA) and Los Angeles International (LAX), the Diverter system would be uploaded with current information pertinent to the flight (weather, en route advisories, NOTAMS, etc.) prior to departure. As the flight progresses, certain information might change. For instance, the weather at LAX might change while the aircraft is in the midwest. Additionally, if severe weather caused a power outage at LAX, then the facilities available would be reduced. Similarly, a radio navigation aid in the midwest might be under repair and removed from service. Since these events occurred after departure, the information would have to be updated in the Diverter database. If Diverter was only to operate using the information current at departure, then changes might make worthless any decisions which are not based on complete and accurate information. This could result in incorrect flight planning and a dangerous situation.

Since the information would necessitate a change in clearance, it would be an "aircraft specific directive" which would be provided through direct datalink transfer only to aircraft necessitating an amended clearance. This information is generally provided through voice communications from ATC as well as company dispatchers. Since Diverter needs the same information, it would be provided via datalink to update the system. Other aircraft would also be provided the same information through datalink modem update, however, not in aircraft specific or flight directive formats. The situation in the midwest would normally be provided by NOTAM. The information, in this case, is not meant to be specific to the particular aircraft, but might alter decision making and flight planning processes. It, too, must be included in database updating routines. In this case, however, the message would be received through the alternate channel since it isn't relevant only to the specific aircraft. The delineation between aircraft specific and general information updates is analogous to current voice communications protocols. General information is distributed through NOTAM as well at ATC advisories. All aircraft sharing a common frequency or that checks for NOTAM updates through flight service is provided with such information. Conversely, aircraft specific directives are also a common means of air traffic control. These vary widely from amended clearances to terminal control directives. At times this information might be useful to all aircraft, but generally the scope of the directive and compliance necessitates the action of a specific aircraft. Similarly, Diverter will be provided information either through general updating of system databases as well as aircraft specific information.

Additional monitoring would occur for onboard systems, just as was the case for external sources of information. Onboard monitoring would be accomplished in one of two ways. If the aircraft contained an intelligent fault monitoring system, such as an Advisory, Caution, and Warning System (ACAWS), Diverter would be linked to such a system and receive system status updates through it. If such a system was not available, it is suggested that Diverter be linked to systems in an individual manner and provided with information as to system normality status and fault monitoring. Again, the goal is to provide Diverter with information about onboard system status without requiring the pilot to manually enter information, especially during a high workload phase of flight.

INFORMATION SOURCES AND EVALUATION

Once a functional analysis of the diversion planning process had been completed, analysis of the sources of information required by Diverter for flight planning was completed (see Diverter Report Addendum). This analysis was accomplished by determining what sources of information are evaluated when pilots are planning a diversion. In addition, however, analysis included sources of information indicative of the need for a diversion, not just the sources of information used in the planning process. By including this information, Diverter was designed to evaluate information indicative of the need for a diversion as well as the information which needs to be considered in planning the diversion action itself.

The first goal of the Diverter system is to evaluate changes in system status. If the evaluation of system status suggests that a diversion is recommended, then the system would evaluate the nature of the change and its impact on the continuation of flight, expendable resources (fuel, oil, oxygen), safety issues, company directives, company operations procedures, federal aviation regulations, etc.

Much of the monitoring action, as indicated in the addendum, involves aircraft system status. System status might be provided though the use of an interface with other monitoring systems designed specifically for the aircraft. If such an interface is not available, or if the aircraft does not contain a centralized monitoring system, then the Diverter system would have to contain both the software for system evaluation as well as data communications connections to sensors in the aircraft which would permit the access of data about system performance. This restriction might be considered a limitation for the application of this system to either current generation or older aircraft which lack centralized system fault monitoring as the incorporation of software and hardware to complete this task would be very costly. However, the only other viable method would be data input from the pilot as to system failure.

While the design proposed does not permit extensive input from the pilot (i.e., manual input of data as to the reason for a diversion), it might be possible to incorporate that into the design. Still, the design of such routines would have to permit rather concise determination and definition of the locus and systemic ramifications of the problem. For instance, a partial malfunction of the electrical system might have effects which range from loss of navigation and radio equipment to reduced control effectiveness and hydraulic system failure, depending on the nature of the fault, the system design, and the ability to use a different electrical bus. As such, the ramifications of such a loss could vary widely as a function of other situational variables affecting the planning of the diversion. While an integrated fault monitoring system would be able to determine the extent of a failure, it is doubtful that this could be easily input by the pilot to represent the same level of information; unless of course, the task involved a rather large amount of input. This latter case would, of course, be unacceptable as workload in such a situation would most likely exceed the capabilities of the flight crew, resulting in an unsafe situation.

A further limitation of incorporating extensive use of manual pilot input is that one of several conditions would have to be met. First, the input could be made through a natural language interface with enough "intelligence" to provide a parse of the string and association of that with some definition of the problem which Diverter could use. This would result in a very large program, perhaps too large to permit incorporation in airborne computer equipment. A second limitation with this type of data entry approach is that the person inputting the information would have to include a rather extensive narrative as to the nature of the problem. This, of course would require the allocation of extensive resources to this task: a result which is hardly acceptable in an emergency or high work load environment. Finally, the current generation natural language interfaces are not flexible enough to evaluate complex narrative describing the variables affecting a diversion. Again, this would result in the pilot having to simplify the narrative. This might include breaking statements down into very simple meaningful chunks, each which could be evaluated but each which would increase input time and cognitive resource allocation to the task of inputting such information. Again, such an allocation is not acceptable. Additionally, these simple statements might not truly convey system status.

It seems, given the aforementioned limitations, that a natural language parser and natural language data entry via a keyboard is not an acceptable method. A second method would involve the use of a command language. This might reduce both the computer processing power required and the time for entry of information. The disadvantages of this method, however, include a limited scope of definition for the fault and a requirement that the crew know what commands to use in a certain situation. Both of these limitations are severe. The limitation in definition scope would effectively reduce the system capabilities to the level of the definition. Such a reduction might result in diversion suggestions which are so limited in informational utilization as to be dangerous. Additionally, requiring the crew to know which commands to enter results in one of several deficits.

The first of these deficits is the expectation that the crew will learn and use the commands in an emergency situation. This constraint could result in crew frustration when the command that they think should be usable is actually incorrect or not acceptable. Additionally, requiring the pilot to enter a command representing a fault state requires that the definition of that fault state be codified in the definition. In other words, the definition must be operationally defined, very specifically, in order for the correct meaning to be imparted to the system. This would result in either a limitation of the "meaning" received through a command (e.g., the use of simple commands like "engine failure" where the real problem is a subsystem of the engine), or the use of a very large set of specific definitions. The latter would again produce a situation requiring high cognitive workload which is not acceptable in this environment.

The third method would involve the use of a menu system which presented all aircraft systems and would allow the pilot to select the fault. This method, like the previous one, would result in either a limitation of the amount of specific information conveyed to the system or the requirement that the system display a large number of faults. Again, the latter would result in the pilot having to cursor though a long list, requiring resources that are relatively scarce in a flying environment.

In summary, while the system could have been designed to include any of these methods of data entry as to the nature of the diversion, if due to an onboard system failure; using such an approach has some severe limitations. These include increased workload, increased head down data entry to a control - display unit, increased cognitive resources allocated to non flying tasks, decreased situational awareness, and limited information conveyed as to the specific cause of and need for a diversion.

In addition to the source and usage of information, the requirements to display the information as well as the allocation of a display format to either a graphical or text format was completed. In the former case, part of the information analysis determined whether the Diverter system should display certain items of information. For instance, the system uses and generates much information when determining a navigational solution to the need for a diversion. This includes navigation aids, routing, airspace conflicts, etc. Much of this information must be displayed in order to provide situational awareness. System status in modern cockpits, however, is increasingly being displayed by a fault annunciation system. In this case, to display the information regarding fault detection provides only a redundant display of information already available in the cockpit. While the integration of such information might be advisable, the purpose of the Diverter system is to use information provided by fault monitoring systems to generate the necessary response to a need to divert. It is not a system to display such information. Since the amount of information is rather large, it was decided to limit it in cases where other cockpit displays would provide a concurrent display. The information analysis provides information about whether the information should be displayed on a system basis.

Similarly, the information analysis also involved determining what sort of format would best be suited for display of information. Concomitant with this determination of format was an analysis of both the advantages and disadvantages of display and control technologies. These included the use of synthesized voice, audio alerts with text messages, voice messages with redundant text, voice messages with redundant text available on demand, audio alerting with symbolic/graphical representations on a dynamic CRT, multiple visual displays for separate graphical and text information provided on CRT displays, and a hybrid system with text overlaying graphics, to include radar input and graphical flight planning.

The voice displays and controls were considered to be limited. The technology associated with voice input and control suggests that it is limited only to simple command line type entries. Additionally, the speech generally must be voiced consistently across occurrences in order for the computer to assess the command. Similarly, extraneous noise is a variable that must be considered in the flight deck environment. It would tend to limit the use of voice controls. The use of voiced displays would only be useful for text information, providing only limited information about graphical or spatial information. While this mode might be considered appropriate given the audio based communications now utilized, one goal was to not overload the audio channel. Further design considerations attempted to reduce the emphasis on the use of audio displays. This stems from evidence which suggests that the audio channel is already saturated and additional information displayed using that channel would only exacerbate the saturation. In summary, the use of auditory displays and controls was considered because this method would be congruent with current display of information, but it was ruled out based on the aforementioned limitations.

The use of audio alerts with text messages was also considered. In this case, the audio alert would indicate the presence of an incoming text message, while the message would be displayed in graphical format on a control display unit. Again, the major disadvantage with this method stems from the already saturated audio environment on flight decks. The trend is away from the use of separate audio alerts to the use of consolidated warning or alerting systems. The use of only a text display also is incompatible with the representation of spatial and graphical information; that which is most common in the representation of navigational information.

Voiced messages with redundant text would compensate for the attentional dependence on a visual display but again would provide redundant information that is not necessary. The advantages of this method would be the omni-directional capabilities as well as audio alerting. There would be a combined increase in demand on both the visual and audio channels and a continued reliance on text to represent spatial information. Given these disadvantages, this method was not considered.

The limitations of the previous example could also be addressed concerning the use of voiced messages with redundant text available on demand. Such a separate and redundant text display would only be utilized when selected by the pilot. This is still limited in that there would be continued reliance on text to represent spatial information.

The use of an audio alert and symbolic/graphical map display on a CRT was also considered. The advantages would be a high degree of compatibility between the graphical nature of navigational information and display using a graphical format. Such a display would also integrate all of the information on a single display, reducing attentional requirements associated with a multiple display system. The disadvantages, however, include the possibility that this format would require complex coding schemes (i.e., the lack of text would require use of graphics to convey information). This incompatibility would reduce the efficiency with which the information would be transferred to the pilot. Similarly, verbal messages would totally be incompatible with a graphical or symbolic format. The use of a single display would also, due to the large amount of information to be displayed, lead to display overcrowding, confusion with other symbols, and decreased legibility.

Yet another disadvantage of the audio alert and symbolic/graphical map display on a CRT is the need for integration from multiple displays, including radar, flight director, etc. This, in conjunction with overcrowding of graphical information would create complications for the use of this format for control input.

Multiple visual displays (separated for text and graphics) minimizes memory load by maximizing redundancy. Again, the use of multiple displays would increase the amount of information available but might increase the workload associated with integration of separate information sources. The increased number of displays and display areas would also increase the amount of information available. It would allow for structuring of displays based on the content or attributes of information to be displayed. In this way, the display could be designed to optimize a particular type of information. This would reduce the number of information transformations required to make use of the information, but as stated earlier, would increase the workload associated with information integration. Similarly, the displays would be limited to the visual modality. Complications could also arise through the use of multiple displays and controls. In this case, the control might not be collocated with a display, leading to incompatibility between the display and the control.

Finally, a hybrid display and control would consist of text overlays on map displays with possible radar input and a separate text display for text intensive display and control. The use of such integrated displays would minimize visual search requirements because all information would be available on a single display (e.g., navigation, radar, and graphical representation of suggested diversion navigational solutions). Similarly, the use of a text control-display unit would centralize the text information into one display without cluttering the graphical/symbolic navigation display. The use of combined controls and displays in one unit would integrate the two actions. This would simplify data entry by providing direct manipulation. The disadvantages would be associated with clutter problems due to the integration of large amounts of information into single CDU units.

The hybrid display was selected because of the integration capabilities discussed above. Such an integration would provide increased situational awareness by providing a comprehensive display of situational variables to be considered when evaluating a diversion recommendation. Also, the use of a graphical display permits the compatible display of navigation data in two dimensions. This poses a slight limitation as the third dimension is not represented faithfully. Possible solutions to this were considered. A three dimensional display was ruled out due to technological limitations at this time, as well as representational problems associated with those currently being considered for air traffic control. The use of a second graphical display for the vertical component of navigation was also considered. New generation radar units are providing this format. Still, the integration with horizontal components is somewhat limiting, requiring an integration of both components for a complete display. Further, there is a limitation in the display of the fourth (time) dimension. This is addressed though the use of a display function which allows the pilot to move a "ghost" of the aircraft though space and time, allowing the display of the situation the aircraft would encounter at a hypothetically selected point in the future (based, of course, on current information and forecast trends).

One of the major goals for control input was the use of direct manipulation. This method provides a strategy whereby the pilot could select and evaluate, symbolically or graphically, the information in a display. This is in opposition to the more common use of text manipulation where data is handled through the use of command input through a keyboard. While the interface would require a keyboard for input when direct manipulation was not possible, it was designed to minimize use of keyboard input and control. A direct manipulation interface will reduce the cognitive workload necessary to evaluate and understand information. It tends to optimize the compatibility between changing a parameter and the input of such a change. As such, the displays selected would provide an avenue for direct management and use of information.

Several alternatives for direct manipulation were considered; including the use of a touch panel display, track ball, and Hands-on-Throttle-and-Stick (HOTAS). The touch panel was selected in favor of the other two alternatives evaluated. The use of the trackball in the flying environment would be limited given the fine resolution of such input devices. Additionally, both track ball and HOTAS are what might be considered only intermediate direct manipulation devices. They both require the slewing of a cursor to a particular position for manipulation.

Touch panel provides a direct control movement which would be a highly compatible response for most data input functions. While touch panels do have some limitations, such as use in high vibration environments, parallax distortion, and confirmation of input, this entry method was judged superior to the aforementioned alternatives. It is expected that vibration in a large commercial aircraft would be minimal. While turbulence might provide some difficulty, its effects can be reduced by including a palm plate. Additionally, parallax has been reduced with newer versions and confirmation of input using finger lift off rather than a finger press has improved performance. The use of a slew function and finger lift off for input would allow the pilot to touch the screen, slew to a position, then select by removing the finger from the display.

The addition of a QWERTY keyboard was also suggested. This would provide for ASCII input when direct manipulation of data screens or menus would prove to be an inefficient method of data entry and control. Generally, though, the system was designed to maximize the direct manipulation touch screen control. The application of the aforementioned decisions to the design of the Pilot-Vehicle Interface (PVI) will be discussed at length in a later section of this document.

REPLICATION OF PILOT PLANNING

The Diverter system was designed to provide a synthetic "associate" crew member to collect and analyze information for use in the planning of an alternative course of action known as a diversion. The use of the terminology "synthetic", "associate", and "crew member" highlight the design objectives. The goal of the Diverter system encompasses more than just the evaluation of information and a consequential altered flight plan recommendation. It must represent the same processes ascribed to its human counterpart in that the recommendations made by Diverter must be considered, by the crew, to represent the same decision making strategies, problem solving approach, and level of processing utilized by flight crews in determining an alternative course of action.

Thus, the Diverter system is more than just an informational source. Instead, the system must present information in a format that a flight crew will accept as a replication of their own pilot planning processes. Instead of the system working on its own, it must be perceived by the flight crew as an integral component of the flight deck; with sufficient computational power and artificial intelligence to replicate the cognitive processes of a human crew member. It must represent information in a format that is not only clear and concise, but also congruent with the formats with which pilots are familiar. In a sense, then, it must represent an associate upon which the pilot depends to make a recommendation which encompasses the evaluation of information to the degree that the same crew member would evaluate information if given the same task.

The importance of this "associate" crew member perception stems from a need for the system to be accepted by the flight crew. The recommendations Diverter makes, in many situations, would encompass more information than its human counterpart could evaluate given their flying duties. These same recommendations, by the mere fact that they extend the information processing capabilities well beyond that of a normal flight crew, are going to have to be accepted and utilized. If this is to be the case, the flight crew using the system will have to trust that the system is evaluating data using its rule base knowledge in such a way as to be congruent with human decision making. If this is not the case, and there is any indication that the planning process does not replicate that of a pilot, the system will not be trusted, and hence, it will not be used. Additionally, even if the system is trusted, the display of information must be congruent with and similar to formats normally used to present information to the pilot during flight planning activities. Any incongruence would create a sense of mistrust of the information presented.

In order to design a system which is congruent with information processing and decision making strategies applied during diversion planning, the diversion planning processes of domain experts were analyzed. This is presented in the form of a functional flow diagram (Appendix A). It constitutes what might be considered the human logic and functional processes involved in diversion planning. The functional flow diagram describes, in greater detail than Phase II, the process by which the pilot decides whether to make a diversion, what information is evaluated during diversion planning, and what courses of action are available and selectable for diversion planning.

Since one of the goals of system development has been to replicate the planning processes of pilots, the functional flow diagram was utilized as a template for system development. In essence, the system represents those processes used by the pilot. While the functional flow diagram provides the structure of the decision making and information processing strategies, it does not provide the knowledge content of the pilot. Decision making involves the application of a structured approach to the evaluation of a knowledge base. The knowledge base is considered to contain two types of information. Some of the information is codified in a set of rules. These guide the decision making process. The other "knowledge" is represented by the information that the system, be it human or computer, assesses. This information is collected from various sources, evaluated to determine its impact on a possible course of action, and then utilized in any decision making once its use is determined to be required by the parameters of the problem.

The pilot is provided with large amounts of information from sources both internal and external to the aircraft (see addendum for detailed information). Similarly, due to the skilled nature of the flying task, the pilot commands a large body of knowledge which is utilized during decision making. Much of this knowledge is acquired through flight training. Additional knowledge is added through experience. Each experience provides additional information as to what decisions work in a given situation. From these instances, general rules learned in training or through earlier experiences are either reinforced or extinguished. The result is the application of what is commonly known as strategy in problem solving.

In order to provide the static knowledge, a rule base was developed representing much of the information learned by a pilot through flight training. It is only a rule base in that it represents a set of static rules which, when given information, suggest a course of action. This rule base (Appendix B) duplicates the static knowledge utilized by pilots. It represents information from flight training manuals, the Airmen's Information Manual (AIM), and the Federal Aviation Regulations (FARs). This information, however, does not replicate the information gained through experience.

In order to supplement the rule base, making it a more realistic representation of the rule base used in human decision making, additional rules were added. Similar to the determination of procedures used in diversion planning, this information was acquired through the use of interviews with knowledge experts. Their information generally augmented the codified information found in such sources as the AIM, but added to it in some cases. The rule base, while much more extensive than that utilized in Phase II, is still far from complete. Additions should be made to represent rules generated and applied by the company. These were generally not included in this development because they would be specific to a company and most likely be added to some basic form of the Diverter system in the future.

An additional mechanism should be provided for the program to generate new rules through its own "experience". While the goal to develop a system which is rule based seems to have worked, to truly replicate human decision making, a dynamic rule base is suggested. In essence, the self generation of rules by a system is a defining property of what is considered an "intelligent" system. Diverter utilizes dynamic information, in the sense that it is able to collect information in real time and apply a set of rules to it to arrive at a recommended course of action. The program also utilizes rules generated through experience as developed through knowledge experts. Finally, the rules applied are dynamic in the sense that a set of weights is developed as a function of additive components descriptive of the situation. Diverter is not, however, able to learn from itself by generating rules in response to conditions and information encountered from previous diversion plans. Future development might provide dynamic rules whose weights are modified as a function of utility of usage, thereby providing the "intelligence" inherent in human decision making.

As discussed earlier, the application of logic statements must be consistent with and congruent to that utilized by the pilots who are using the system. The nature of the design method utilized should provide this consistency as the goal of the system has been to replicate the processes utilized by its human counterpart. Additional consistency might be added if the software was able not only to learn from itself, but also to learn from the actions of the flight crew. Specifically, individuals differ in the way that they approach problems. There are large individual differences in the application of problem solving strategies. Future development might include a method for the modification of rules that represent decision making and problem solving strategies such that the system, while executing a standard rule base (representing, for instance, specific FARs), might also execute rules which represent the problem solving strategy of the pilot or flight crew. This would result in diversion planning and display which nearly mirrors the actions of the particular crew member(s) utilizing the system. While the recommendations might not differ significantly from a system which does not permit such adjustments in program, the display and execution of such recommendations might be more congruent with a pilot's strategy. This would result in possibly greater trust, usage, and execution of diversion recommendations.

Initially, it is expected that pilots will be very skeptical of the power of the Diverter system. Later, once pilots accept the system, it is expected that any possible error, whether real or merely perceived due to a discrepancy between the pilot and the system, will again result in mistrust of the system. In order to minimize this mistrust, the system should provide a simple means of providing traceability and availability of the logic applied to reach a recommendation. Consider the following simple example which illustrates this point. Suppose an aircraft has departed New York en route to Chicago. The system receives a weather update indicating that the weather in Chicago has deteriorated such that a landing in Chicago is not feasible. Since the weather forecast did not indicate that such a diversion was even a possibility, it will not be expected by the pilot. If, then, there were no traceability; he might decide that the weather report is erroneous and that flight on to Chicago is the best alternative. So, providing traceability both of information sources and history, as well as the application of the rule base to any data, would facilitate trust in the system.

In addition, such traceability would provide a means by which pilots could troubleshoot the system, determining if erroneous information or an inappropriate rule was applied to the data resulting in an incorrect or inappropriate diversion recommendation. The format of the PVI, which will be discussed later, provides information as to the sources as well as the timeliness of information. This information would provide traceability by allowing a determination of the information source and its timeliness. The menu structure of the PVI will also provide traceability with regard to the application of rules and the determination of a diversion recommendation. Additionally, the Diverter interface was designed to include categorical reasons for decision making. In this way, the end product of the application of rules to data pertinent to a diversion would be available for logic traceability and trouble shooting.

The Diverter system has been designed to accept information from as many sources as possible. It integrates all of this information into a format which provides the best possible solution to the diversion requirements. In addition, it provides a comprehensive display of information relevant to acceptance and execution of the recommendation as well as a high level of situational awareness. Enhanced situational awareness is important during any phase of flight when a flight plan is altered. Such awareness is imperative when the alteration of a flight plan is the result of a Diverter flight plan recommendation, especially when the crew questions the suitability of the recommendation. Additionally, the use of multiple sources of information provides a comprehensive description of the situation but requires that the reliability of the information and the credibility of the source be evaluated.

For instance, Diverter would assimilate information from several sources when evaluating the weather. These would include forecasts, current conditions, en route updates to forecasts or current conditions, information from ATC controllers, information from airborne weather radar equipment, and information from other aircraft in the operational area. Each of these sources must be assessed for credibility and reliability. The source itself would determine this to some degree. For instance, the current conditions at an airfield are generally considered more reliable than the forecast conditions. Additionally, the timeliness of the weather forecast might also impact its reliability. Certainly, the more recent the forecast, the greater the credibility; even if trend information is provided in addition to less timely forecasts. Source credibility is also ascribed to information. For instance, recent pilot reports might be considered more credible than forecast conditions, especially if the pilot report is very recent and represents a small geographical area.

The Diverter system has been designed to evaluate the credibility and reliability of any information available to or used by the system. The results of this evaluation must be made available to the pilot. Source identification and timeliness of flight planning information is expected to generally be sufficient to establish credibility. Diverter display screens provide the pilot with both the source and timeliness of information. In addition, because information sources differ in credibility and such difference are relevant to the alternative recommendation which is selected, information sources are evaluated by Diverter. This evaluation is integrated in the flight planning processes by including a variable that represents a rating of source credibility. When the system completes its evaluation, this variable contributes to the impact that a particular source of information will be given when included in the diversion planning.

DISPLAYS AND CONTROLS REQUIREMENTS

The information analysis provided data on the type of information input and output necessary for diversion planning display and control. These will be considered separately although the selected PVI design integrates both controls and displays into single devices.

Displays:

The information analysis identified the need to include two basic types of displays: text and graphics. The information provided and utilized by pilots in diversion planning tends to be highly text dependent. Weather reports (i.e., Terminal Forecasts, Area Forecasts, Pilot Reports, current conditions at an airfield, SIGMETS, AIRMETS, Winds Aloft) all tend to be presented in a text format. In addition, however, weather maps provide a graphical representation of weather phenomena. They are generally large scale (i.e., significant weather prognostic charts, surface observation charts, etc.). The heavy emphasis on text formats suggested that text displays be used to represent the information in a format similar to that which the pilot usually uses.

Graphical information, as suggested above in reference to weather maps, also is the norm for the representation of navigation information. Charts are generally graphical with an additional text component. Additional spatial information is represented graphically through the use of radar information from airborne equipment. Generally this has been dominated by color weather radar equipment, so color is a determining factor in display selection.

Similarly, navigation displays are becoming more complex. The high fidelity moving map display is an example. It provides navigation information on a CRT display similar to what is available on paper. Navigation data is then entered into a flight navigation computer which drives the display.

The need for both graphics and text displays suggests that they both be incorporated in PVI design. A combined display was considered but would generally produce very cluttered formats. Additionally, providing a display size large enough to present both spatial navigation or weather information with text display in an alphanumeric report format was a limiting factor.

The design, then, aimed at having a text display with graphics capabilities for the presentation of a menu driven, text based display and an integrated navigation display which provided graphically coded, spatial navigation information. This would also have the capability to display limited amounts of text relevant to the replication of en route charts. The display, however, was designed to integrate the information from navigation displays (horizontal Situation Indicator (HSI), Electronic Flight Information Systems (EFIS), etc.) with information from onboard and ground based radar and weather reporting information. The integration of this data with flight planning and navigation information (e.g., route planning) would provide the pilot with global situational awareness and an ability to evaluate, modify, or plan diversions with a graphical representation of the variables directly affecting the diversion planning.

Controls

There are several types of control functions required by the Diverter system, although control had less impact on the design process than display parameters. The control requirements center around the input of data into the Diverter system, the manipulation of information displayed by Diverter when recommending a course of action, the control of Diverter functions, and the execution of a diversion once the recommendation has been accepted. Several of these issues were discussed earlier in this document but will be highlighted here.

The design of Diverter was predicated on the use of a direct manipulation interface. Direct manipulation provides control actions that are cognitively congruent with displayed information. Additionally, it was assumed that workload constraints during diversion planning would require that the PVI be designed so as to minimize the need for pilot input. As such, the input has been minimized by automating the data transfer to the Diverter system.

For example, Diverter must be provided with and include information about aircraft system status when planning or evaluating a diversion. Instead of designing the PVI to require manual input, the system was designed so that the data would be fed directly from an automated fault monitoring system to the Diverter system. This reduced the data input requirements. A similar logic was applied to communications with ground based systems, include ATC, company dispatchers and meteorologists, and Flight Service Stations. It is assumed in these cases that Diverter will receive information from datalink communications; thus, not requiring any data entry by the flight crew.

Direct manipulation was augmented by the selection and incorporation of a touch screen for data input. As discussed earlier, navigation data will be presented in a graphical format. Since navigation often requires data input of such information as waypoint selection, navigation identifiers, and route specific information, the use of a direct manipulation device would provide an efficient and simple way of manipulating this information. Such a direct manipulation device, if coupled to a display which provides information from a moving map navigation system, data from airborne and ground based radar, and information from other onboard navigation equipment, would further increase the integration of information while providing for increased efficiency of data input. This would simplify both flight planning and the evaluation of Diverter recommendations as well as reduce work load normally associated with keystroke intensive data entry. In addition, the integration of data display and control minimizes the crew station "real estate" dedicated to the system - a commodity that is very limited in any aircraft cockpit.

The control requirements for text display manipulation also suggested a direct manipulation interface, using either a "hard-wired" CDU or a touch screen CDU. The determining factor on the use of a touch screen CDU centers on the available surface area. Touch screens that represent buttons on a screen require a rather large area. As such, if the CDU was rather small, as is the case in many applications, the available area might not be sufficient and there would be a consequential increase in clutter. The design selected was the use of a menu driven text CDU with a set of buttons which, depending on the mode of the menu being viewed, would correspond to a particular type of data input. In this case, the input is more the manipulation of text information rather than data input. In as many cases as possible, data entry was eliminated or reduced to a minimal amount.

Some of the data entry reduction centers around the integration of the graphical navigation display and the menu based text display. At several points in the Diverter system architecture, the pilot might be allowed to enter information ascribed to a navigation field on a CRT display. This increases the workload beyond what is considered satisfactory or recommended. Instead, Diverter integrates the two display-control devices. For example, the pilot might need to define a particular route which could include VOR identifiers, latitude and longitude, and other navigation fixes. Diverter permits these navigation fields to be entered either through the ASCII keyboard or though touch screen input. For instance, if the pilot wanted to navigate by the O'Hare VOR (ORD), he might input the characters "ORD" to define a navigation point. Alternatively, the pilot might also input the same information simply by "pointing" to the O'Hare VOR symbol on the touch screen, thereby selecting the navigation point. The use of both a graphical navigation touch display and ASCII input provides an integration of both a direct manipulation control/display device and a alphanumeric CDU, facilitating data entry when the input is spatial in nature.

A further example of this integration would be if the pilot was en route and notified that the weather at his destination was below minimums and was forecast to be so at his estimated time of arrival. If the cockpit utilized a moving map display on an EFIS system, the route would be displayed. Incorporation of the Diverter system would present the same information as is currently provided through EFIS, but with the flight planning capabilities of available through the Diverter moving map interface. This would provide an integration of all of the required flight data with flight planning data. First, the pilot would be notified of the change in weather by a message displayed on the text CDU. As will be discussed later, Diverter would present a recommended diversion after it had completed its analysis. This integration of control and display would permit the pilot wanted to evaluate certain parts of the graphical depiction of the diversion or enter data into a pilot alteration of the recommendation.

Thus, instead of requiring the manual entry of a waypoint name and position data, the pilot would touch the screen over the area in question. In this case, additional information would be provided automatically, thus reducing the keystrokes associated with the manual definition of a waypoint or navigation point. If an alternate flight profile was being considered the pilot would, in this scenario, utilize the graphical navigation display as a direct method of data entry into the text CDU. Therefore, a course change is reduced to several data entry movements through the use of a touch screen instead of inputting the three to 11 alphanumeric characters per waypoint into a text based CDU.

So, as illustrated above, the display and control technologies selected will be integrated both into the same unit and between the different modes of data input. All text information was designed into a hierarchical architecture of menus. This is the case for both data entry and data display. The architecture consists of three to four levels, and is minimized at all points to simplify data entry. Both the architecture and menu driven displays and controls will be discussed later in this report. All communications with Diverter which are external to the aircraft will be automated through datalinked communications. Additionally, information regarding system status will automatically be provided to Diverter through an onboard communications network.

Since Diverter might be installed on current generation aircraft, several considerations were evaluated. First, the QWERTY keyboard suggested would be inappropriate given the use of a yoke instead of side stick controllers. This means that the text based CDU would have to be replaced with a CDU more typical of that utilized on the current generation Boeing 747-400 series. This would intensify the manual data entry requirements of the system dramatically.

As previously stated, the system assumes the existence of and an onboard communications network between Diverter and other onboard systems. These include an ACAWS type centralized fault alerting system and a flight management computer which could evaluate the effects of diversion parameters on certain flight performance characteristics. Again, if these systems were not to exist on the aircraft (or if communications links with them were not possible), then the data input requirements would again increase significantly. Since the design incorporates CRT displays which would permit the overlay of a moving map display with the Diverter navigation displays on a color radar display, (or the integration of these three on a CRT not normally used for radar depiction), this PVI design would not be configured for older aircraft that lacked CRT type displays. This limitation would severely reduce the data integration and increasing pilot workload dramatically. It is suggested, therefore, that the Diverter cockpit integration incorporate the CRT displays configured for the integration of the aforementioned information sources.

TECHNOLOGY EVALUATION AND SELECTION

For each component of the Diverter system, the available technology was surveyed. This included technology related to the communications between Diverter and other information sources. These sources included ground based systems, onboard data transfer between Diverter and other aircraft systems, displays, and controls.

Data Link

The system design assumes the existence of a datalink system which could provide information in real time as relevant to the particular aircraft and all aircraft in an operational area. The goal of the datalink is to replace the transmission of relevant data via auditory channels and greatly augment the amount of information which can be transmitted to an aircraft.

The first point, the replacement of voice transmissions of data, presupposes the existence of a datalink system with a format that can address a particular aircraft. This would assume the necessary safeguards and information transfer checking procedures to ensure that the information is transmitted and received by the aircraft both accurately and completely. Obviously, inaccurate or incomplete data would not only be of little or no value, it could result in dangerous situations. Therefore, data communications would have to include error checking to ensure that the information has been received completely. In addition, the error checking would have to include routines to ensure that the values transmitted are correct. For instance, a change in altitude might be one piece of information transmitted during and update of a clearance. The current procedures require the correct read back of data transmitted in a clearance. So, too, the data transferred in a clearance would have to be echoed back to the host, and compared with the original message, before it is either utilized for diversion planning by the system or made available to the flight crew for inspection or evaluation. Such exchange of information would produce additional load on the datalink communications system, but this level of information confirmation is of the utmost importance in ensuring safe communications transfer and subsequent flight planning.

In addition to data checking, the Diverter system should include routines whereby the data is checked against expected or required parameters. For instance, the information transmitted and received might be correct in content, but erroneous when FARs are considered. Since the Diverter system is designed to act as an "associate" crew member, it should contain a knowledge base that evaluates information received, checking it against expected or boundary values. This would reduce the possibility of the system utilizing information that would be considered a controllers mistake. It would also faithfully maintain the current status of pilot responsibility. That is, the FARs place the responsibility on the pilot. He/she shall not operate the aircraft in violation of rules set forth in FARs. By including the rule base and evaluation, the associate crew member idea is propagated one step further.

The datalink must also be capable of receiving general information relevant to aircraft in a particular operational area. This was discussed briefly above. The datalink would provide direct aircraft specific communications. However, to reduce the amount of information transmitted verbally, the system must provide a means of reception and evaluation of information which currently is received by pilot's monitoring sector frequencies. The basis for this stems from the maintenance of situational awareness. By providing data to Diverter, relevant to an area, the level of "awareness" would be maintained or enhanced. Such might be useful when other airborne Diverter systems are receiving weather information important to aircraft which will enter an area. This might be illustrated by the current day monitoring of verbal pilot reports, whether official or not, about icing, turbulence, or thunderstorm activity.

The use of this second channel, which is specific to a geographical area, would probably also reduce the amount of information on the channel reserved for direct transmission to a particular aircraft. This would be the case because area advisories would not have to be repeated on each channel for each specific aircraft.

A second issue that was considered when evaluating the datalink was the process by which information from ground based sources is evaluated. This design question hinged in the interface with ground based systems and the point at which either ground personnel or flight personnel are notified of a recommendation. Consider a weather diversion in which the primary destination would be unavailable. Diverter could evaluate the data relevant to a diversion and arrive at a recommendation. It could then present the recommendation to the flight crew for evaluation and acceptance, whereby, the recommendation would then be transmitted to controllers' computers for evaluation and subsequent presentation and acceptance to a controller. The problem would occur when the diversion presented to the pilot in this scenario is vetoed by the controller. In this case, the evaluation would have to begin again. Another recommendation, acceptance, and execution would have to be instituted by the flight crew. As one could imagine, if this loop occurred more than once the flight crew is going to feel out of control and will terminate the whole process by declaring an emergency.

Instead, the datalink procedure was designed such that Diverter would evaluate all options and rank them accordingly. Subsequently, it would communicate with ground based ATC computers to evaluate the integration of each option with ATC data (which might include flow control, traffic constraints, etc.). At this point, the options which are not feasible according to ATC are placed in either a cue representing options that are not feasible and should not be considered, or options which would fall under an "emergency" heading. The result would be transmitted back to Diverter, and the options would be presented in rank order to the pilot for selection. The drawback would be that the process would take slightly longer between Diverter activation and recommendation. Subsequent PVI design has filled this time void with an evaluative function which will be discussed later. Additionally, in the case of emergencies, the flight crew may be overloaded by completion of flight tasks needed to return the aircraft to normal operations.

The time delay might be minimal depending on the speed of data processing and communications. However, the process would provide the pilot with only "viable" alternatives in rank order. Should he select one such recommendation, the execution of the recommendation would again transmit a shorter checking routine (as the alternative was already approved) and result in rapid execution. If the pilot was to specify an alternative, or modify a recommendation (both options will be discussed later), then the acceptance would occur after diversion planning; rather than during it.

Integrated Fault Monitoring:

The aircraft must include an integrated fault monitoring system which could provide a data communications path to other onboard systems, in this case, Diverter. This requirement stems from the aforementioned topic of system monitoring and fault detection. It would be very advantageous, and would reduce input workload substantially, if the Diverter system interfaced directly with onboard ACAWS like systems. If such an integration was not possible, a Diverter fault monitoring system would be a second choice. This would accomplish the same task but would be much more expensive; perhaps too expensive for realistic incorporation. The last, and least preferred method, would be to have the pilot enter information relevant to system status. Such manual data entry , as discussed above, would severely limit the usefulness of the system as it would most likely result in a lot of time in which the pilot was "head down" in the cockpit, allocating much of his resources to data entry. The flight deck is not conducive to such activities, especially when there are system failures, as has been demonstrated by the FAA's continued emphasis on head up operations with attention allocated to scanning for possible traffic conflicts and to the maintenance of situational awareness. The design has therefore assumed the existence of such an interface with other onboard systems.

Voice displays were considered as a means of data input. This would relieve some of the "head down" burden of manual data entry. However, this technology is limited at this time. While the form favors an omnidirectional type of control, the speech aspect is limited. Present technology speech parsing programs are limited to specific commands. Further, the analyzers require fairly consistent intonation and volume. Noise and intonation changes caused by stress would limit the recognition capabilities of this interface. As such, this method of data entry was not recommended.

Flight Management System:

Due the need for information from systems that calculate flight performance, such as fuel usage at a particular altitude, Diverter must interface with aircraft flight management systems. These systems would provide performance information to the Diverter system, permitting recommendations which would consider consumables and navigation in considering both vertical navigation and the dimension of time. This system would also have to provide an iterative process whereby Diverter could evaluate different performance parameters until it had optimized the result, given the global aircraft situation. Again, if this integration with performance evaluation systems was not possible, Diverter would either have to incorporate such a system in its own programming or would require manual data input from the flight crew. The latter would be the least acceptable given workload increases similar to the aforementioned fault monitoring systems. Again, the design of Diverter has assumed that such an interface with flight management systems will be possible and utilized.

Integration Issues:

One of the primary goals was the integration of Diverter with the other flight deck navigation and communications systems. This posed several problems. The first was the type of aircraft that the system would be installed in and whether that aircraft had to be retrofitted to include the system. Secondly, the application of Diverter to flight planning, navigation and communication would not progress instantaneously. This poses a problem with the transition from primarily auditory communication to datalink transfer. The transition, of course, would have to provide redundancy of information source, in essence providing required flight information in modes acceptable and utilized by Diverter equipped aircraft as well as current generation aircraft which might lack Diverter. Additionally, even if all transport aircraft had Diverter installed and operating it is highly improbable that the system would have widespread use in general aviation aircraft. With the exception of corporate jet aircraft, the general aviation sector will most likely continue to use voice communication and voiced data transfer.

In response to these limitations, the current development of Diverter has assumed that it will be incorporated within the design of an aircraft that is yet to be built, rather than retrofitted into an aircraft. This assumes, then, that the systems integration with datalink, onboard fault monitoring, onboard navigation systems, etc. would be provided; thereby limiting manual data entry requirements. Additionally, it is assumed that the touch panel displays, side stick controllers, QWERTY keyboard, and integrated navigation displays would be available.

Should the system be put into an existing aircraft, there would be severe limitations. It is expected that such an aircraft would utilize the current yoke type flight controls. This makes the use of an QWERTY keyboard for data entry incompatible. As such, the system would have to utilize a CDU type display keypad, similar to those utilized on a 747-400 series flight deck. Additional limitations would be introduced if the aircraft didn't have a fault monitoring system which could interface with Diverter for direct, digital communications. Again, the increase in workload would possibly make the system an unworkable alternative.

Display and control design have also assumed that touch screen displays which integrate navigation information, information from Diverter, and information from both onboard and ground based weather sources could be utilized. If the system were put in current generation aircraft, with electronic displays, it would be difficult to integrate the system optimally. While this is a lesser problem than retrofitting the system to other aircraft with electromechanical displays, there would be continued deficits in human performance with controls and displays that lacked integration. Scanning effort and cognitive effort to integrate the information from separate sources would increase workload and decrease the efficiency of information transfer.

In summary, the system was designed to be incorporated into an aircraft that incorporated the technology represented in NASA's Advanced Concepts Simulator. While the display and control technologies utilized might not directly match this those in the ACS, the flight deck environment and integrated systems represented in the ACS would be assumed to exist in the aircraft in which Diverter is installed. Examples of PVI display and control formats, utilized technologies of the ACS so as to facilitate the next phase of development in that environment.

APPLICATION OF TECHNOLOGIES TO PILOT-VEHICLE INTERFACES

The technologies discussed earlier were utilized in the design of the PVI. These included the following:

Control Technologies

Touch Panel for:

- Integrated Navigation, Flight Planning, Weather Display
- CDU capable of text and graphics

QWERTY keyboard for:
- manual data input
- menu selection and evaluation

Display Technologies:

Integrated color graphics display capable of:
- graphic display of spatial navigation information
- text display of navigation information
- graphical display of onboard weather radar information
- graphical display of weather information from ground
- symbolic display of predicted weather areas
- real time, moving map capability

Integrated CDU for:
- display of text information, messages, advisories
- text or limited graphic display in menu format
- integration of text CDU info into color graphics navigation display

Direct Manipulation Interface:

The whole goal of the PVI design was to provide a direct manipulation type of interface. The advantages of direct manipulation are that it is congruent with the task of manipulating information and solving navigation problems. Additionally, direct manipulation is not memory intensive. Command and control requires the use of either displayed or memorized command sets. These requirements both increase clutter and cognitive workload, reducing the efficiency with which information is presented, comprehended, and utilized. Direct manipulation, if applied correctly, also reduces the number of inputs required for data entry, data manipulation, and manipulation of spatial information.

Direct manipulation was incorporated into both of the displays designed to comprise the Diverter PVI. The primary graphics display will be a color navigation display that will temporarily replace the primary navigation display during the display and evaluation of any Diverter function. The Diverter display replicates most of the information presented on the primary navigation display. This reduces the risk of any loss of situational awareness which might induce spatial disorientation and subsequent confusion. Since the primary display is usually navigational in nature, it would be transferred to a different location. Such a transfer, in an ACS type configuration, would move the primary navigation display from in front of the pilot to a center display, perhaps replacing an engine monitoring display. The Diverter primary navigation planning display would then be placed in front of the pilot. Since most of the current navigation information would be utilized by Diverter, this replacement would not be detrimental to flight control (as it is assumed that one crew member would handle flying duties while the other completed diversion planning). The selection of which position to present the Diverter planning display would be annunciated as part of the diversion activation or diversion annunciation. Thereafter, the selected crew member's displays would change as a function of his flying task.

The primary graphics display (Figure 1), was designed to replicate the typical instrument chart utilized for in the particular operational area. The design provides for an initial presentation of all information on the display with subsequent decluttering of information available to the pilot. The decision to present all navigational information was predicated on the notion that the pilot, in removing any information, would know what information had been available and could just replace it if necessary. The declutter included the removal of information including color weather radar, range marks, text identifiers of navigation aids and routes, and any part of the en route structure not associated with the current or proposed flight plans.

In addition to permitting the pilot to remove information, the PVI is designed to allow him to manipulate the range of the display. All functions and decluttering are permitted at each range selection. This provides continuity between interface modes. Additionally, in order to reduce clutter, the route structure not directly related to the current route, planned recommendation, or pilot specified flight plan is presented in a subdued format. The reason for this format is that it provides situational awareness by presenting the route structure, while limiting the amount of clutter. The subdued route structure is really only noticeable if the pilot attends to it. So, the structure is there without demanding attentional resources.

The decluttering and range functions were selected to replicate those used on most radar displays. They include multiple ranges of up to 300 miles and the removal of range markers. Since this display integrates both moving map information containing navigation information and weather information from radar and graphics displays of ground based information, a decluttering of weather information is provided. By so doing, the display is relegated to simply a moving map navigation display. So too, the display can have all of the

Figure 1. Thunderstorms Conflict with Continuing On-Flight Plan to Colorado Springs. Diverter Recommends New Route to New Destination of Denver

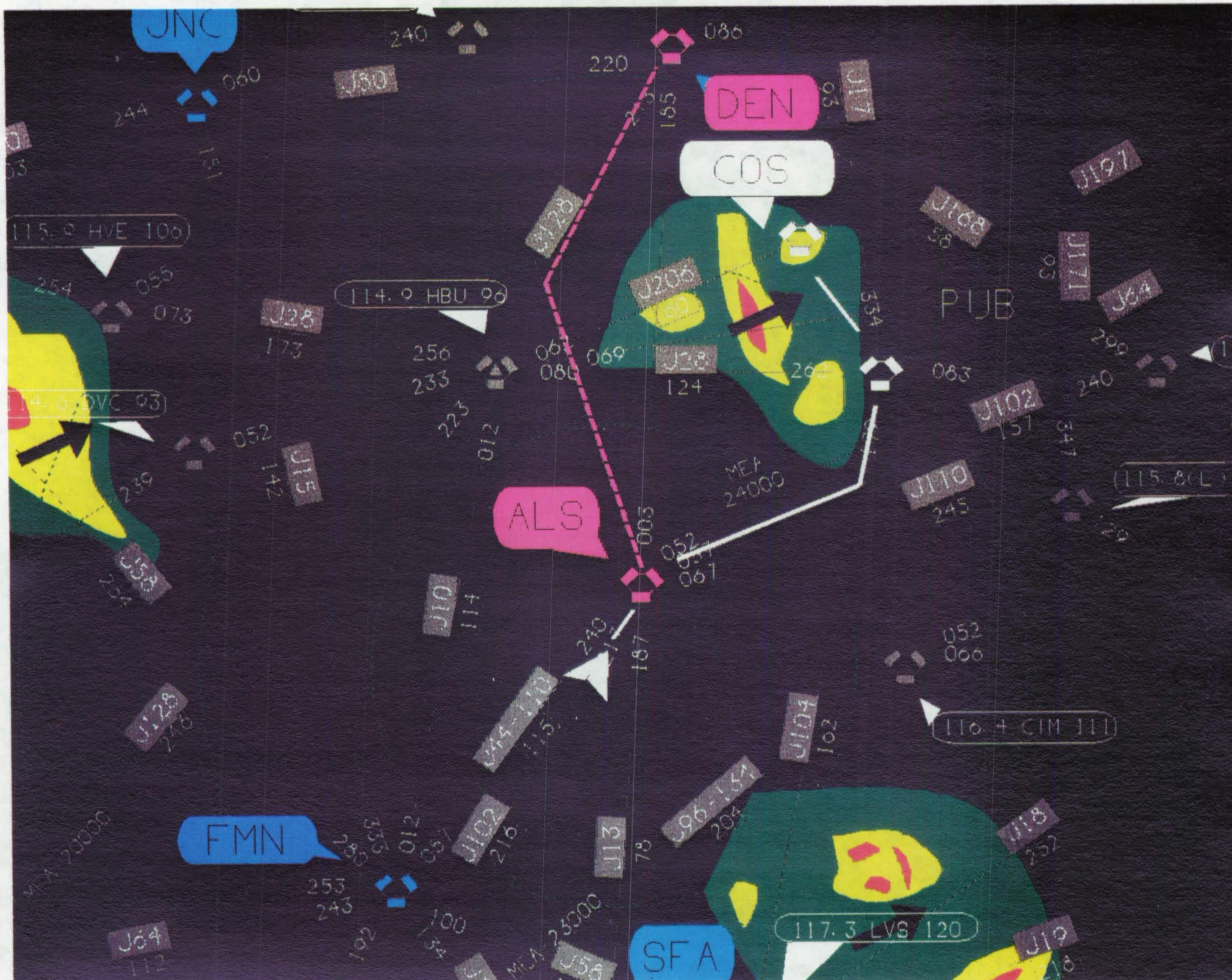


Figure 1. Thunderstorms Conflict With Continuing on Flight Plan to Colorado Springs. Diverter Recommends New Route to New Destination of Denver

en route navigation information removed, resulting in a radar display. The other declutter modes provide several options. The maximum declutter (in which subdued en route structure and navigation information are removed) shows only the current route to the originally planned destination plus the possible diversion points, and if generated, the recommended route to the primary. This format was included to only present a simple display of the possible alternates and weather. This permits a global situational awareness without specific route structure information. The intermediate declutter levels permit the pilot to configure the display to his individual preferences. This makes the interface more usable, resulting in greater subjective rating of the system and perhaps both greater trust in and use of the system.

The display is also color coded. Weather is presented in the typical format with areas of convective activity presented in three levels (red, yellow and green). Figure 1 illustrates these cells which are located at the left edge, slightly right of center and near the lower right edge of the display. This corresponds with the returns of a radar display. Weather cells of severe intensity are coded in red, moderate are coded in yellow, and light are coded in green. In addition, each cell has a black arrow which displays the general movement of the cell. If the weather is from a ground based source, it is presented with the same color coding schemes. In this case, the return would not be exactly like an airborne radar return. Instead, a slight hatching of the area would be presented. Pseudo echo intensity would be symbolically presented in the same color formats as are common on airborne radar.

Similarly, color coding is used to depict route structure, current planned route, en route terrain/airspace conflicts and radio aids to navigation. In all cases, the colors selected are congruent with those used on current navigation charts or moving map navigation displays. For instance, VORs are presented in blue, present route in white, proposed route in magenta. The route structure is also presented in a format congruent to that utilized on instrument charts, with route identifiers and mileages presented in the current format. Again, the reason for such congruence is acceptance and familiarity. Pilots will use that with which they are familiar.

As illustrated in Figure 1, when Diverter is activated and has completed its planning, it displays a situational assessment on the graphical Diverter moving map. This would include the enroute structure. The en route segments not utilized by either the current route or a displayed Diverter recommendation are presented in a subdued gray. This reduces clutter while providing adequate description of the overall route structure. The present route, in this case to Colorado Springs (COS), would be presented as a solid white line. Diverter's recommendation is presented by a dashed magenta line. The color coding represents the route as a recommendation. The dashed versus solid coding format represents whether the particular route is derived from a planning mode or is actually being used for navigation. Since the current route is still to COS in Figure 1, the route is white and solid; while Diverter's recommendation to Diverter to Denver (DEN) is represented as a dashed magenta line.

As discussed earlier, every attempt was made to remain consistent with current color coding formats. This would reduce training and provide information in a format that is consistent with other sources. Therefore, VOR identifiers are presented in blue flags. The destination VOR or airport is presented in white, as that is consistent (as discussed above). Similarly, when the pilot evaluates a VOR, waypoint, intersection, or airport, the color changes representing the magenta coding associated with the "flight planning" mode.

When a pilot selects a course and destination, and Diverter is presenting a recommendation, then the magenta color coding is retained but the pilot's course selection is presented as a dotted line (see Figure 2). This aids in differentiation between pilot selected routes and Diverter recommendations. Finally, as illustrated in Figure 3, when the pilot executes an alternative, whether pilot specified or a Diverter recommendation, the color coding and line format change to represent its use in navigation. So, what was a dashed, magenta line from the present position to DEN in Figure 2 is changed to a solid, white line after the pilot selects DEN as his new alternate. After diversion execution, the Diverter moving map display is replaced with the regular navigation display mode.

Changes in the detail of information is also adjusted depending on the range selected. As shorter ranges are selected, the information becomes increasingly specific. This is exemplified in a 25 NM range around an airport. In this case, the Diverter moving map would replicate the plan view information of the proposed instrument approach procedure in use for the selected runway. These adjustments in specificity reduce clutter for displays of large areas while maximizing information when the range is minimal and clutter is not a limiting factor.

In addition to range selection through specific buttons under the display, the pilot can select and view a particular area in detail. This is accomplished though the CDU text/graphic menu control. In this mode, the function of the touch screen on the main navigation display changes so that the area the pilot designates will be presented in the greatest detail. Only one magnification level was included. While zooming in and out were considered, it was determined that this might produce spatial confusion and increase workload. So, the pilot is permitted to zoom down to a preset magnification level, thus increasing the specificity of the display. The function of the button on the CDU concomitantly changes from "zoom in" to "zoom out" permitting the pilot to return to the original display magnification.

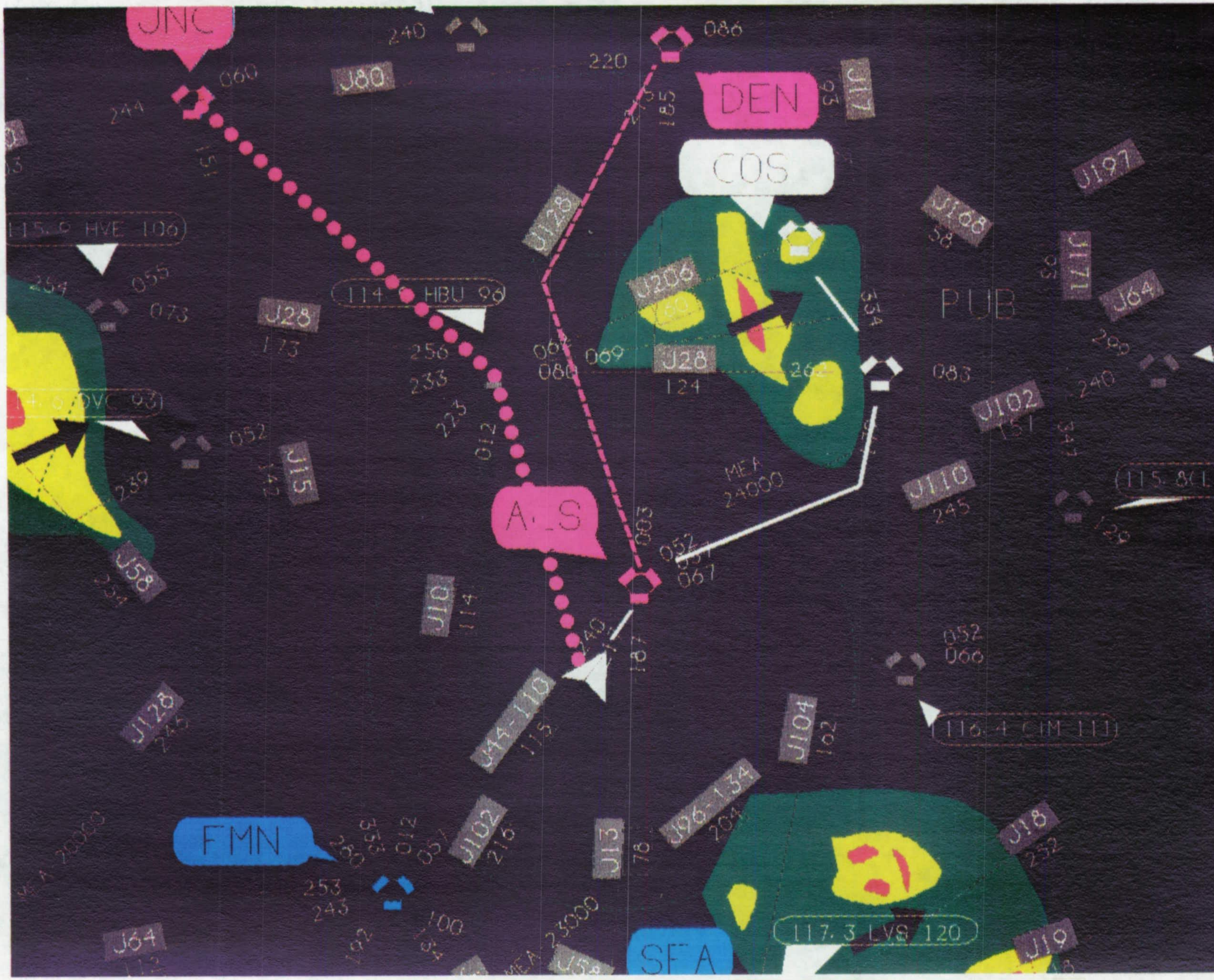


Figure 2. Pilot Queries System About Diversion to Grand Junction. Map Display Shows Original Flight Plan, Diverter's Recommendation and Pilot's Query.

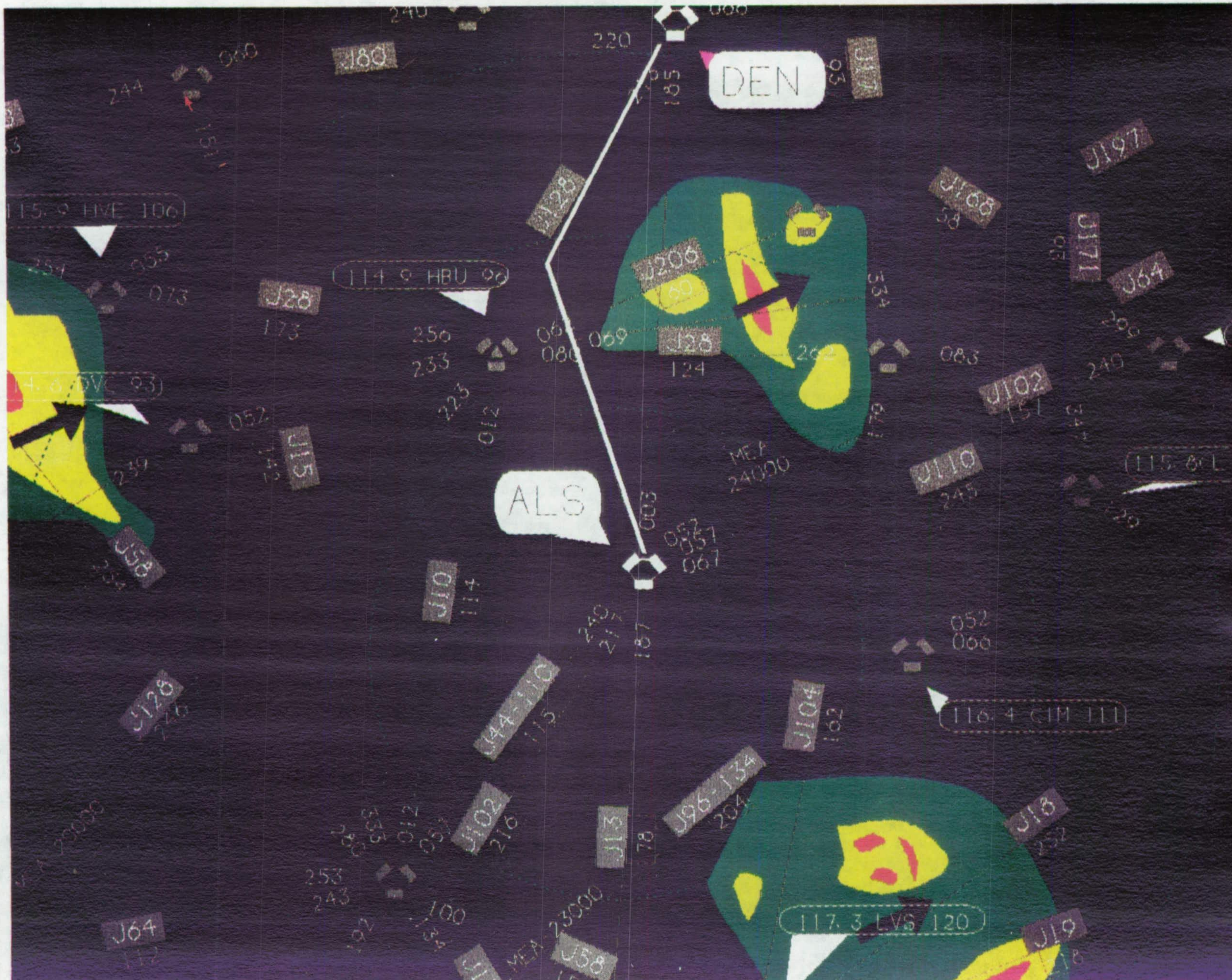


Figure 3. Pilot Accepts Diverter's Recommendation. Original Flight Plan and Other Candidate Routes Are Removed From the Format

The navigation display is also integrated with the flight planning options presented on the CDU. When in a flight planning mode, the pilot can specify route options by pressing points to represent waypoints in both the navigation plan or on the graphical display. For instance, the pilot can specify a waypoint by touching the navigation display at a particular location. The information is automatically fed into Diverter for evaluation. This reduces the data input for defining a navigation waypoint or destination. Instead of entering several characters or a latitude/longitude of the coordinate, one touch specifies the navigation data. This entry allows definition of any point in space. If that point is collocated with an aid to navigation (e.g., VOR, NDB, airfield), then that point is used. If no such point exists, a latitude and longitude definition of the point is used. This information is automatically utilized in any flight planning displayed on the CDU.

The touch screen is also utilized to move a symbolic representation of expected weather to a point where it would be expected to be at a particular time in the future. Since the aircraft is navigating along a particular route at a set speed, it will enter into areas of predicted weather. Diverter provides one option for the pilot to move a "ghost" image of the aircraft to any point in its operational area. Given the current and forecast movement and existence of weather, "ghost" images of the expected weather are presented. This permits the pilot to visually analyze the effects of weather on different routes. It provides greater situational awareness by presenting predicted weather information in such a way as to consider both time and navigation path. This also enhances the transfer of information to the pilot, and enhances understanding of the impact of weather on the flight planning.

The CDU is also a direct manipulation device, as shown in Appendix C. The CDU was designed using a hierarchy of menus. A menu structure was selected as it minimized the control required to retrieve information as well as the cognitive workload associated with finding and displaying information. A command line would increase cognitive load by requiring the pilot to learn the location or command required to retrieve information. By presenting a hierarchy, increasing levels of information are presented in a linked format. The CDU is divided into two parts; one presenting functional options while the other presents the requested information. The menu structure was limited in most cases to not more than three levels. This would reduce the chance of getting lost in the structure. Additionally, each menu has a header and current location footer. These enhance the ease of navigation through the menu hierarchy. Additionally, each menu option has a direct recourse to the previous menu or the top menu. This minimizes the keystrokes necessary to either retrieve information or to leave the menu level.

The information presented on the menus was formatted to present global information at the highest levels with increasing specificity at the lower levels. The idea was that the highly processed information at the global level should be sufficient for pilot flight planning, evaluation of Diverter recommendations, and decision to execute the planned alternative. However, if the pilot desired specific information relevant to the category associated with a diversion, he can access that information in detail ranging from highly processed to formats representing source level information. So, this hierarchy permits the categorization of information for easy evaluation as to the reasons for a diversion and global information which would impinge on flight planning and acceptance of the diversion plan. If this was not sufficient, then increasingly specific information relevant to a category could be selected which would allow the pilot to analyze the actual information, its source, and its timeliness. As the specificity is increased, the format of the report is also increased to faithfully represent the formats with which the pilot is familiar. This would enhance acceptance and usability. The highly abbreviated format of such reports as terminal forecasts is revised into an easier to read format with less abbreviation, but the report structure is maintained.

Appendix C illustrates both the structure and examples of the menu formats. This provides an easy trace of the system logic and manipulation of examples of a diversion. The text CDU is split vertically into two halves. The right side of the CDU display presents functional options while the left side presents requested information. Diverter planning and evaluation is split into two phases. As was discussed earlier, it was decided that the system should only present viable alternatives to the pilot. This requires that the Diverter system evaluate information, generate a series of recommendations which are rank ordered, and confirm the feasibility with ATC. This would all be completed through datalink. The resultant rank ordered list would be presented to the pilot as a recommendation and several alternatives in order of rating on the pertinent variables affecting the diversion planning. This communication and feasibility assessment with ATC will take some time, although it is not known exactly how long. Since the Diverter system will have a preliminary list of possible options, it presents that information to the pilot for evaluation. This evaluation system is identical to that utilized in evaluating a recommended course of action; however, it is limited to the description of the situation, the reasons for diversion, and the options most likely to be considered. In this way, the pilot can utilize the time when the system is confirming feasibility. This would result in greater situational awareness, and effective use of time. Such an evaluation, it must be stressed, is only one option available to the pilot. If the situation requires attention to emergency procedures, or if the pilot doesn't want to evaluate diversion information, the system will not force such an evaluation. In either case, when the diversion is planned and a course of action is to be recommended, the pilot is informed of the status change. If he is evaluating the diversion situation, he may continue to do so until he chooses to evaluate a recommendation. In this way, diversion evaluation control resides with the pilot.

Appendix C, Formats 1 through 15 illustrate the planning alternative Diverter presents to the pilot during which the system is planning a recommendation and verifying its feasibility with ATC. Format 1 illustrates the display format. System functions are presented on the right side of the display, while information query menus are presented on the left. In this case, Diverter has sufficient information to suggest a destination change due to three general reasons: destination weather, approach facilities, and en route weather. By pressing buttons associated with each option the pilot might evaluate the reasons for a diversion in much more detail. The format allows him, however, to manipulate the information at either a general level or to whatever level of detail he requires. For instance, pressing the button next to "destination weather," the system would present Format 2. This indicates that the weather criteria that are important are ceiling and visibility (both current and forecast) as well as brake action. Additionally, the critical values are also presented. This permits the pilot to operate at this slightly more detailed information level while reducing the depth of query required to obtain relevant information.

Still, if the second and more specific level of detail is not sufficient, the pilot can select the particular attribute. Such a selection would move the pilot to a more detailed format (Format 3) which reproduces much of the information depicting the current weather for the location being queried. Notice that the information is provided in a form consistent with other weather reports. This consistency would reinforce the credibility and reliability of the information as well as increase the efficiency of transfer (due to consistent formatting). In addition, the timeliness of the report is indicated along the top header.

With increasing depth, the right side of the display adds functions that permit the pilot to jump back in a step-wise fashion or more quickly to a previously viewed option. In the case of Format 3, the pilot might select the top level display by pressing "preliminary flight planning" or might only back up one level by pressing the "destination weather" option. Additionally, other functions are presented which allows analysis of pilot selectable alternatives at any time during the evaluation of the information variables presented on the left side of the display. Notice that the functional options on the left correspond to the bottom banner on each previous format. This will reduce the possibility of the pilot becoming confused in the menu structure. Formats 1 through 9 illustrate typical formatting and structure of this menu system for several common diversion parameters.

Format 1 also presents an option called "select alternative". This permits the pilot to evaluate the information that would be relevant to a diversion for any possible destination. By pressing the button associated with this option, Format 1 would be replaced by that illustrated in Format 9. In this case, the information display on the left is replaced by input fields for destination and route specification. The input could be made though the graphical moving map display by direct manipulation. For instance, by pressing "enter destination ident", the moving map display would become an input device permitting the pilot to touch the screen position corresponding to the destination desired. Pressing "enter destination ident" again returns the moving map to a display mode and enters the data associated with the point selected. The system would not accept the selection points on the moving map that do not correspond to an airfield.

If the pilot wanted to enter the data for an identifier through the CDU, the input could also be made through that keyboard. This might be desired if the pilot happened to know the four letter identifier of an airport (e.g., KDEN for Denver Stapleton). This might also be the only mode of data input if the implementation of Diverter did not permit the integration of the moving map for data entry.

Similarly, the pilot would define the desired route by pressing the button associated with this option. Again, the moving map display would change modes to permit direct route specification through touch screen input. Each segment would be displayed as a magenta line on the moving map and textually on the CDU. The CDU representation of the route would be accomplished by using airway specification or defining the route as direct navigation between two points defined by latitude and longitude parameter. This would permit the pilot to select route options that do not coincide with published routes.

Once the destination and route selection is accomplished, the pilot is presented with an option on the left side of the screen which permits him to evaluate these data. Diverter would again present a menu structure displaying the variables pertinent to situational awareness for diversion planning. The format and hierarchy would be consistent with that already discussed and is illustrated by Formats 10 through 15. In this case, Farmington was the selected destination.

When Diverter has completed its flight planning and has verified the feasibility of its recommendations with ATC, an option called "evaluate recommendation" will be added to the menu structure currently being viewed. This option allows the pilot to transition in the menu structure from evaluating situational information to the evaluation, planning, and execution phase of diversion planning. As was discussed earlier, while Diverter continually updates information stored in its databases, it must ascertain that it has received all information relevant and required in diversion planning. A substantial amount of this is received from ATC during diversion planning by the system. This interval is utilized to permit the pilot to evaluate the situational variables affecting the flight. At such a point as a recommended plan of action has been derived, the system permits the pilot to switch over into the planning structure. This permits him to finish any situational evaluation rather than automatically switching him to another set of menu functions.

The menu formats for diversion evaluation, planning, and execution are consistent with those used in situational assessment permitted the pilot during Diverter planning. The left side of the screen permits evaluation of information found relevant in the selection of a recommended diversion alternative. As illustrated in Format 16, the alternative landing point recommended by Diverter is Denver Stapleton. The pertinent variable of that selection are "destination weather", "en route factors", "destination facilities", and "aircraft performance". Just as was the case with evaluation of variables which caused diversion planning to be initiated, these variables can be evaluated in increasing detail. Jump functions to prior levels are also retained; thereby consistent with prior system architecture.

The system presents several options. The first is acceptance with subsequent execution of the planned recommendation. In this way, the pilot can execute the recommendation with as little as two steps (acceptance and execution). The other options include comparisons of options, input and evaluation of a pilot plan, or evaluation and comparison of Diverter's recommendations to either recommendations of lower rank order or to pilot planned diversions.

In either case, each menu format is consistent throughout evaluative phases. Data input in a pilot planned diversion is presented to highlight important information and inconsistencies recognized by diversion planning. Further, communications between functions eliminates the need to enter data for a pilot plan when the parameters of a diversion are evaluated in another function, or vice versa. As specified earlier, the CDU logic and formats are illustrated in Appendix C.

Accepting Diverter's recommendation causes the generation of a clearance as illustrated by Format 47. This is consistent with current practice of clearance update when planning an IFR flight. The format consistency permits easy understanding and congruence with accepted procedures. Concomitantly, the accepted diversion clearance is retransmitted to ATC. The computers would then activate the clearance change (as its feasibility had already been verified prior to display to the pilot). Upon execution of the diversion, the display changes presenting the options illustrated by Format 48. The associated navigation and communications parameters could automatically be updated permitting smooth transition of navigation flight control to the new route. Additionally, hard copy printouts would be provided in case discrepancies as to clearance limits occurred. Finally, exiting Diverter results in replacement of the Diverter's moving map display with the regular moving map display and returning Diverter's function to background monitoring.

Both "select comparison" and "enter pilot plan" are similar to the "select alternative" function, both in architecture, data input, and screen format. The former permits the pilot to compare diversion plan alternatives generated by Diverter or entered manually. These comparisons are pair-wise, allowing side-by-side comparison of variables that differ. Data input is permitted through touch screen or CDU. Similarly, the pilot can manually specify a diversion plan and either compare it to Diverter's rank order list of alternatives or to any other pilot plan he has entered. Additionally, this function allows the pilot to define a diversion and execute it, permitting datalink communication, verification, and navigational planning normally provided through Diverter recommendations.

In any case, the pilot is presented with the variables of the diversion that are found to be critical, thus highlighting information which is often overlooked during manual diversion planning. Still, the control of diversion acceptance and execution remains with the pilot.

DIVERTER PROTOTYPE

The Diverter system was prototyped and demonstrated on a Symbolics 3640 Lisp processor in preparation for installation in the Advanced Concepts Simulator. Certain constraints, such as the size of the operating area, number of airfields considered, and search range, were placed on the system to make it manageable for a demonstration. Components of the Diverter system are described in the following sections.

System Definition and Development

The Diverter system considers three major areas when making its decision; runways, airfields, and routes (see Figure 4). For each possible diversion, the areas are evaluated independently based on factors such as safety, passenger comfort, facilities, schedule, weather, and economy. These factors represent the attributes upon which the three major areas will be evaluated and are listed completely in the sections below. The attributes are considered not only for their values, but also how these values fit into the rules relevant for use in Diverter (see addendum for details). Then the scores from each area are combined to achieve a total score for the possible diversion. Once all diversions have been evaluated, the diversion with the highest score becomes the suggested course of action.

Two of the three major areas (runways and airfields) are broken down into a set of important attributes about that area. Weights are then assigned to the attributes to indicate their relative importance. The value of these weights must be carefully chosen, as they represent the way to alter the behavior of the Diverter system. During the planning process, the runways and airfields are ordered based on their values for the appropriate attributes. Then they are assigned a rank for each attribute, with the best in each attribute receiving a rank of 10, and each subsequent airfield or runway receiving a rank decremented by 1 from the rank above it. Then the rank is multiplied by the weight, and the result is the score for that runway or airfield for that attribute.

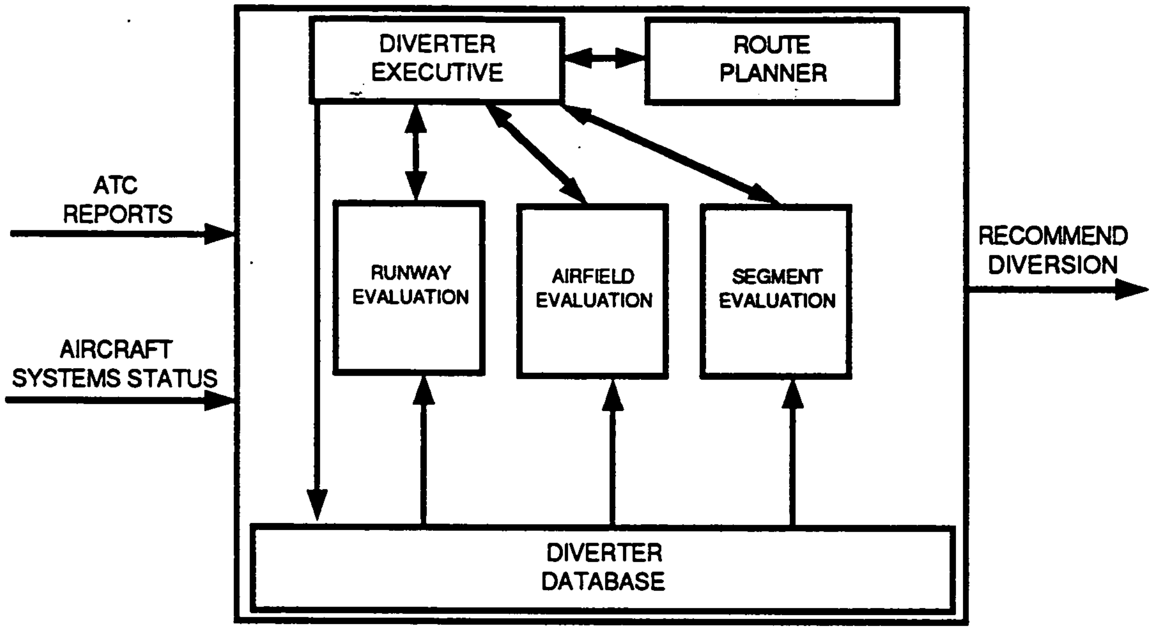


Figure 4. Diverter Software Architecture

Route evaluation is handled in a different manner than the runway and airfield evaluation. If the route planning was done at the highest (route) level, the same concept described above could be applied to evaluate each route based on a predefined set of characteristics. However, the route planning is, instead, performed at a lower (route segment) level. This dependence on evaluating individual route segments stems from the inherent nature of a route. A route is composed of segments. These segments are defined by fixes determined by navigation aids or defined locations. For instance, a route from Albuquerque to Denver might include individual segments from Albuquerque to Las Vegas VOR to Pueblo VOR then to Denver (see Figure 5). Conversely, the route might include segments from Albuquerque to Alamosa VOR then to Denver.

Due to the nature of a route being a group of segments, in order to define all routes from a particular location to a destination would be an insurmountable task; especially since any point in space can be defined, through inertial navigation, as a waypoint. To evaluate every route would require a definition of all possible route segment combinations. Such a definition would, inherently, include segments common to many routes. So, instead of designing a system which requires an a priori definition of all routes, it was decided that route segments would provide a computationally feasible unit of evaluation.

The problem with route segments is that each segment is evaluated individually. This mandates the need for an algorithm to evaluate segment combinations in order to define the best possible route. Figure 5 shows part of the high altitude airway structure defined by the Federal Aviation Administration. For the purposes of Diverter, any portion of a route between two defined points, such as two navigation aids, two intersections, or a navigation aid and an intersection, is defined as an airway segment. The current Diverter implementation uses a subset of the air segments in the Colorado Springs area as defined by FAA flight information publications, and shown in Figure 6. Each segment is assigned a value, which represents the cost of the segment to the planner. This cost is based on attributes of the segment that are listed in a later section (physical runway, approach, weather, and miscellaneous attributes). Each attribute of a segment also has a weight. If a segment attribute is true, the weight of the attribute is multiplied by the segment distance, and added to the segment cost. Once all of the segments have costs, the route planning algorithm is called to find the route with the least cost to each airfield being considered. The route planning algorithm applies an A* search technique to solve the problem of finding the lowest cost route to each airfield. Finally, the route with the lowest score receives a rank of 10, and each subsequent route receives a lower rank in proportion to the costs of the routes.

The weights in the Diverter system represent the method for controlling the system's behavior. This can be seen in simplified examples demonstrated in Figure 7. In example 1, with runways, airfields, and routes all weighted equally, choice 1 has the highest total

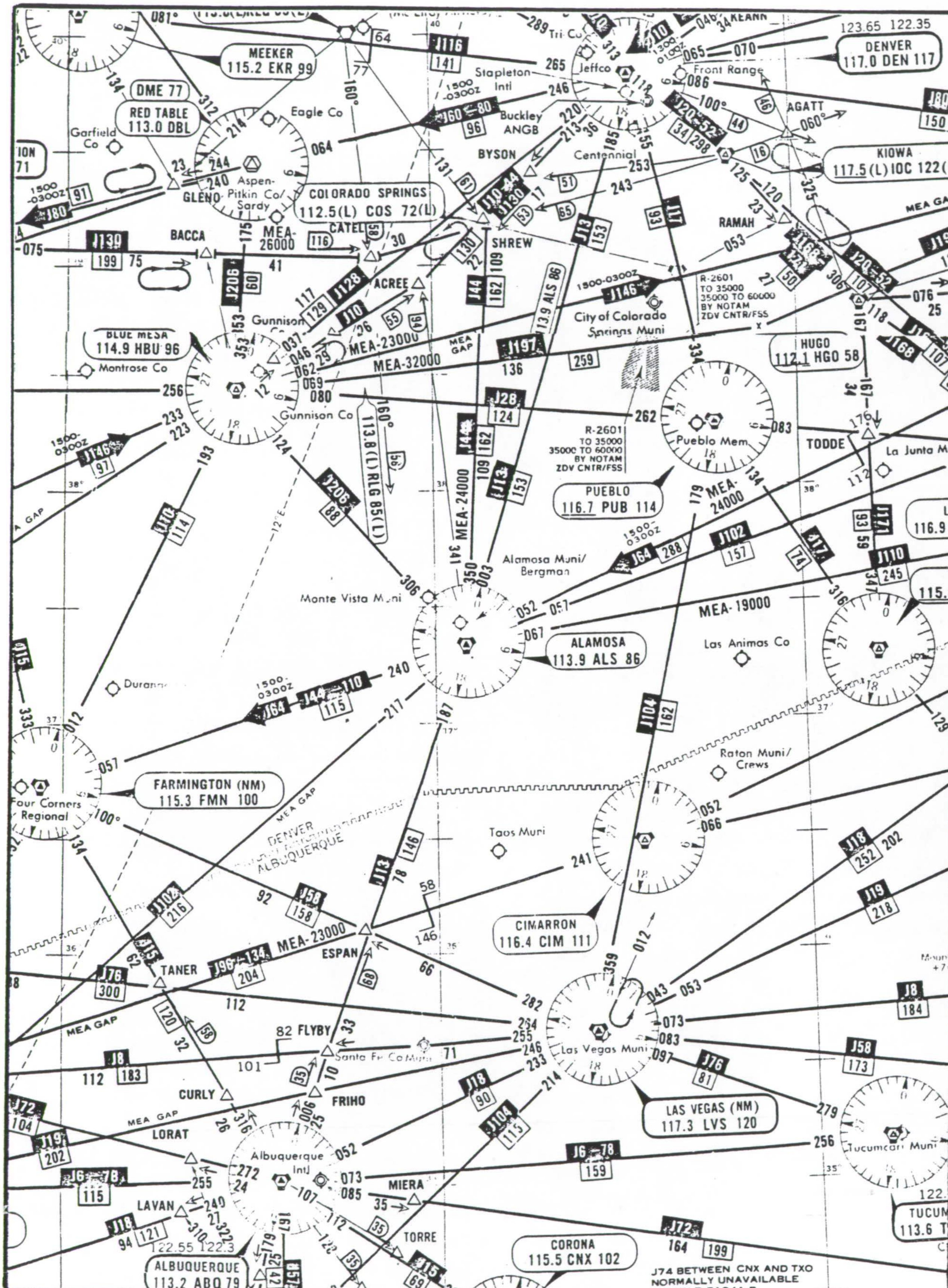


Figure 5. Aircraft Are Routed Via the Federal Airway Structure

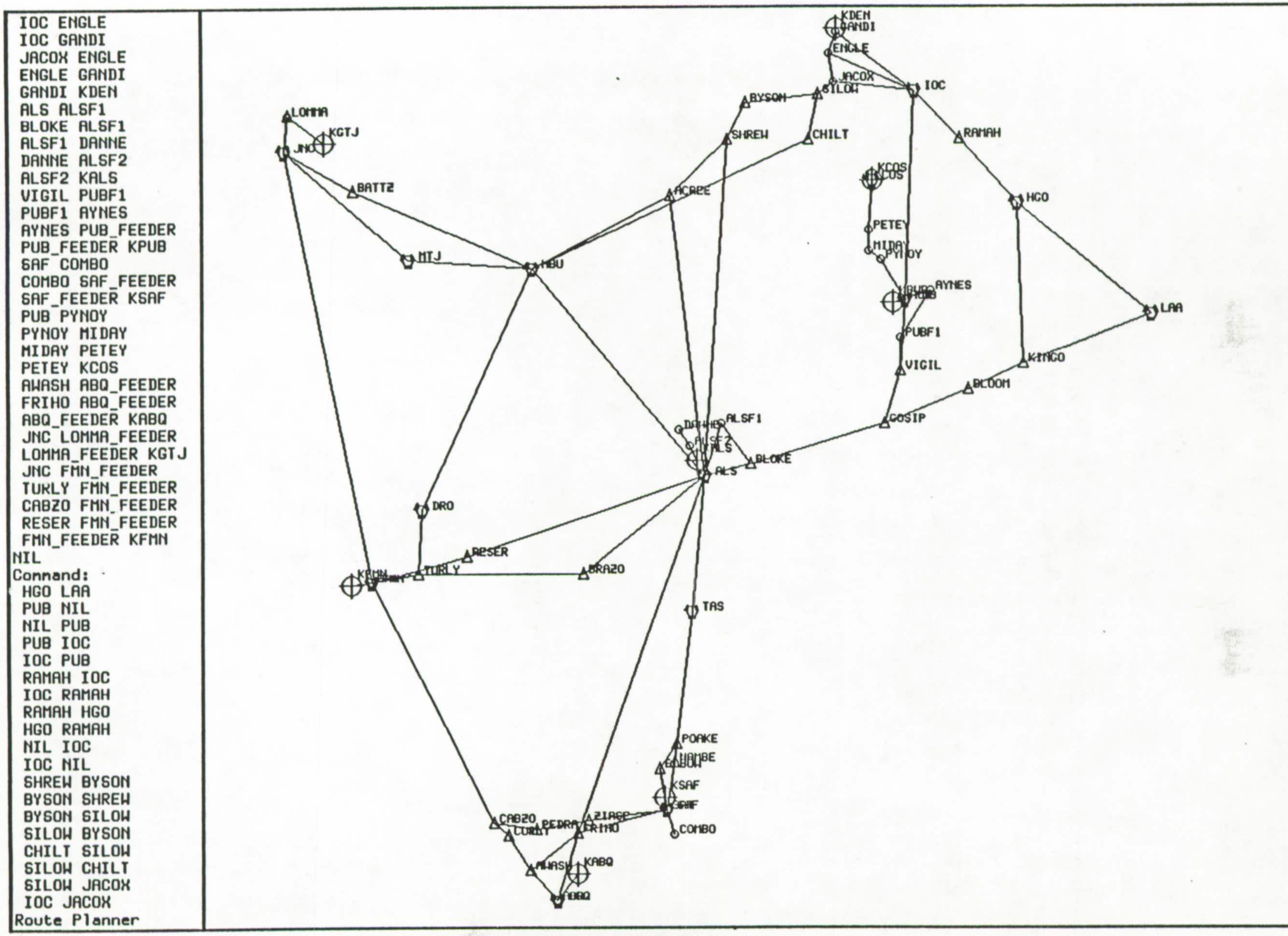


Figure 6. Diverter Software Evaluates Route Segments Identical to Those on FAA En Route Charts

	SCORE CHOICE 1	SCORE CHOICE 2	WEIGHT
RUNWAY	100	90	20
AIRFIELD	100	90	20
ROUTE	90	100	20

```
TOTAL =      (RUNWAY-SCORE * RUNWAY-WEIGHT)
           + (AIRFIELD-SCORE * AIRFIELD-WEIGHT)
           + (ROUTE-SCORE * ROUTE-WEIGHT)
```

TOTAL FOR CHOICE 1 - 5800

TOTAL FOR CHOICE 2 - 5600

EXAMPLE 1

	SCORE CHOICE 1	SCORE CHOICE 2	WEIGHT
RUNWAY	100	90	10
AIRFIELD	100	90	10
ROUTE	90	100	40

```
TOTAL =      (RUNWAY-SCORE * RUNWAY-WEIGHT)
           + (AIRFIELD-SCORE * AIRFIELD-WEIGHT)
           + (ROUTE-SCORE *ROUTE-WEIGHT)
```

TOTAL FOR CHOICE 1 - 5600

TOTAL FOR CHOICE 2 - 5800

EXAMPLE 2

Figure 7. Simplified Examples of Diverter's Weighting System for Calculating a Recommendation

score and would be recommended by Diverter. However, in example 2, the weights illustrate that the route is the most important factor in the decision. This could be because of a malfunction, a company policy, or another factor. In example 2, even though the scores have remained the same, the new weights influence Diverter's decision. Diverter will recommend choice 2 in example 2. Thus, the choosing of the weights is a very important step in building a Diverter system.

The overall flow of procedural control for Diverter is represented in Figure 8. Each box represents a functional area within the Diverter software. Each function breaks down into sub-functions listed to the right of the original function. The order of execution of these functions is ordered from top to bottom. Thus, in the Diverter system, the runway scores are generated first. Then, the scores for each airfield are evaluated. Next, the scores for each segment are generated. Using these segment scores, a graph is made representing the segments and their scores. A route to each destination is generated, and finally the scores are totalled and the destination with the highest score is suggested to the pilot.

Runway Evaluation

In order to establish bounds on the Diverter search space, the Diverter software limited the possible landing fields to within 200 miles of the aircraft's current position. The first step in the replanning process is to narrow the choices to all runways that meet the minimum landing requirements of the aircraft. Selection of the possible choices is performed by a ruleset implemented using the Symbolics Joshua expert system tool. This ruleset makes sure that the attributes of each runway can support the minimum levels necessary for the aircraft. Then, for each attribute listed below, all of the runway choices are ranked according to their value with the best runway receiving a rank of 10 and the rest of the rankings decreasing accordingly. The following attributes are considered when evaluating the runways:

Physical Attributes
-length
-width
-weight-capacity
-surface

Approach Attributes
-visibility minimums
-ceiling minimums
-Runway Visual Range minimums

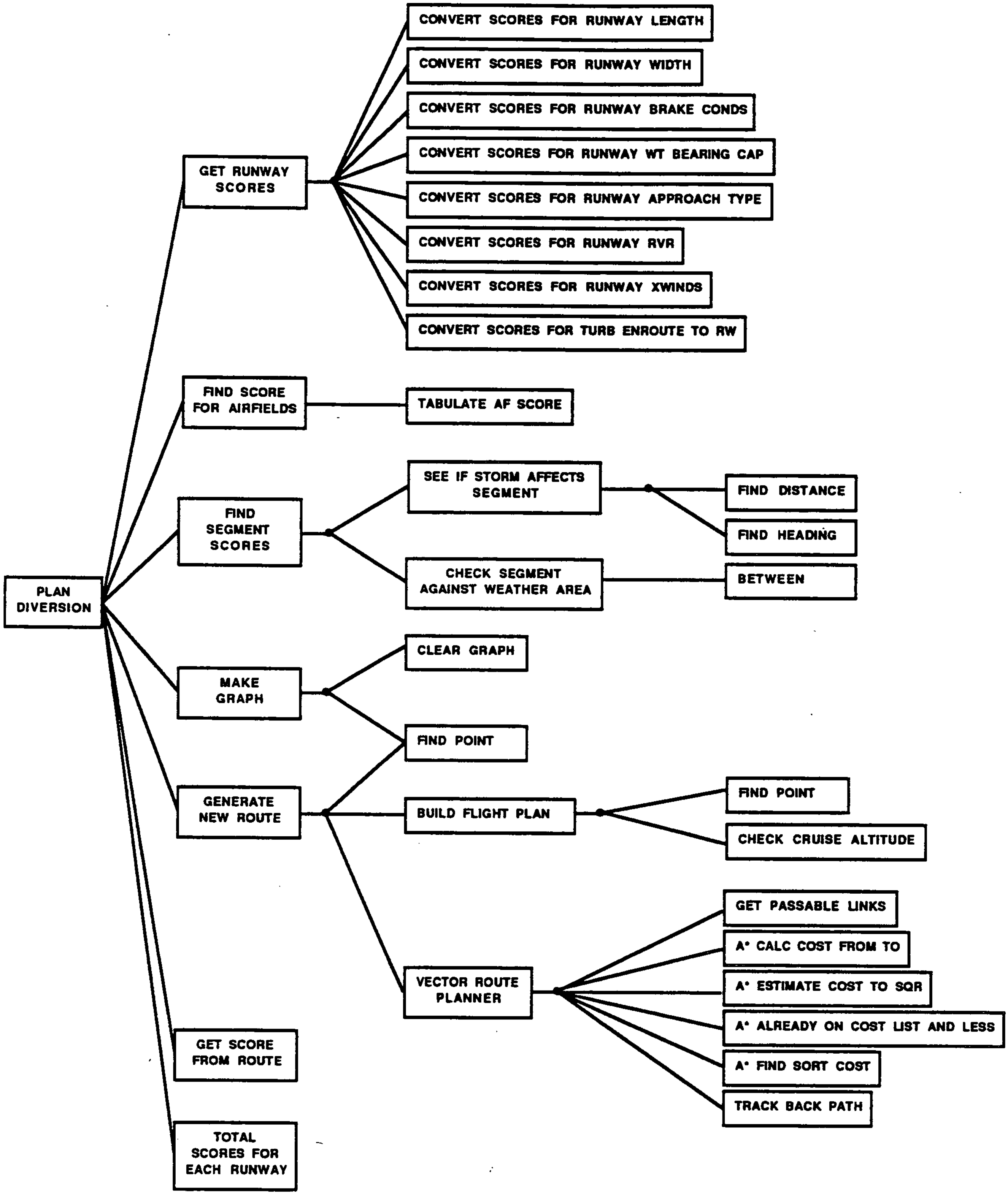


Figure 8. Planning/Replanning Functional Flow Diagram as Obtained From Actual Diverter Software

Weather Attributes
- crosswinds limits
- runway conditions
- wind shear conditions

Miscellaneous Attributes
- IFR approach attributes
- traffic acceptable
- runway open or closed
- company policy acceptability

Airfield Evaluation

Following the runway evaluation, a list of potential airfields is compiled that contains the airfield for every runway possibility. For each attribute listed below, all of the airfield choices are ranked according to their value with the best airfield receiving a rank of 10 and the rest of the rankings decreasing accordingly. If the attributes have a boolean value (true or false) instead of a numerical value, then the rank assigned is a 10 if it is true, and a 0 if it is false. The following attributes are considered when evaluating the airfields:

taxi-ramp-weight-capacity
emer-equip-avail
fuel-avail
oxygen-avail
maint-avail
power-cart-avail
px-terminal-facilities
nearby-lodging-avail
ground-transport
gate-avail
suitable-stairs-avail
relief-crew-avail
airline-flight-reciprocity
current-destination

Segment Evaluation

In order for the route planner to be able to generate routes to the various destinations, it must have a domain to search. This domain is created by evaluating each of the segments in the Diverter database based on the attributes listed below. Each segment must be assigned a cost that represents the relative cost of traversing that segment. The starting cost for each segment is defined to be the distance covered by that segment. Each of the attributes listed below has an associated weight, and if a given segment is affected by an element of that attribute, the cost of the given segment is increased by a value equalling the weight of the attribute times the distance of the segment. All of the attributes except minimum altitude have four levels of severity, each having its own weight: light, moderate, severe, and extreme. The minimum altitude attribute is checked to make sure that the capabilities of the aircraft currently meet or exceed the requirements of the given segment. For moving weather cells, the aircraft movement and the cell movement are projected forward in time based on current speeds to determine if the paths will meet. For the stationary weather areas, if the segment intersects the weather area, then the segment is said to be affected by the weather area.

The following attributes are considered when evaluating the segments:

minimum altitude
moving weather cells
turbulence
icing
clear air turbulence
thunderstorms

Route Planner

Once all of the segments are assigned their costs, an internal graph is built representing the relationships between the segments. The route planner then finds a path from the current aircraft location to each airfield being considered. The list of possible destinations is derived from the list of runways that are suitable for the aircraft. The route planner uses an A* algorithm to locate the route with the lowest overall cost. The route to the airfield is then stored with each possible runway at that airfield for later use in computing the overall score of the runway.

Simulation Tool

The interface between Diverter and the simulated outside world is provided by a simulation tool that is provided with the Diverter system. The simulation tool allows the user to input reports about static weather areas and moving weather cells. The different types of weather available are fog, turbulence, clear air turbulence, icing, and static and moving thunderstorms. The simulation tool also allows the user to input aircraft system problems, such as an engine problem or a pressurization problem. This new information is stored in global variables that act as the interface between Diverter and the outside world. The simulation tool will also simulate the movement of the aircraft along the current route, updating position and fuel usage. Display of the aircraft, its current route, proposed routes, and the weather areas is also handled by the simulation tool.

DEMONSTRATION

The Diverter prototype software runs on a Symbolics 3640 Lisp processor, utilizing the Statice and Joshua software packages developed by Symbolics. The Statice software package is a database manager used for reliable information storage. The database is stored on the computer hard disk, and thus does not need rebuilding when the system is rebooted. This enables the user to build the database necessary for Diverter only once. Accordingly, the Statice database is only used to store information that does not change. This includes information such as runway length and width, aircraft stall speed and maximum take-off weight, and segment length and endpoints. The information that changes constantly is contained as Joshua facts, or predicates. Joshua is a tool developed by Symbolics and used for building expert systems. The setup used in the Diverter demonstration used a tight coupling of Joshua and Statice that enabled the Joshua rulebase to reason about information stored as Joshua predicates or in the Statice database while keeping all of this interaction transparent to the user.

To demonstrate the software, the scenario used a commercial airliner en route from Los Angeles to Colorado Springs. About 70 miles prior to Alamosa, notification is received that there is a line of thunderstorms over Colorado Springs moving at 30 miles per hour, heading 075 degrees. Diverter plans ahead and determines that the storms will be out of Colorado Springs at the expected arrival time, so no diversion is necessary. Then, Diverter receives another report that there is a second line of thunderstorms approximately 20 miles behind the first line moving at the same speed and direction. Diverter recognizes in replanning that the storms will be over Colorado Springs at the expected arrival time, and now recommends a diversion to Pueblo. This diversion is accepted by the pilot and approved by ATC. This scenario has demonstrated Diverter's ability to reason about moving weather areas and project them ahead in relation to the aircraft's expected route. Next, an area of severe turbulence is reported in the Pueblo area and is predicted to remain there for a period of time. Once again, during replanning Diverter recognizes the effect of this weather area and suggests a new diversion to Albuquerque. This scenario shows Diverter's ability to reason about static weather areas and how they affect the airway segments in consideration. The pilot also accepts this plan. Finally, the aircraft experiences a cabin pressurization failure. Diverter now recognizes the reduced operating limits of the aircraft, and since the route to Albuquerque travels along high altitude segments, recommends a diversion to Denver travelling directly east to get beyond the mountains, then along low-altitude segments. A copy of the Symbolics screens as seen during the demonstration are included in Appendix D.

DIVERTER STATUS AND RECOMMENDED IMPROVEMENTS

In the current software prototype, Diverter is capable of combining all the available information and using the built-in knowledge to determine the best combination of runway, airfield, and route. This resultant route is then suggested to the pilot. Some of the information used in Diverter would be contained in an onboard database of attributes about runways, airfields, and aircraft. Other information about weather and navigation aid status may be obtained through data link or pilot input. The Diverter system did not attempt to define how this information transfer would take place. It also did not attempt to define in what form the information would be in. Rather, Diverter assumed that the information it needed would be made available to it.

During simulation using the prototype, the system was very slow in generating a recommendation. For comparison purposes, a second version of the Diverter software was created that did not use the Statice database tool. All of the necessary information was stored as Joshua predicates. The exclusion of the Statice database tool required redefinition of the Joshua data model which tells Joshua where to look for the information. Results of several tests showed that a severe overhead was noticed by using the Statice tool. The overhead associated with the use of Statice was fairly obvious since Joshua predicates were stored in memory and information stored in Statice had to be retrieved from disk. Since the replanning process requires access of considerable information, a lot of time was saved by not using Statice. In a prototyping environment, this is very helpful. However, in an actual implementation, data integrity is more important, and loss of data due to a hardware problem can be very costly. Statice seems to be more applicable to an implementation environment.

The Phase III Diverter software contains two major improvements over the Phase II Diverter software. The first change involves the route planning during a diversion. The Phase II approach involved planning the possible routes ahead of time and evaluating the routes as an entity during the replanning process. During Phase III, the A* searching technique was used to introduce more dynamic route planning during the diversion. This method does not exclude any possibilities beforehand, and also allows easier updating of the Diverter system should the segment definitions ever change. The Phase II approach involved determining all possible routes and going back into the system and updating the necessary structures, while the Phase III approach involves just adding the representation of the segment to the database.

The other major difference between Phase II and Phase III software involves the overall methodology of planning the diversion. Phase II chose the airfield for the diversion and then evaluated the routes to that airfield in order to find the best route. In Phase III, runways, airfields and routes are considered simultaneously in order to choose the best diversion. This means that the airfield with the best combination of attributes may not be the final destination recommended by Diverter if the route to that airfield is poor. The destination recommended by Diverter will be the best selection overall, although it may not be the best in any one category.

Certain areas of Diverter were not developed and leave areas for future work. One area not investigated was the use of direct routing. Methods for using direct routing would have to be incorporated into the route planning algorithm, since it would be impossible to model direct routing in the current route planning methodology (the system would always try to fly direct). There would also have to be a way to simulate responses from ATC concerning direct routing requests. This capability could be added to the simulation tool either to generate an automatic response, or to prompt the user for a response.

Another area of future work would be to allow the pilot to use pieces of Diverter as a tool. Functions that the pilot may be able to use include browsing of the onboard database, querying the database for information, and route planning to a specific point indicated by the pilot.

The software could also be modified to analyze more about the approach characteristics of a runway: ceilings, RVRs, mechanical conditions of equipment, etc. This would help Diverter generate a more complete flight plan including specific altitudes, speeds, and approach types. Once a complete flight plan is generated and approved, the Diverter system could then download this information directly to the FMS.

An additional area that needs more research is how to assign the weights to the different attributes. Dynamic weight choices are necessary based on combinations of diversion factors. These weights must be carefully chosen to control the behavior of the Diverter system.

Finally, the idea behind an intelligent system is that it has the capability to learn from itself, not just apply static knowledge. While Diverter is applying more dynamic weights than those utilized in Phase I and II, the system does not have the capability to learn from its past performance. This might include a feedback loop where the situation is rated so the specific rules are modified to more accurately represent how the decisions can be effectively applied. Simultaneously, Diverter should be able to learn from the flight crew. As discussed earlier, the system needs to be representative of an associate crew member. If the system could modify the application of rules to more realistically represent the individual differences in the application of strategy to decision making, then the system would more faithfully represent such an associate and would more likely be accepted, trusted, and utilized by flight crews.

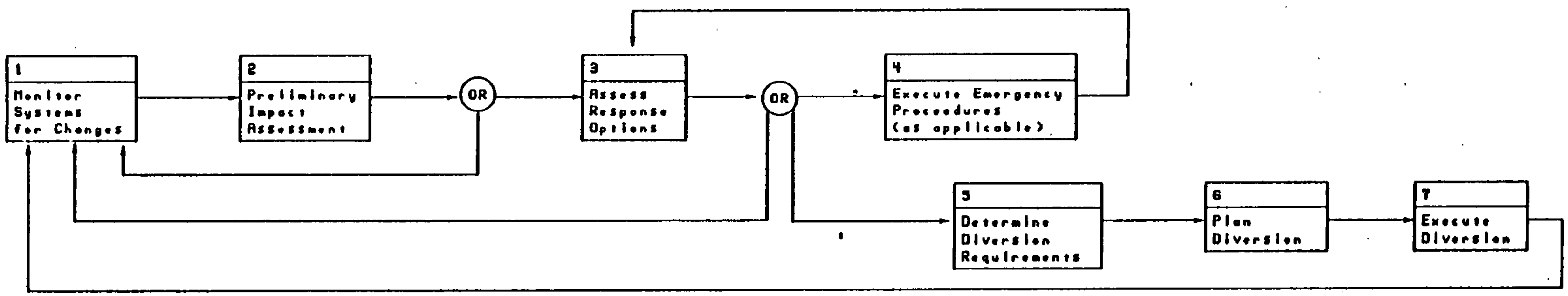
CONCLUSIONS AND RECOMMENDATIONS

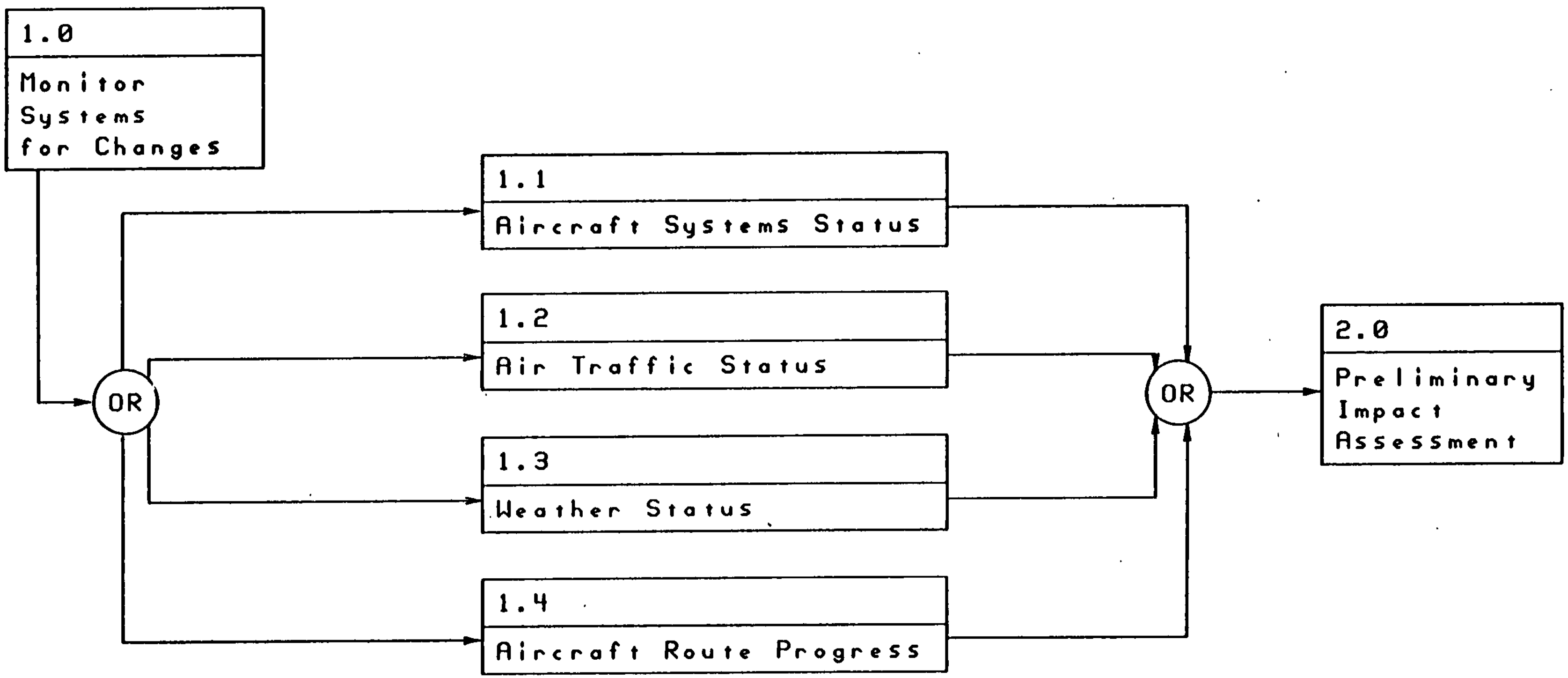
Artificial intelligence technology can provide pilots with the help they need in making the complex decisions concerning changes in the flight plan. A Diverter system should have the capability to take all of the available information and produce a recommendation to the pilot. In addition, Diverter could be used as a resource to the pilot, providing information services, and as an aid to enhance his planning capabilities. This prototype provides considerable capability and forms the cornerstone for development of a very useful and necessary pilot decision aiding system. Further development of the system described in the preceding section and evaluation of the pilot vehicle interface in NASA Langley's Advanced Concepts Simulator is recommended.

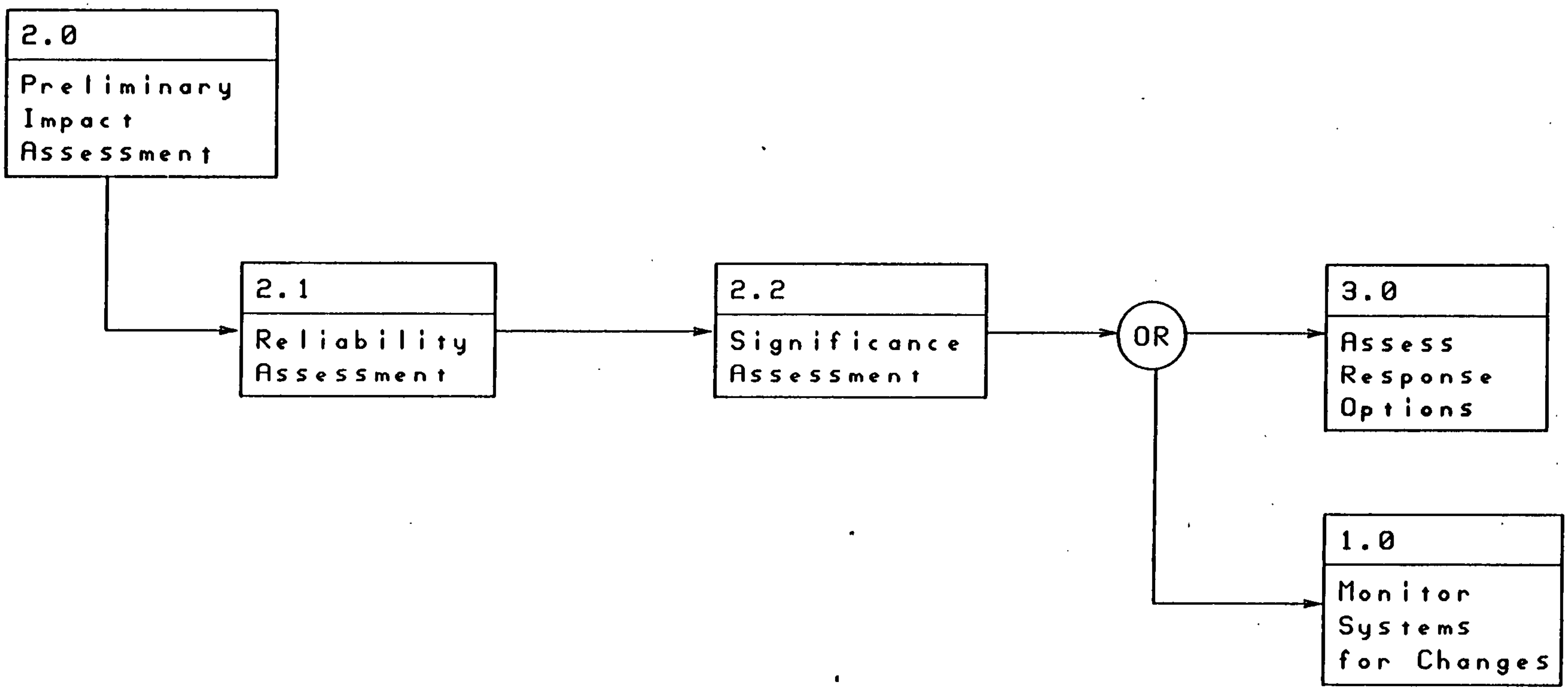
APPENDIX A

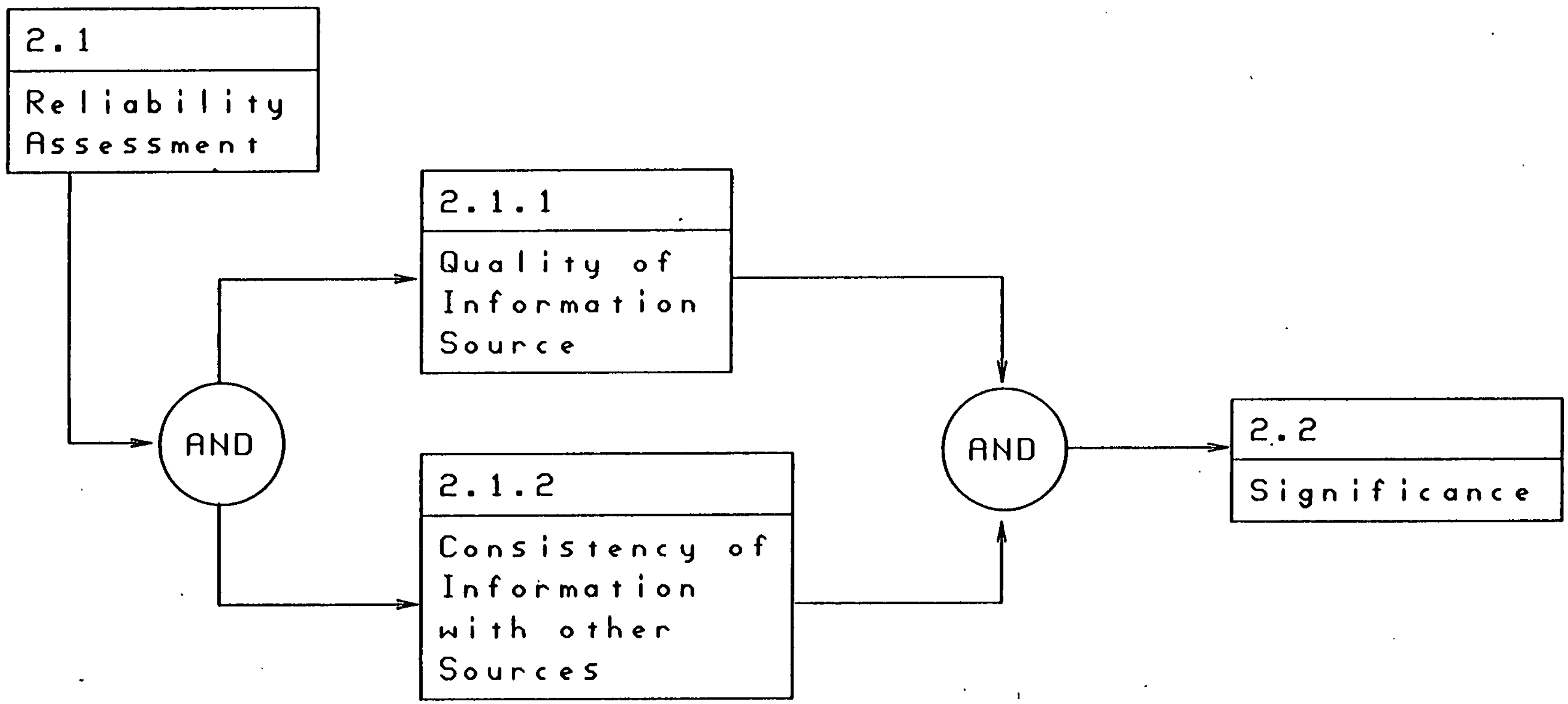
Diversion Planning Functional Flow Diagram

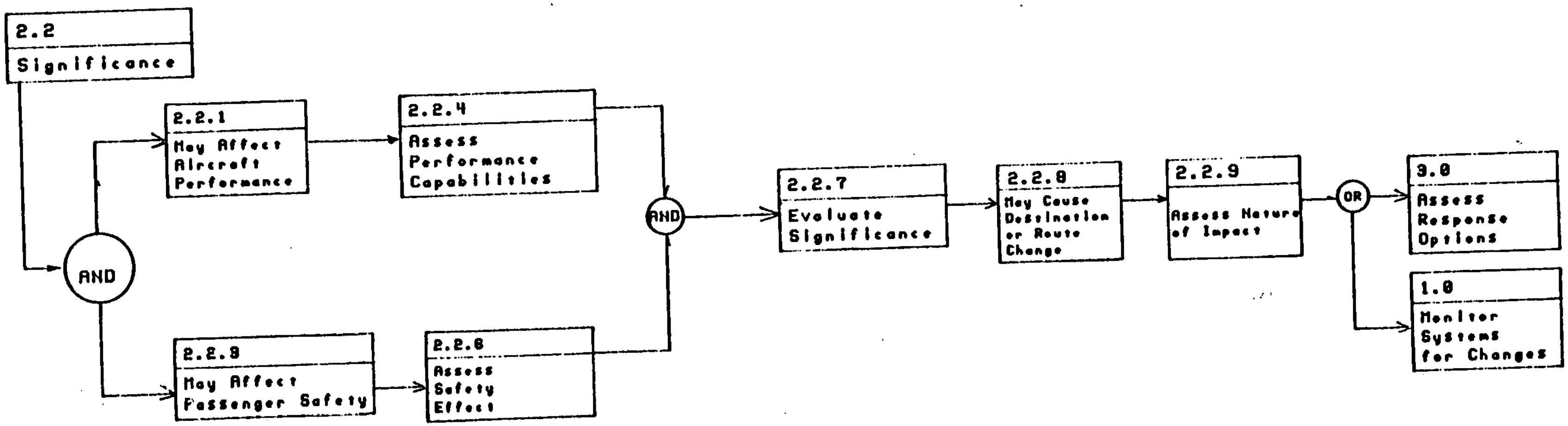
This appendix summarizes the functions required for planning an inflight diversion. It represents both the functions utilized by pilots during diversion planning as well as the model used for system development and replication of pilot planning processes.

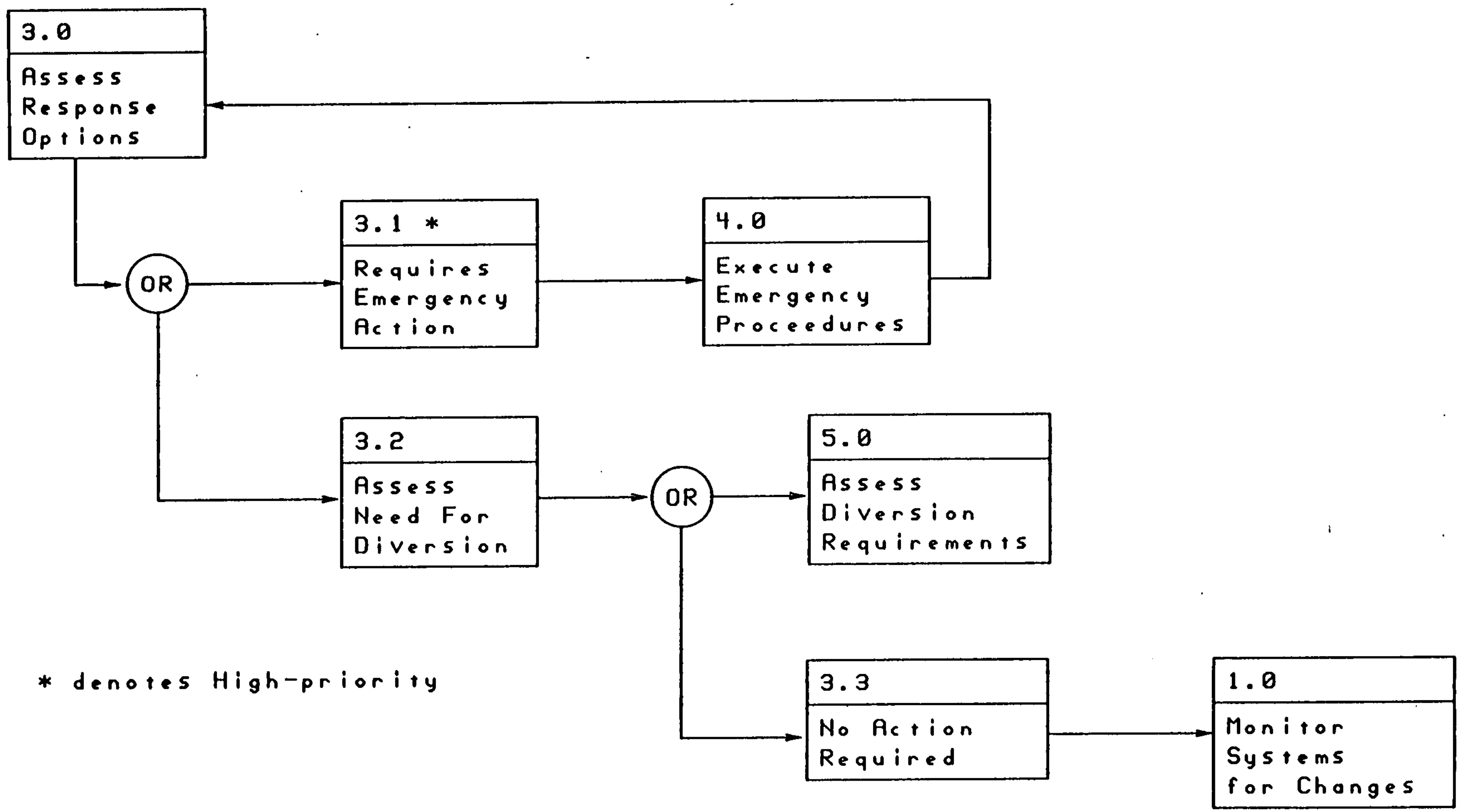

1
Monitor Systems for Changes
2
Preliminary Impact Assessment
OR
3
Assess Response Options
OR
4
Execute Emergency Procedures (as applicable)
5
Determine Diversion Requirements
6
Plan Diversion
7
Execute Diversion


1.0
Monitor Systems for Changes
OR
1.1
Aircraft Systems Status
1.2
Air Traffic Status
1.3
Weather Status
1.4
Aircraft Route Progress
OR
2.0
Preliminary Impact Assessment

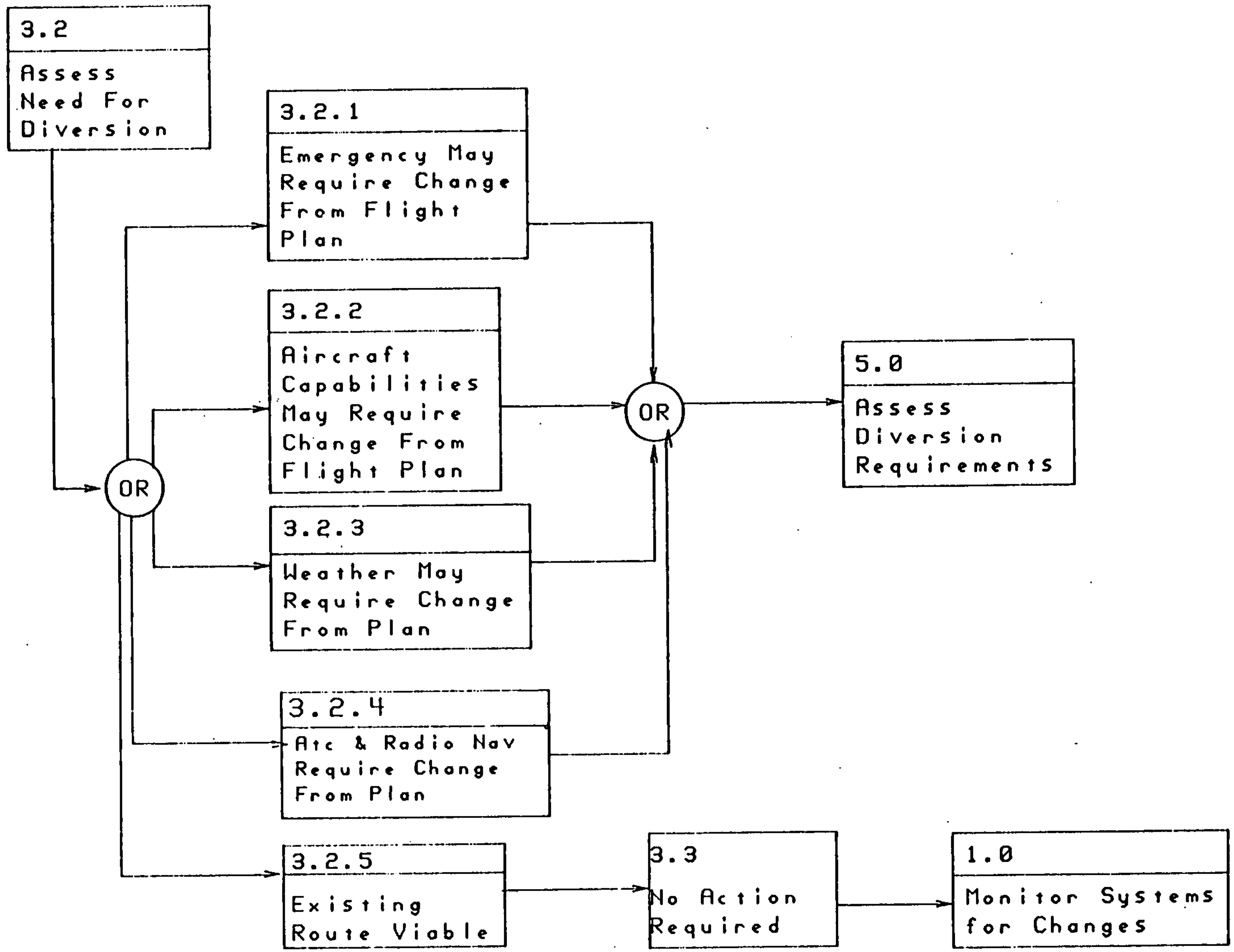

2.0
Preliminary Impact Assessment
2.1
Reliability Assessment
2.2
Significance Assessment
OR
3.0
Assess Response Options
1.0
Monitor Systems for Changes

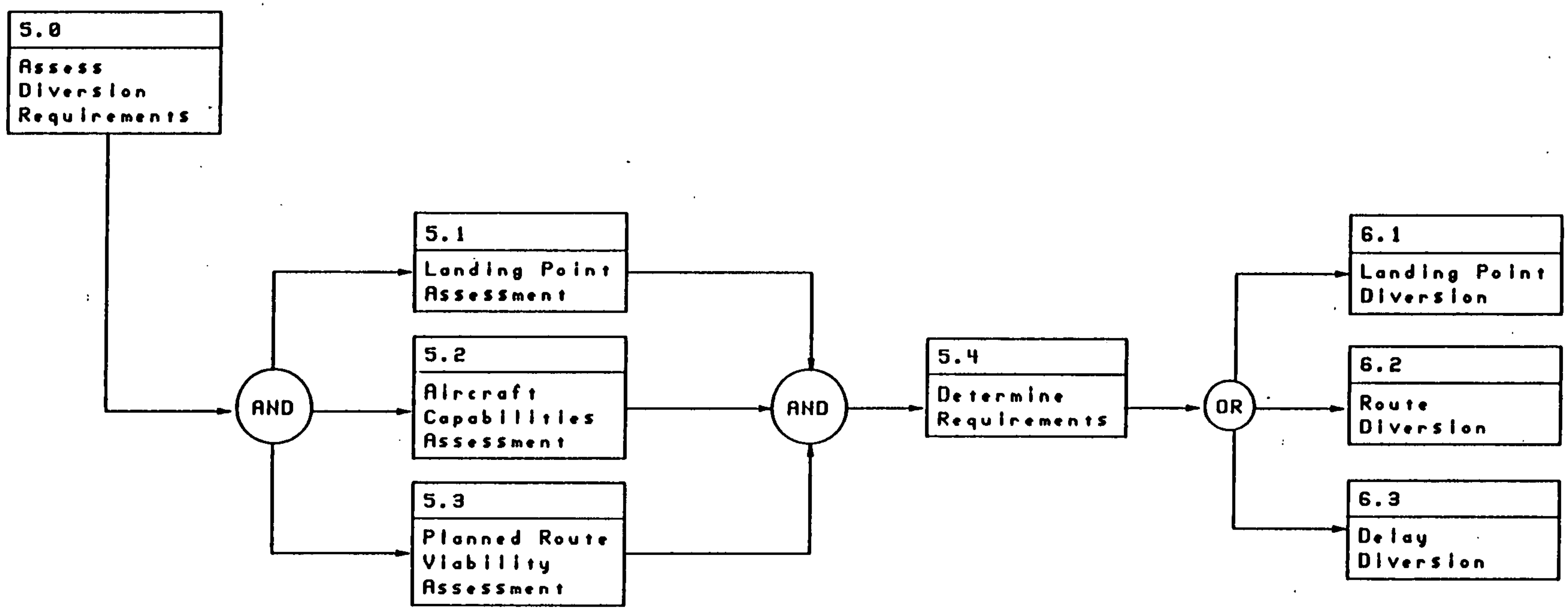

2.1
Reliability Assessment
AND
2.1.1
Quality of Information Source
2.1.2
Consistency of Information with other Sources
AND
2.2
Significance

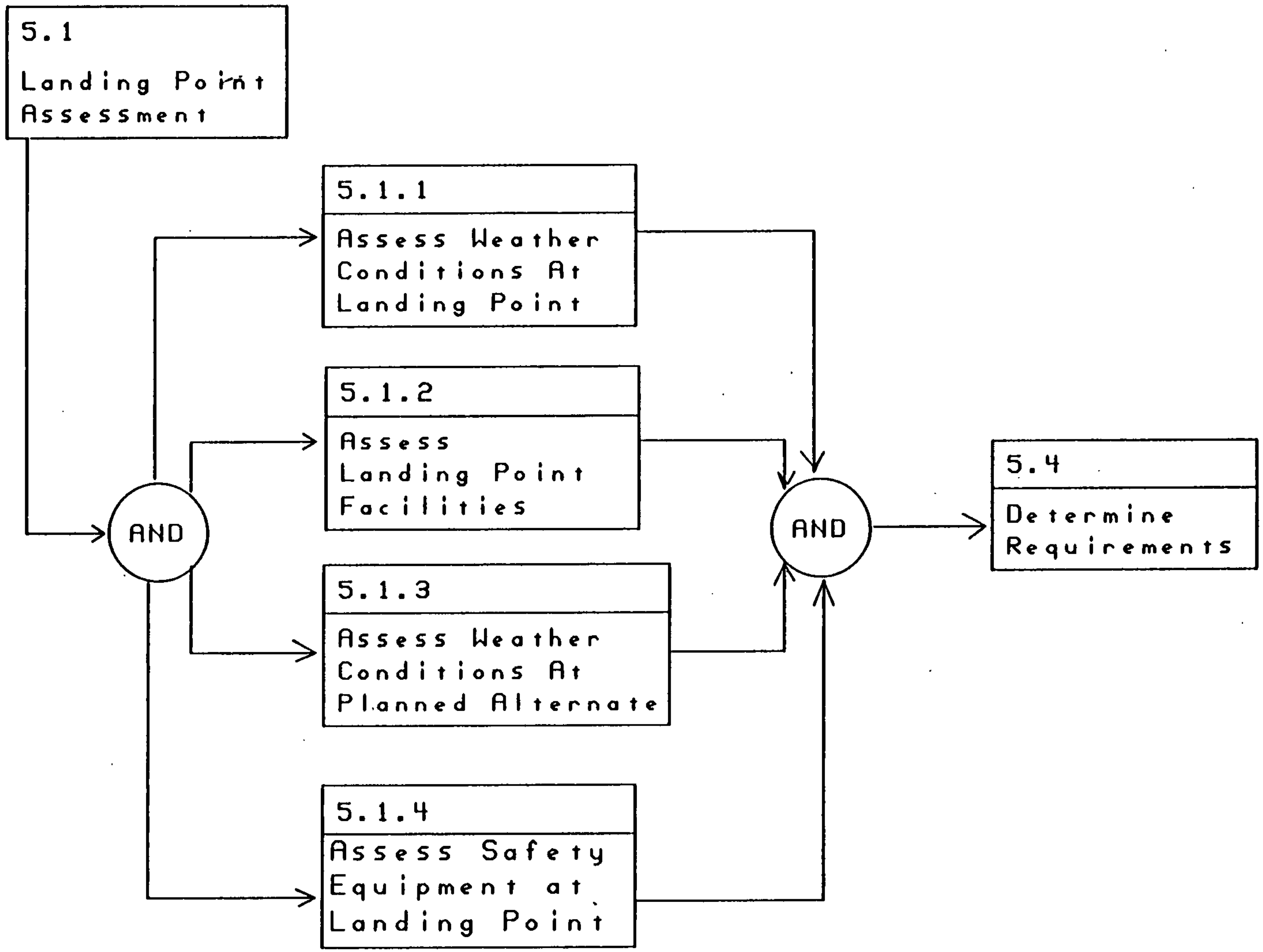

2.2
Significance
AND
2.2.1
May Affect Aircraft Performance
2.2.4
Assess Performance Capabilities
2.2.3
May Affect Passenger Safety
2.2.6
Assess Safety Effect
AND
2.2.7
Evaluate Significance
2.2.8
May Cause Destination or Route Change
2.2.9
Assess Nature of Impact
OR
3.0
Assess Response Options
1.0
Monitor Systems for Changes

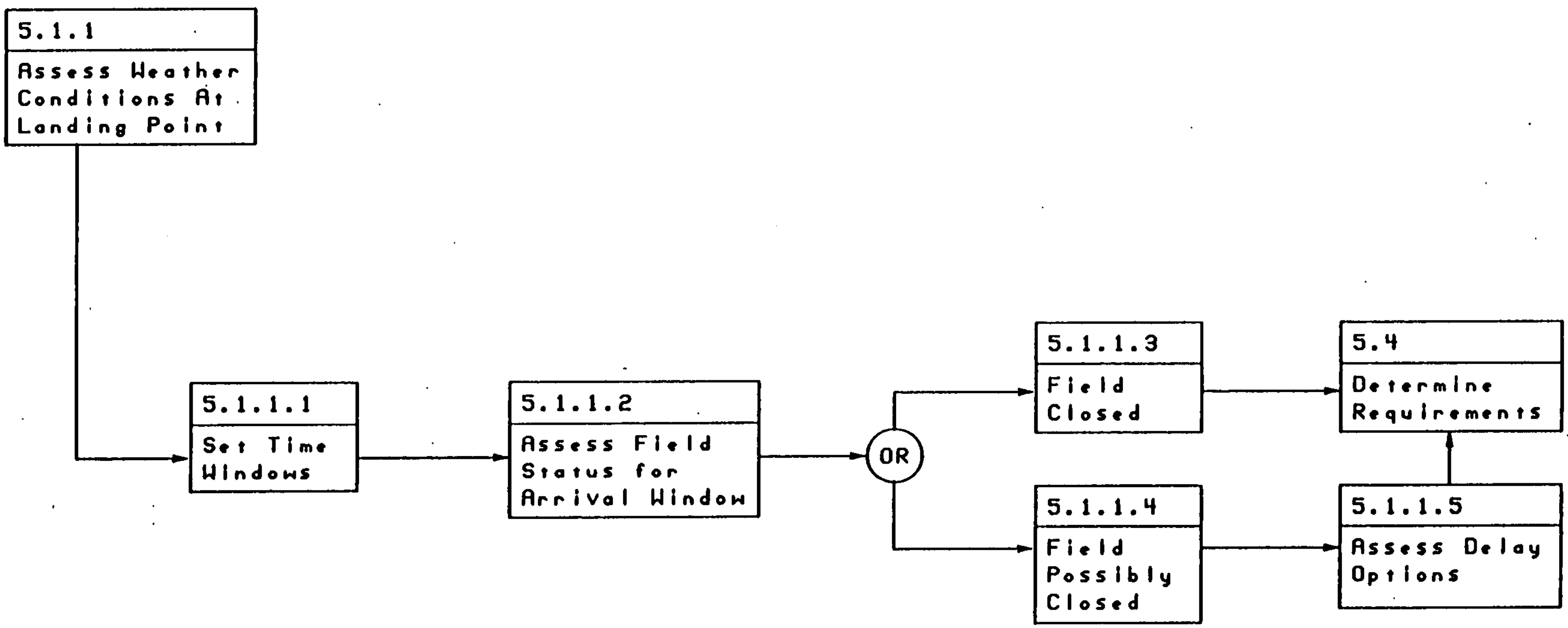


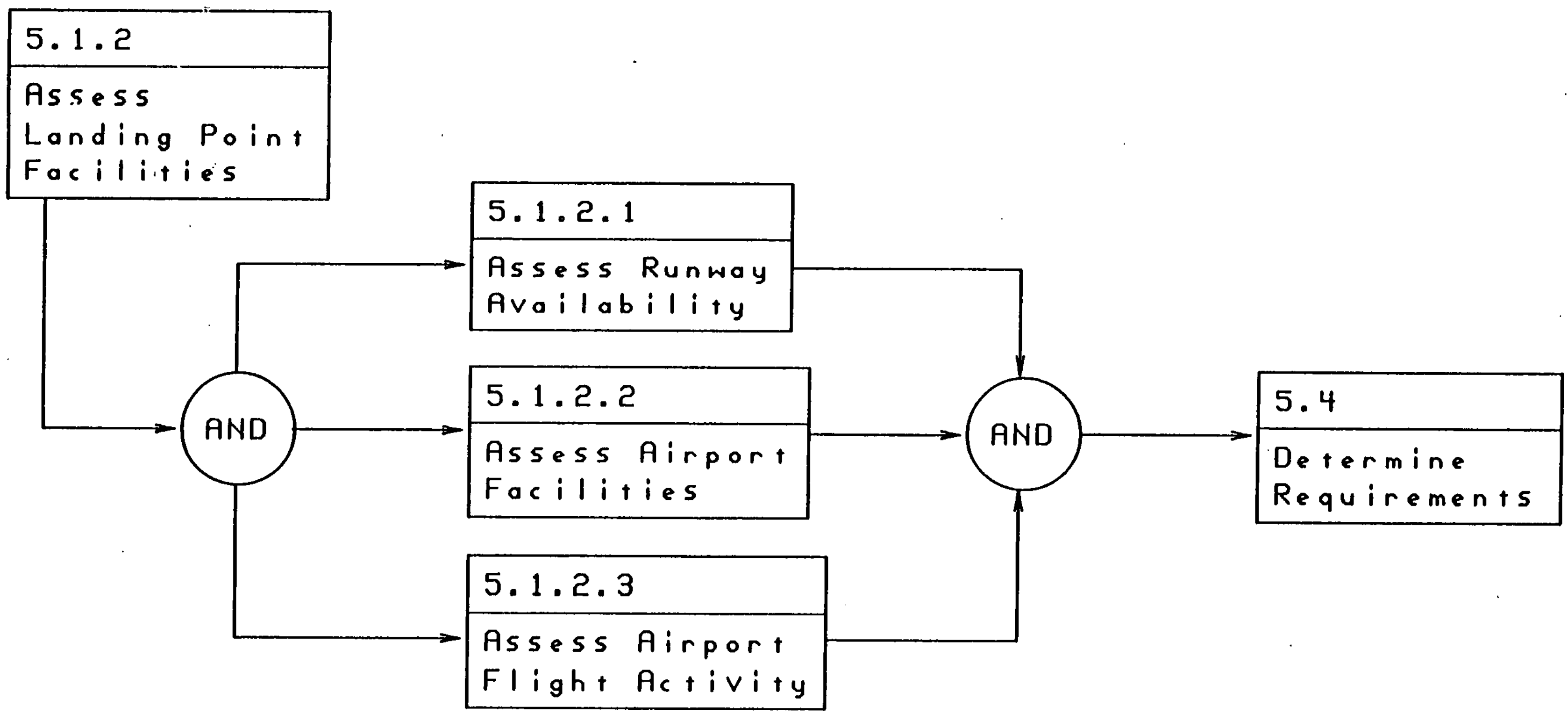
* denotes High-priority

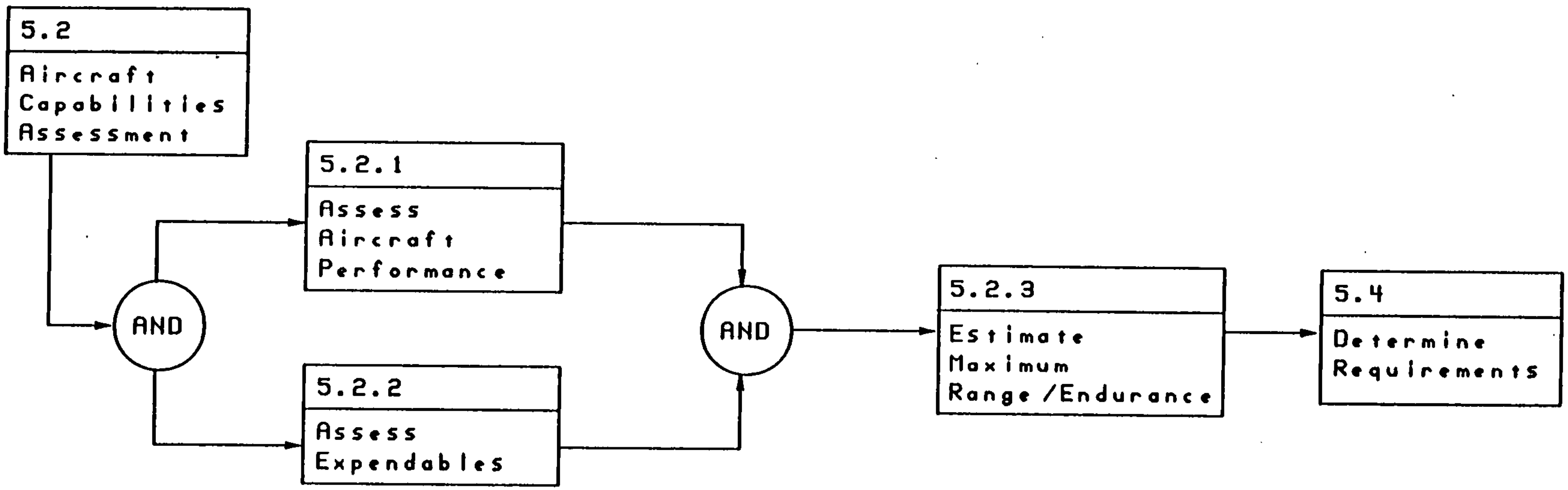

3.2
Assess Need For Diversion
OR
3.2.1
Emergency May Require Change From Flight Plan
3.2.2
Aircraft Capabilities May Require Change From Flight Plan
3.2.3
Weather May Require Change From Plan
3.2.4
Atc & Radio Nav Require Change From Plan
3.2.5
Existing Route Viable
OR
5.0
Assess Diversion Requirements
3.3
No Action Required
1.0
Monitor Systems for Changes

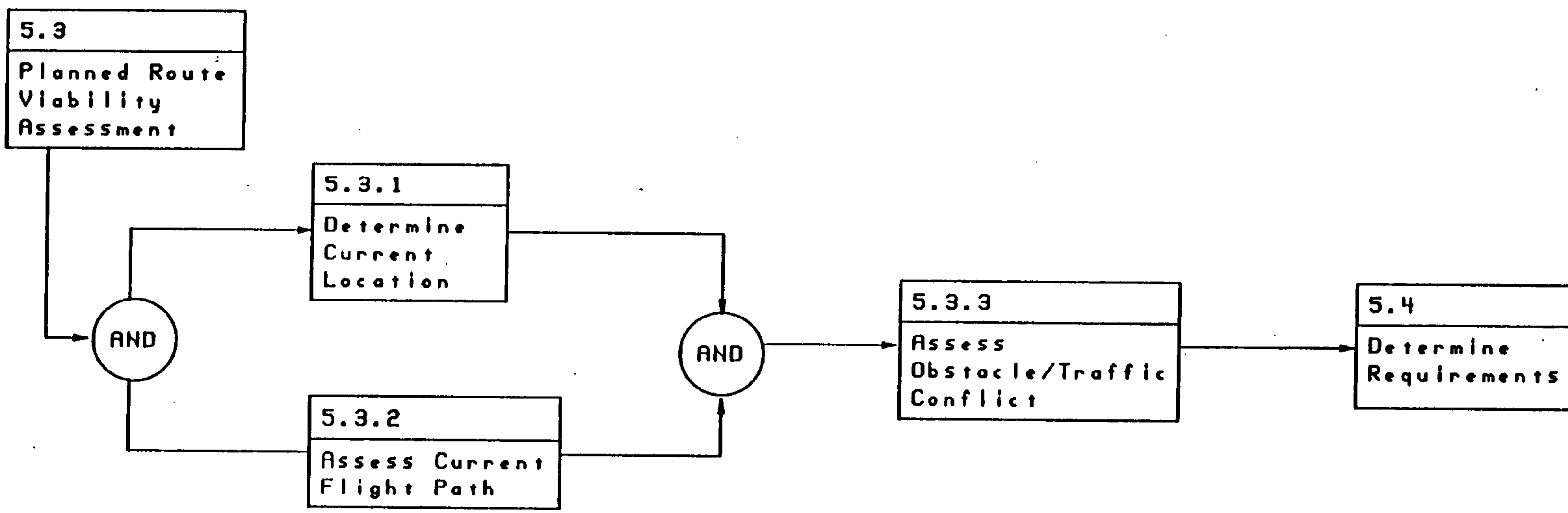

5.0
Assess Diversion Requirements
AND
5.1
Landing Point Assessment
5.2
Aircraft Capabilities Assessment
5.3
Planned Route Viability Assessment
AND
5.4
Determine Requirements
OR
6.1
Landing Point Diversion
6.2
Route Diversion
6.3
Delay Diversion

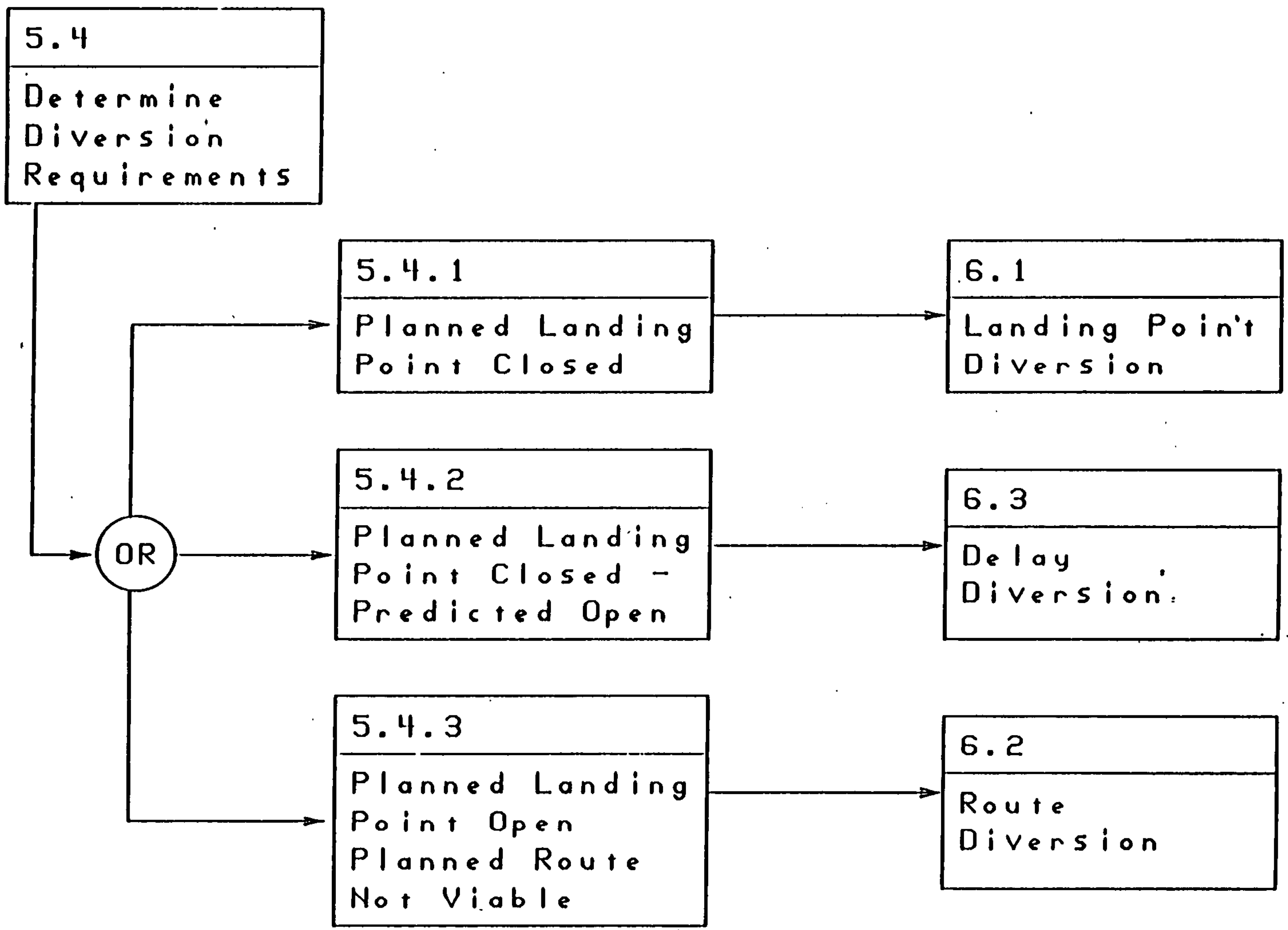

5.1
Landing Point Assessment
AND
5.1.1
Assess Weather Conditions At Landing Point
5.1.2
Assess Landing Point Facilities
5.1.3
Assess Weather Conditions At Planned Alternate
5.1.4
Assess Safety Equipment at Landing Point
AND
5.4
Determine Requirements

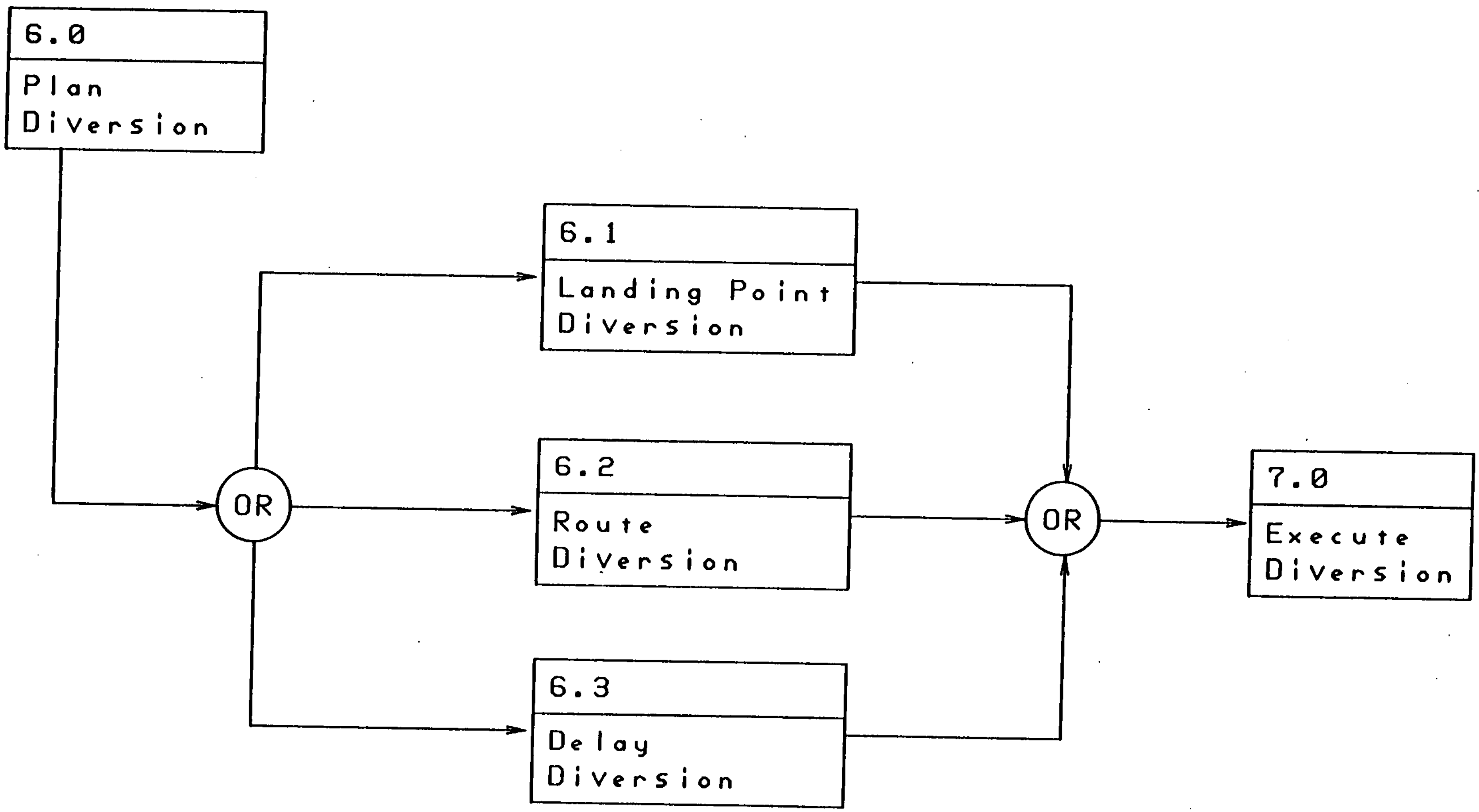

5.1.1
Assess Weather Conditions At Landing Point
5.1.1.1
Set Time Windows
5.1.1.2
Assess Field Status for Arrival Window
OR
5.1.1.3
Field Closed
5.1.1.4
Field Possibly Closed
5.4
Determine Requirements
5.1.1.5
Assess Delay Options

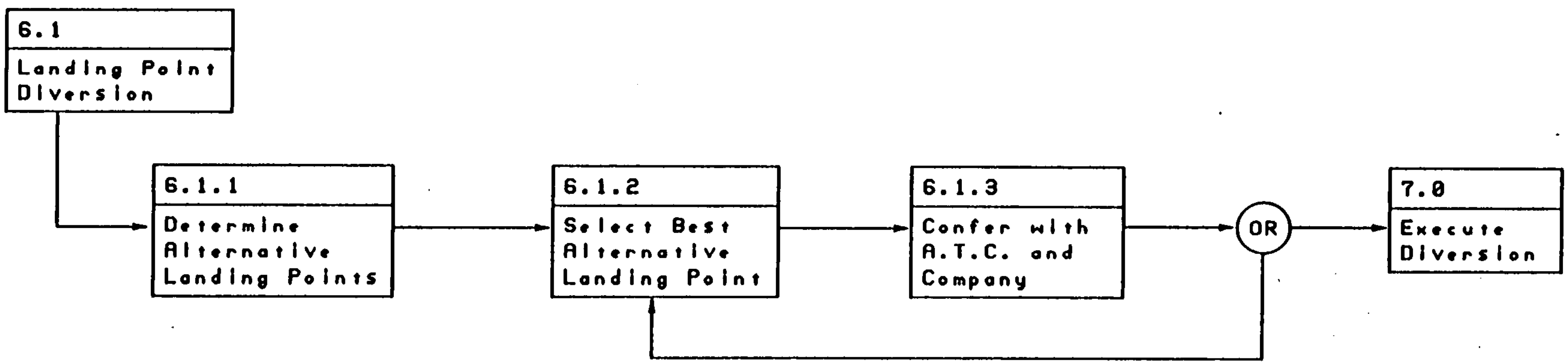

5.1.2
Assess Landing Point Facilities
AND
5.1.2.1
Assess Runway Availability
5.1.2.2
Assess Airport Facilities
5.1.2.3
Assess Airport Flight Activity
AND
5.4
Determine Requirements

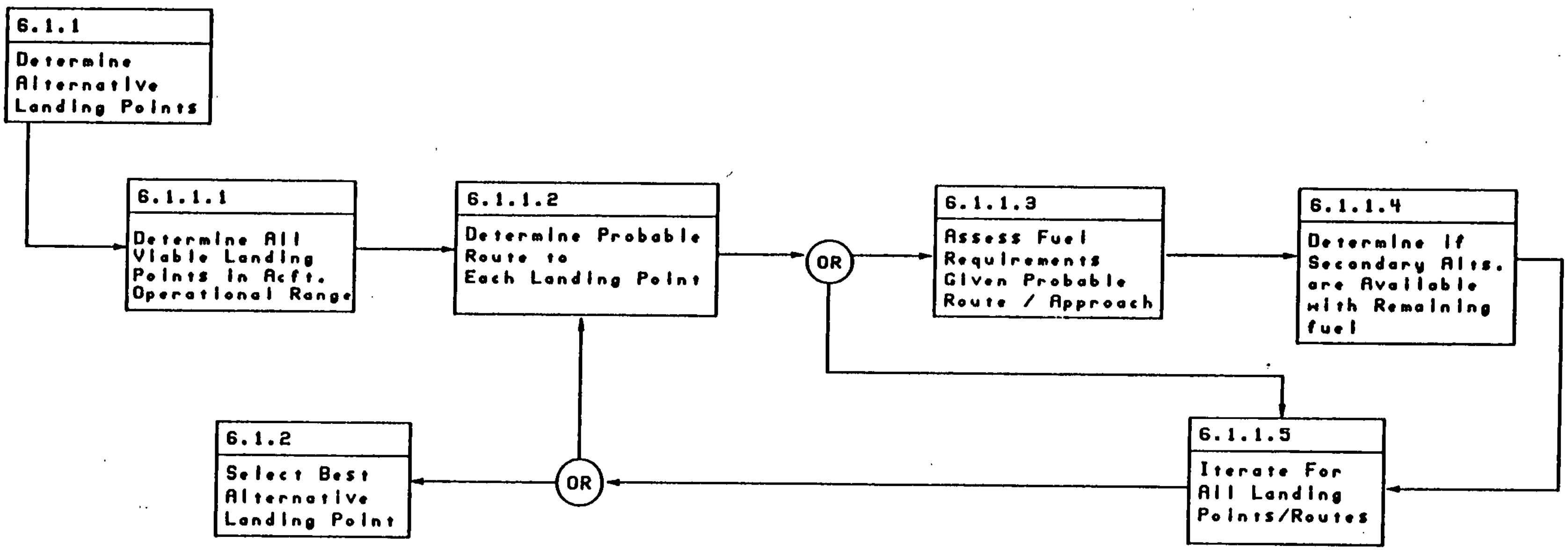

5.2
Aircraft Capabilities Assessment
5.2.1
Assess Aircraft Performance
5.2.2
Assess Expendables
AND
AND
5.2.3
Estimate Maximum Range /Endurance
5.4
Determine Requirements

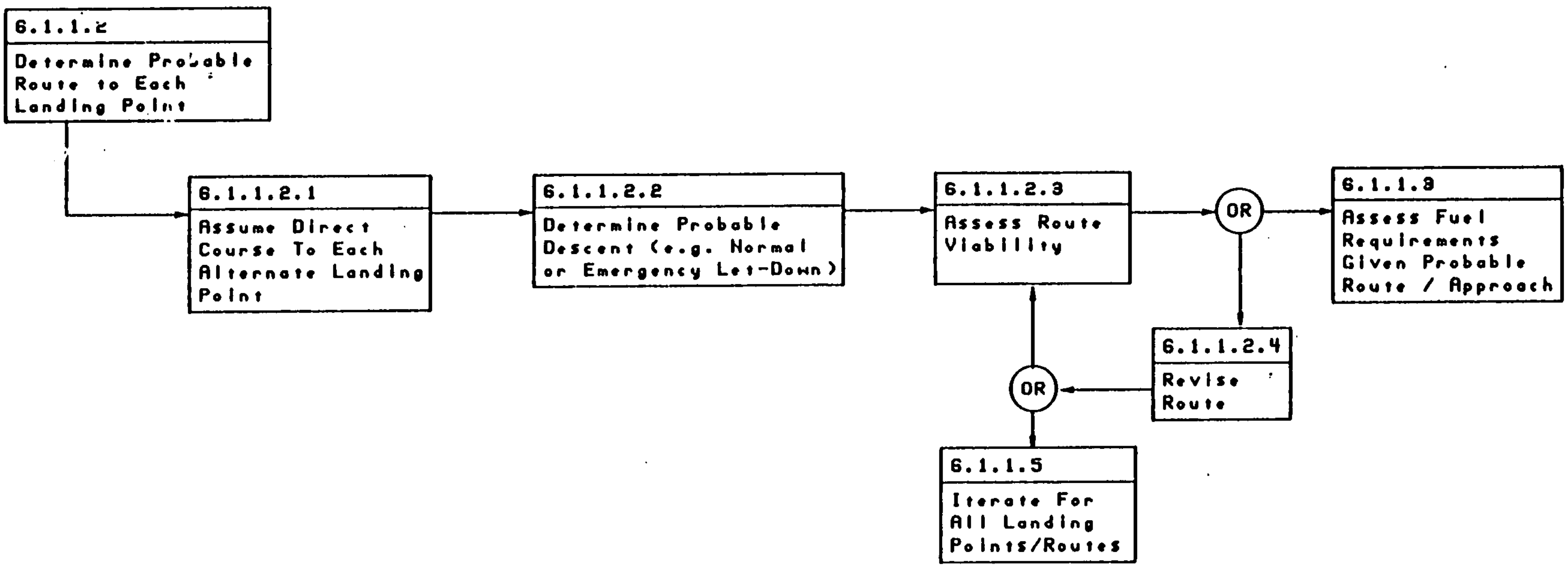

5.3
Planned Route Viability Assessment
AND
5.3.1
Determine Current Location
5.3.2
Assess Current Flight Path
AND
5.3.3
Assess Obstacle/Traffic Conflict
5.4
Determine Requirements

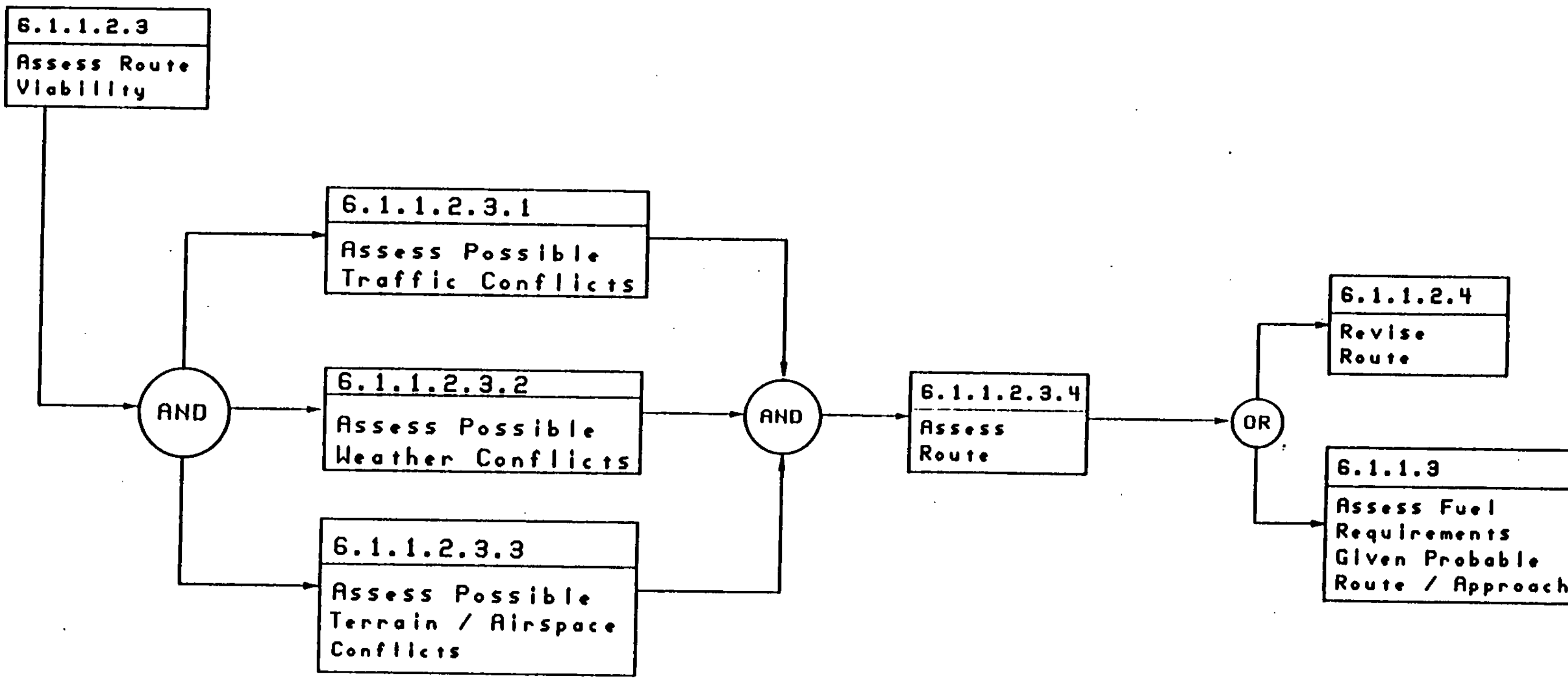

5.4
Determine Diversion Requirements
OR
5.4.1
Planned Landing Point Closed
5.4.2
Planned Landing Point Closed - Predicted Open
5.4.3
Planned Landing Point Open Planned Route Not Viable
6.1
Landing Point Diversion
6.3
Delay Diversion
6.2
Route Diversion

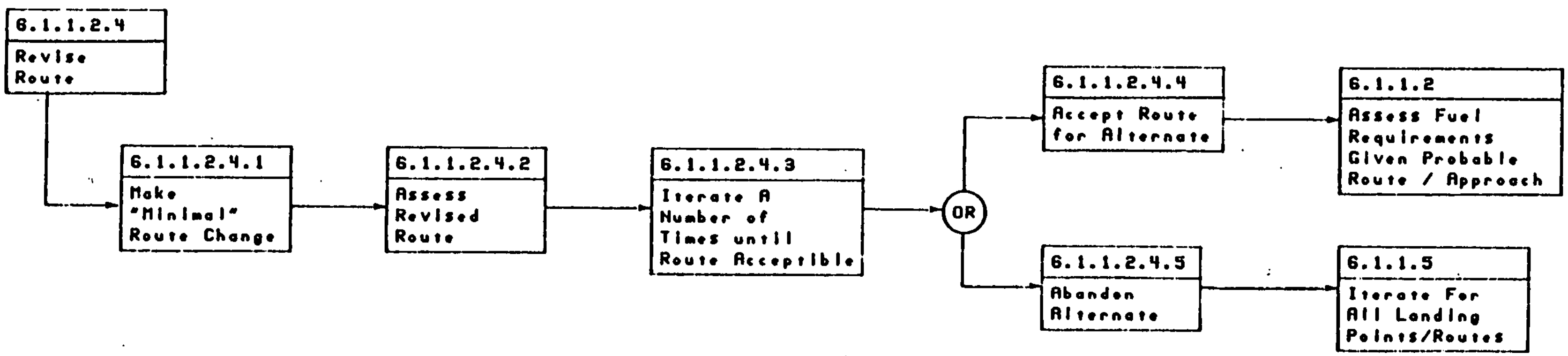

6.0
Plan Diversion
6.1
Landing Point Diversion
6.2
Route Diversion
6.3
Delay Diversion
OR
OR
7.0
Execute Diversion

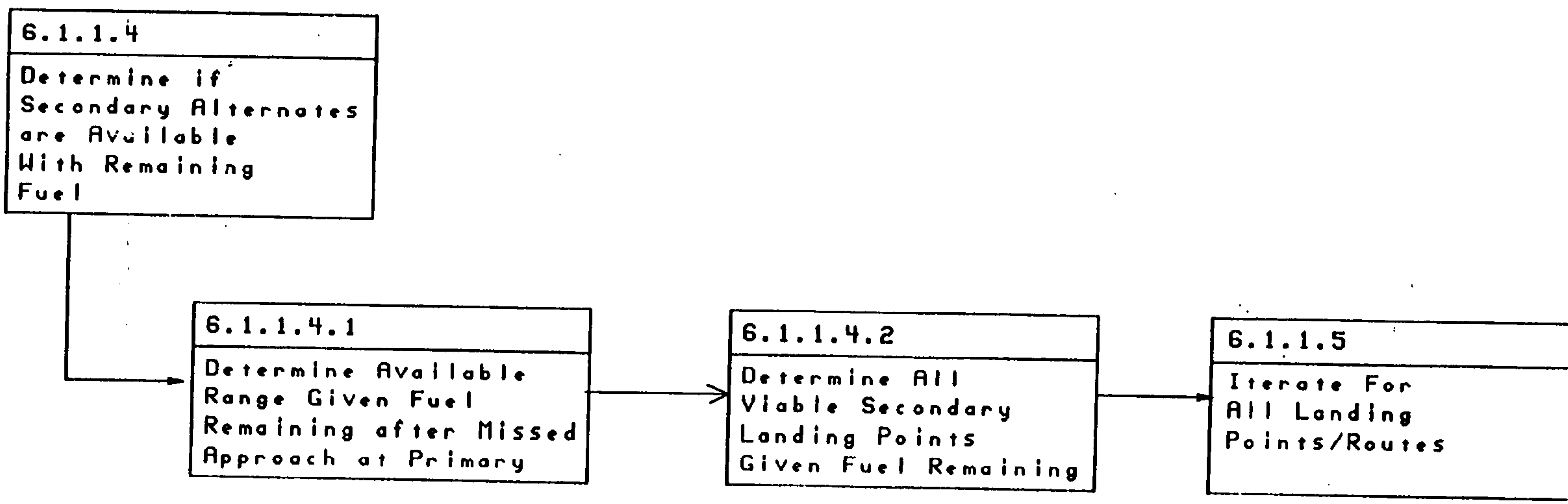

6.1
Landing Point Diversion
6.1.1
Determine Alternative Landing Points
6.1.2
Select Best Alternative Landing Point
6.1.3
Confer with A.T.C. and Company
OR
7.0
Execute Diversion

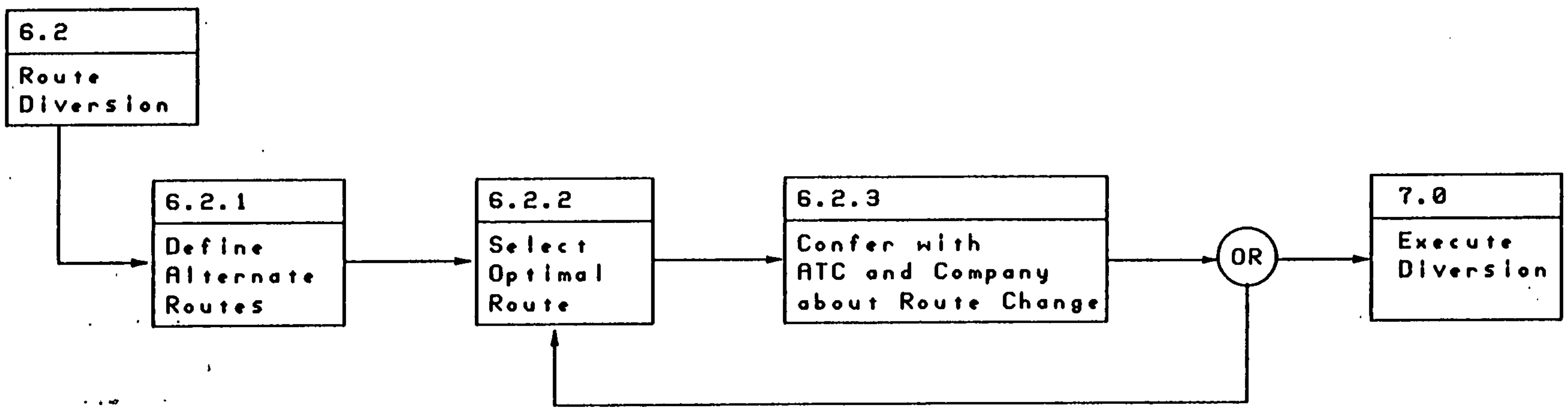

6.1.1
Determine Alternative Landing Points
6.1.1.1
Determine All Viable Landing Points in Acft. Operational Range
6.1.1.2
Determine Probable Route to Each Landing Point
OR
6.1.1.3
Assess Fuel Requirements Given Probable Route / Approach
6.1.1.4
Determine if Secondary Alts. are Available with Remaining fuel
6.1.1.5
Iterate For All Landing Points/Routes
OR
6.1.2
Select Best Alternative Landing Point

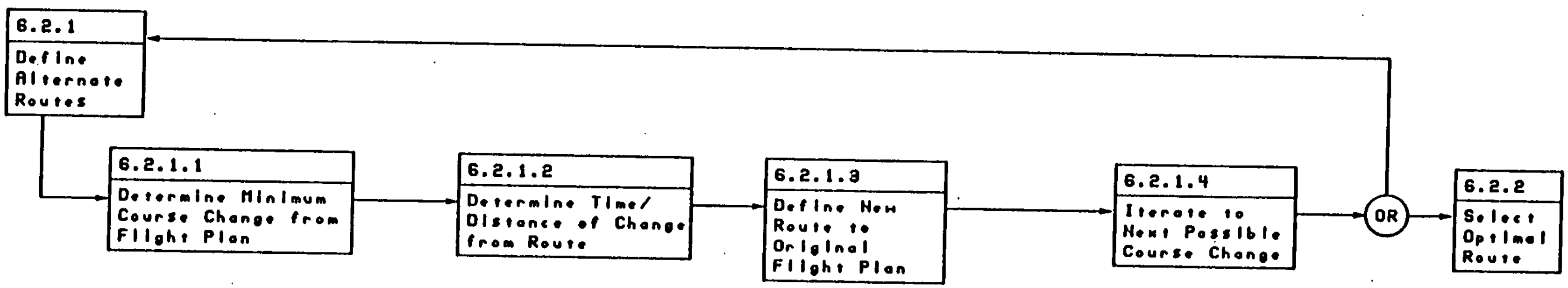

6.1.1.2
Determine Probable Route to Each Landing Point
6.1.1.2.1
Assume Direct Course To Each Alternate Landing Point
6.1.1.2.2
Determine Probable Descent (e.g. Normal or Emergency Let-Down)
6.1.1.2.3
Assess Route Viability
OR
6.1.1.3
Assess Fuel Requirements Given Probable Route / Approach
6.1.1.2.4
Revise Route
OR
6.1.1.5
Iterate For All Landing Points/Routes

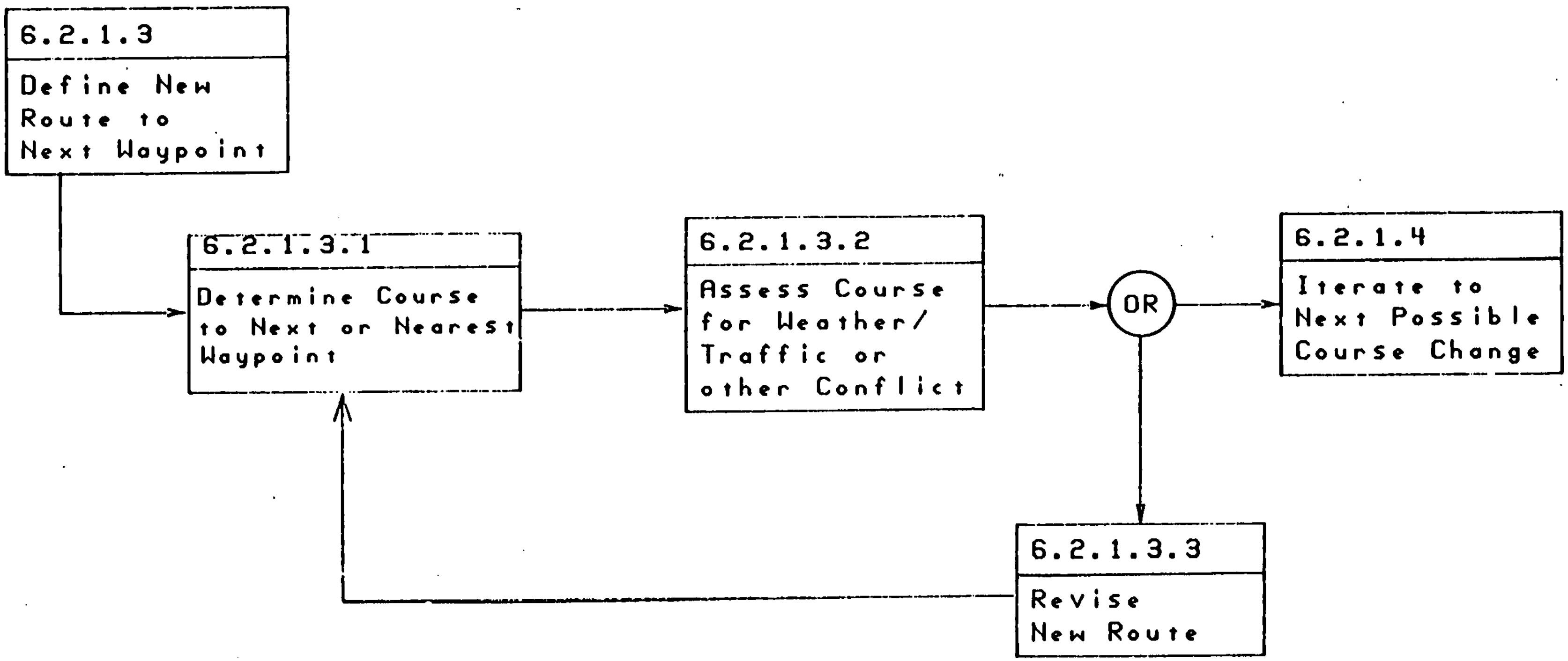

6.1.1.2.3
Assess Route Viability
6.1.1.2.3.1
Assess Possible Traffic Conflicts
6.1.1.2.3.2
Assess Possible Weather Conflicts
6.1.1.2.3.3
Assess Possible Terrain / Airspace Conflicts
AND
AND
6.1.1.2.3.4
Assess Route
OR
6.1.1.2.4
Revise Route
6.1.1.3
Assess Fuel Requirements Given Probable Route / Approach

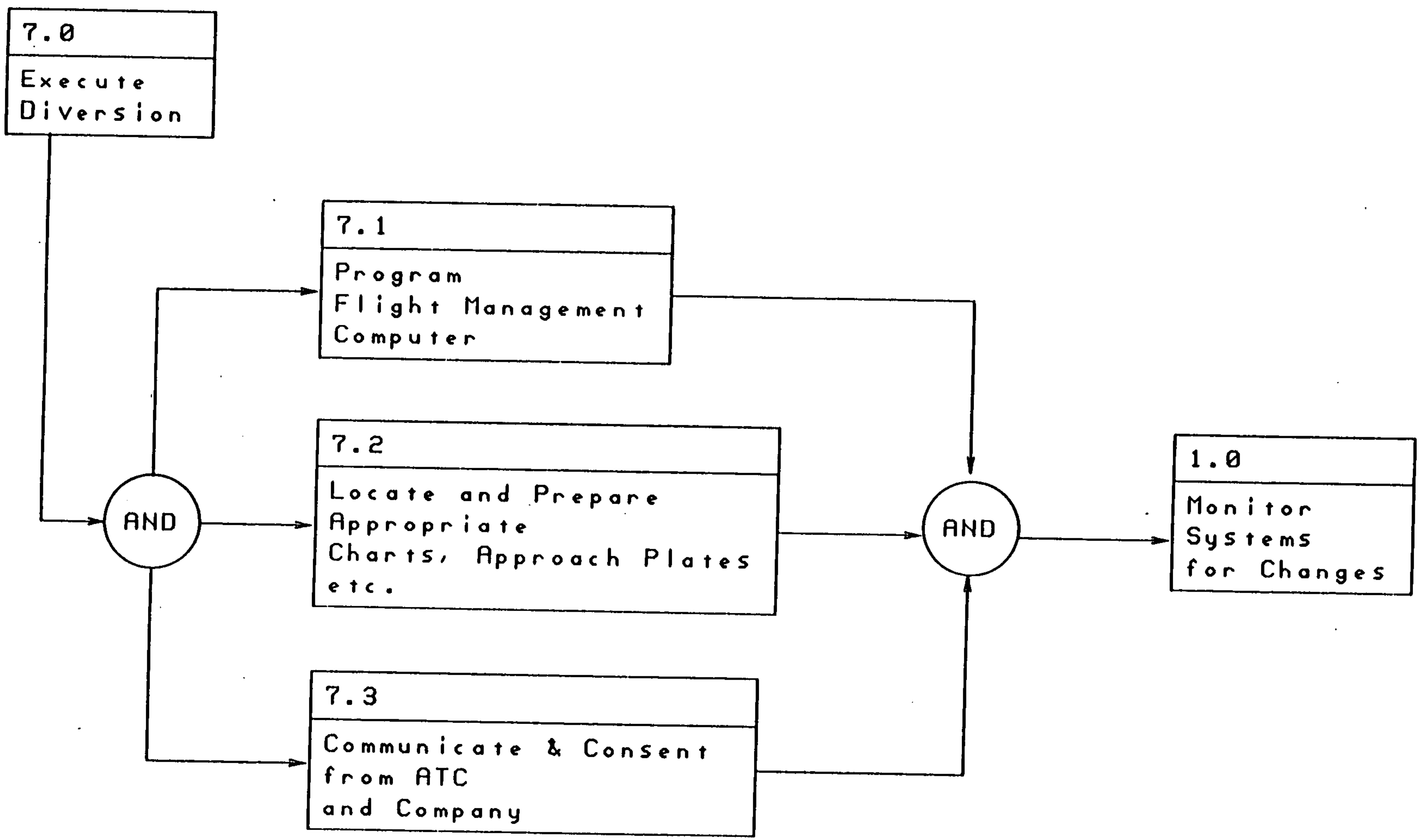

6.1.1.2.4
Revise Route
6.1.1.2.4.1
Make "Minimal" Route Change
6.1.1.2.4.2
Assess Revised Route
6.1.1.2.4.3
Iterate A Number of Times until Route Acceptible
OR
6.1.1.2.4.4
Accept Route for Alternate
6.1.1.2
Assess Fuel Requirements Given Probable Route / Approach
6.1.1.2.4.5
Abandon Alternate
6.1.1.5
Iterate For All Landing Points/Routes


6.1.1.4
Determine if Secondary Alternates are Available With Remaining Fuel
6.1.1.4.1
Determine Available Range Given Fuel Remaining after Missed Approach at Primary
6.1.1.4.2
Determine All Viable Secondary Landing Points Given Fuel Remaining
6.1.1.5
Iterate For All Landing Points/Routes


6.2
Route Diversion
6.2.1
Define Alternate Routes
6.2.2
Select Optimal Route
6.2.3
Confer with ATC and Company about Route Change
OR
7.0
Execute Diversion


6.2.1
Define Alternate Routes
6.2.1.1
Determine Minimum Course Change from Flight Plan
6.2.1.2
Determine Time/ Distance of Change from Route
6.2.1.3
Define New Route to Original Flight Plan
6.2.1.4
Iterate to Next Possible Course Change
OR
6.2.2
Select Optimal Route


6.2.1.3
Define New Route to Next Waypoint
6.2.1.3.1
Determine Course to Next or Nearest Waypoint
6.2.1.3.2
Assess Course for Weather/ Traffic or other Conflict
OR
6.2.1.4
Iterate to Next Possible Course Change
6.2.1.3.3
Revise New Route


7.0
Execute Diversion
AND
7.1
Program Flight Management Computer
7.2
Locate and Prepare Appropriate Charts, Approach Plates etc.
7.3
Communicate & Consent from ATC and Company
AND
1.0
Monitor Systems for Changes

APPENDIX B

Compilation of Relevant Operational Rules and Regulations

This appendix summarizes the set of aircraft operational rules and regulations relevent for use in Diverter. These rules were extracted from Federal Aviation Regulations (FARs), Airman Information Manual (AIM) and Air Traffic Procedure (ATP) documents. These rules represent both the instantiation of each specific rule as well as the logic of application of the rule base for diversion planning. The coding of these rules was complete in Phase III, however, their application was not complete. Limitations included the availability of instrument facilities & operational status, emergency facilities at the landing point, company communication or policy, direct routing, performance limitations, and altitude selection.

Assumptions:

1. Diverter will utilize a database that contains all relevant information about airport facilities. This will include pertinent information including but not limited to physical information about runways (i.e., length, width, load handling capabilities, surface type); approach lighting; navigation equipment associated with planned approach procedures; data relevant to instrument SID's, Stars, and general procedures (i.e., MCA, DH, MDA, locations of LOM, LMM, FAF, Visibility Requirements including that information relevant when components of the approach are inoperative.

2. The diverter database contains information about all possible landing points, navigation aids, airways, etc. It will NOT be designed only to include airports suitable for a given type of aircraft.

3. For the purposes of this diversion we are considering the scenario where weather precludes continuation of the flight to the originally planned landing point; therefore a landing point that is above minimums for the equipment available both on the aircraft and ground facilities is required. The scope of this begins with the decision that a landing point diversion is necessary. It is assumed that the weather has been assessed and that either a route diversion to avoid weather between the aircraft's current location and planned destination or a delay diversion to allow the weather at the destination to change and allow the planned destination to be used have been ruled out. These issues will be developed more fully in further functional discussions.

6.1 Landing Point Diversion

6.1.1 Determine Alternate Landing Points

6.1.1.1 Determine All Landing Points

- An overall delimiting factor for the selection will be that no landing point beyond 200 **Nautical Miles (NM)** from the current aircraft position at the Diversion point will be selected. It should be noted that alternate airport minimums require that the landing point be above the published minimums for the instrument approach to be used as well as above the alternate minimums if airport is used as a primary alternate. Further, an alternate to the primary destination must be designated if the ceiling and visibility at the primary alternate expected to be less than 2000 feet above the airport and 3 miles within 1 hour before or after estimated time of arrival (FAR 91.23). If an alternate is required, the aircraft must have sufficient fuel to fly for 45 minutes at normal cruising speed after executing a missed approach (FAR 91.23).

*** Note: For future development it might be more beneficial to consider the total fuel range and time, in the absence of any mechanical problems, in determining the radius or area from which to select an alternate. In particular it seems probable that many, if not most, diversions occur to airports that are more than 200 miles away from the decision to divert. ***

- For each of the following factors each landing point is assessed. If this assessment reveals that the landing point does not satisfy the any of these requirements, then the landing point is not feasible. If the landing point does satisfy these requirements, then it is ranked with all other airports.

A. Runway Attributes:

** (Note : this information comes primarily from FAR 135.229.

1. Runway Length

- IF a runway at the airport is not long enough to permit a full stop landing within (IF large transport category with reciprocating engine THEN 70% ELSE IF large transport category with jet engine THEN 60%) of the effective length of the runway given the expected runway pressure altitude, temperature, wind conditions, breaking action, and expected landing weight upon arrival THEN the runway is not suitable and will not be considered.

Repeat Until:

i. a suitable runway is found or
ii. no runways remain

IF no runways remain at the location THEN the airport is not acceptable.

- Ranking of runway length is based on the required length for operations at the particular landing point, the winds, temperature, and altitude. It is expected, given these parameters, that the required landing distance can be calculated for the landing point. A comparison is made between the distance required and the distance available. Since available distances less than the required distance will cause a parsing away of the landing point; these will not be considered here. However, if the runway available is longer, then rank all landing points based on the percentage extra runway available. This will have the effect of ranking those airports with longer runways higher than those with shorter runways but ranking will be based on the amount of runway required for the particular operation and not on some discrete amount. Once the rank is determined a weighting of the attribute can be made. See notes at the end of the document.

**(Note : This information from FAR 135.387).

**(Note: It is assumed that the Flight Navigation computer will determine the expected landing distance required. This will be based on the communication of information about forecast weather conditions such as temperature, wind speed, wind direction, dew point, etc. in conjunction with a database of aircraft performance materials and information about runway lengths, gradient, coating, etc. The end result of these calculations will be a number based on the expected conditions of the aircraft and landing point.)

**(Note: Consideration of landing points is to be made on a runway (termed Landing Point) by runway basis; not on an airport by airport facility basis. The reason for this is that the attributes of different landing points at the same airport can be considerable. Such a landing point comparison will allow a finer considerations of the suitability of the landing point.)

2. Runway Width

- IF the runway at an airport is not wide enough to permit landing THEN the runway is not suitable.

Repeat Until:

i. a suitable runway is found or
ii. no runways remain

IF no runways remain at the location THEN the airport is not acceptable.

- All landing points that satisfy the minimum requirements for runway width for safe operations will then be ranked on the basis of width. Once they are ranked a multiplier will be used to assess the importance of runway width in the computation of whether to use the landing point.

3. Runway Weight Bearing Capacity

- IF the weight bearing capacity of the runway is not sufficient to permit landing THEN the runway is not suitable.

Repeat Until:

i. a suitable runway is found or
ii. no runways remain

IF no runways remain at the location THEN the airport is not acceptable.

- This is a binary yes no decision and that is really all. The weight bearing capacity of runways and taxi / ramp locations must be suitable to the different conditions under which the aircraft would operate in that environment. For example, the runway must be sufficient to permit landing at the expected landing weight. Further, if the aircraft is to be refueled and additional passengers will be onboard, the aircraft will have a increased take off weight. The ramp and runways would have to be able to handle these weights. So, this really would not be used in any weighting scheme to determine whether one airport is more suitable than another.

4. Runway Surface Material

- IF the Runway Surface Type will not allow safe landing or will not comply with company requirements THEN the runway is not suitable.

Repeat Until

i. a suitable runway is found or
ii. no runways remain

IF no runways remain at the location THEN the airport is not acceptable.

- This will be a binary classification and will not have a direct impact on landing point selection. It will interact later in the weather section as a determinant in such selection.

5. Taxi-way and Ramp Bearing Capacity

- IF the weight bearing capacity of taxi and ramp areas is not sufficient for the aircraft given expected landing weight as well as normal take off weight THEN the airport is not suitable and will no longer be considered.

- In this case, this factor will be utilized on a binary basis. The ramp and taxiways must be of sufficient capacity to handle the expected load at landing weight, ramp weight and take off weight for the particular airplane. It really is not important in airport selection beyond parsing away those landing points that are not suitable.

** All of these conditions are required to be fulfilled for airport selection. In this way, these are binary (yes/no) decisions and not a rating scheme. The goal here is to evaluate landing points (at the runway level) at each airport in the divert area. Those that do not fulfill these rules are dropped on a 1 by 1 basis resulting in the removal of all runways that are not acceptable. Further, if no runway at a location is acceptable on all of these dimensions, then the entire airport is removed from consideration.**

B. Approach Attributes

1. Need for Instrument Approach

(Note: The goal of this section is to determine whether a landing may be completed under visual flight rules or that a landing must be made under instrument flight rules. It is assumed to some degree that an instrument approach will be necessary for a diversion due to weather factors. However, future scenarios where instruments fail would place greater emphasis on this determination.)

- IF airport is forecast to be under **Instrument flight rules (IFR)** at expected Time of Arrival AND has no published instrument approach procedure THEN is not acceptable and is removed from consideration.

- IF landing point is forecast (IFR) at expected time of arrival THEN IF (forecast Ceiling <= ceiling for approach procedure with the lowest minima) THEN landing point not acceptable.

Repeat Until

i. (Landing point Minima>=forecast Ceiling) or
ii. no landing points remain

- IF no runways remain THEN Airport is unsuitable and is removed from consideration.

**Sources of information are FAR 135.221, FAR 135.225, FAR 91.119.

- This factor could be utilized as a minimums section in both the ranking and selection of candidate diversion landing points. In this case, it might be best to rank the differences between the actual conditions and the minima for the field. Beyond this, there could be a separate ranking of both ceiling and visibility. Given these rankings, a multiplier could be applied to the sum of the ranking based on overall minimums or separate rankings could be applied to ceilings and visibility; thereby emphasizing differences in importance of these two attributes. In the case of a diversion due to weather, it is only important that the landing point is above minimums. In this case, the landing points could be ranked, however, the multiplier would be zero. Therefore, as long as the minima are met, the differences in conditions is unimportant. Conversely, in an emergency situation where differences in minima might be an important factor (or the important factor), the multiplier would be much higher; accentuating this importance in the final airport selection decision.

2. Aircraft Classification

A. Weight

- IF aircraft maximum Take Off (T.O.) weight >= 300,000 lbs THEN aircraft is heavy

- IF aircraft maximum T.O. weight > 12500 and < 300,000 THEN aircraft is large

- IF aircraft maximum T.O. weight <= 12500 lbs THEN aircraft is small

* from AIM glossary

B. Landing Speed

IF 1.3 Vso (at maximum landing weight) < 91 THEN Aircraft Approach Category A

IF 1.3 Vso >= 91 AND <121 kts THEN Category B

IF 1.3 Vso >= 121 and < 141 Kts THEN Category C

IF 1.3 Vso >= 141 and < 166 Kts THEN Category D

IF 1.3 Vso >= 166 THEN Category E.

3. Instrument Facilities Available & Operational Status:

** Often, the pilot might obtain information that certain components of the instrument landing system are not in operation. This information can come from **Notices to Airmen (Notams)**, **Flight Service Stations (FSS)**, **Air Traffic Control (ATC)**, Approach Plates, etc. The required parameters of the approach are determined by the equipment available. Therefore, if equipment is missing, the approach often will not have the normally published minimums, might not fulfill requirements for landing depending on the current meteorological conditions at the field, or might not be operative at all. **

- IF info from ATC, Notams, FSS, etc. indicates that all equipment required for use of an instrument approach procedure is totally inoperative and Instrument meteorological conditions exist at the landing point (see weather for criteria) THEN the landing point is unsuitable and is removed from consideration.

- IF some components of Instrument System are not operative THEN

-IF specific published minima for inoperative components THEN use minima specified by **inoperative component (Inop)**.
ELSE

-IF approach is **Instrument Landing System (ILS)**, **Microwave Landing System (MLS)** or **Precision Approach Radar (PAR)** THEN

IF Inop is **Middle Marker (MM)** and Category is a,b,c and NOT PAR THEN (Decision Height (DH) = DH + 50′)

IF Inop is MM and Category d and NOT PAR THEN (DH=DH+50') and (Visibility (Vis)= Vis+1/4 mi.)

IF Inop is **(Approach Lighting System 1 (ALSF1))** or **(ALSF 2)** or **(Medium Intensity Approach Lighting System with runway alignment (MALSR))** or **(Simplified Short Approach Lighting System with Runway Alignment (SSALR))** THEN (Vis=Vis+1/4mi.);

-IF approach is ILS and Visibility Minimum is 1800 to 2400' **Runway Visual Range (RVR)** THEN

IF Inop is MM and Category is a,b,c THEN (DH=DH+50) and Vis =2400' RVR;

IF Inop is MM and Category d THEN (DH=DH+50) and Vis = 4000' RVR;

IF Inop is ALSF 1 or ALSF 2 or MALSR or SSALF THEN VIS = 4000' RVR;

IF Inop is **Touch Down Zone Lighting (TDZL)** or **Runway Centerline Lighting System (RCLS)** THEN VIS =2400' RVR;

IF Inop Runway Visual Range System THEN Vis = 1/2 mile

- IF approach is **VOR (VHF Omni-directional Range)**, **VOR/DME (VOR with Distance Measuring Equip)**, **VORTAC (VOR with Tactical Air Navigation** [military uses tacan]), VOR(TAC), VOR/DME(TAC), **LOC (Localizer)**, LOC/DME, **SDF (Simplified Directional Facility)**, SDF/DME, **RNAV (Area Navigation)**, **ASR (Area Surveillance Radar)** THEN

IF Inop ALSF 1 or ALSF 2 or MALSR, or SSALR THEN Vis = Vis + 1/2 mile

IF Inop SSALS or MALS or ODALS and Category is A or b or c THEN Vis = Vis + 1/4 mile.

- IF approach is NDB (Non - Directional Beacon) THEN

IF Inop ALSF 1 or ALSF 2 or MALSR and Category is C Then Vis = Vis + 1/2 mile

IF Inop ALSF 1 or ALSF 2 or MALSR and Category is a or b or d Then Vis = Vis + 1/4 mile

IF Inop MALS or SSALS or ODALS and Category is a or b or c THEN Vis = Vis + 1/4 mile

- IF Inop Minimums > Forecast Landing Point Ceilings THEN the Landing Point is unsuitable and is removed for consideration and

Repeat Until

i. Inop minimums for Landing point < forecast Ceilings or

ii. no runways remain

- IF no runways remain then the airport is unsuitable and is removed from consideration

- IF Alternate Minimums for landing point THEN

IF Alternate Minimum > Forecast Ceilings at ETA THEN the landing point is not suitable and is removed from consideration.

Repeat Until

i. Alternate Minimum for landing point < forecast ceiling at ETA or

ii. no runways remain

IF no runways remain then the airport is unsuitable and is removed from consideration

IF Alternate Minimum AND Not Alternate Minimums not authorized due to facility being unmonitored or the absence of weather reporting service THEN landing point is not suitable and will not be considered.

- For this attribute, the importance of the availability and operation of equipment used in the approach would indirectly be determined by the minima associated with such facilities. However, this attribute could also be ranked based on the type of equipment available for the approach. In this case, if the equipment and published approach was a microwave landing system, then this type of approach would be preferred in favor of an ILS approach (assuming aircraft are equipped and equipment is operational so as to fully use the approach procedure) even if the both approaches had the same minima. The ranking order would be as follows:

TYPE OF APPROACH	RANK
Microwave Landing System	10
Instrument Landing System	9
Precision Approach Radar	8
VOR Approach	7
Localizer Approach	6
Area Navigation (RNAV)	5
Area Surveillance Approach	4
Non - Directional Beacon Approach	3

C. <u>Weather</u> <u>Criteria</u> at Landing Point

1. VFR Visibility / Cloud Separation Minima:

** Note: Information from FAR 91.105.

*** Note:What follows is a defining legal characteristics of VFR versus IFR flight. While it is realized that most landing point diversions due to weather will require instrument approaches; these definitions will allow for further parsing of the landing point database.***

- IF in Uncontrolled Airspace THEN:

IF (Altitude<1200' AGL (Above Ground Level)) THEN

IF (Visibility<1 statute mile) or NOT Clear of Clouds THEN IFR flight rules apply;

IF (Altitude>1200' AGL) and (Altitude<10,000' MSL Mean Sea Level)) THEN

IF (Visibility<1 statue mile(SM)) or NOT (500' below clouds) or (1000' above clouds) and (2000' horiz.) THEN IFR;

IF (Altitude>1200' AGL) and (Altitude>10,000' MSL) THEN

IF (Visibility < 5 SM) or NOT (1000' below) or (1000' above) and (1 SM Horiz.) THEN IFR;

- IF in Controlled Airspace THEN:

IF (Altitude<1200' AGL) THEN

qIF (visibility<3 SM) or NOT (500' below) or (1000' above) and (2000' horiz.) THEN IFR.

IF (Altitude > 1200' AGL) and (Altitude < 10,000 MSL) THEN

IF (Visibility<3 SM) or NOT (500' below) or (1000' Above) and (2000' horiz.) THEN IFR.

IF (Altitude > 10,000 MSL) THEN

IF (Visibility < 5 SM) or NOT (1000' below) or (1000' above) and (1 SM horiz.) THEN IFR.

2. Visibility

A. Conversion of Visibility to RVR

IF approach is not Category II (CAT II) or Category III (Cat III) AND RVR not reported THEN

- IF ground visibility = 1/4 SM THEN RVR = 1600 feet

- IF ground visibility = 1/2 SM THEN RVR = 2400 feet

- IF ground visibility = 5/8 SM THEN RVR = 3200 feet

- IF ground visibility = 3/4 SM THEN RVR = 4000 feet

- IF ground visibility = 7/8 SM THEN RVR = 4500 feet

- IF ground visibility = 1 SM THEN RVR = 5000 feet

- IF ground visibility = 1.25 SM THEN RVR = 6000 feet

from (FAR 91.116)

3. Weather at airport

a. Wind

- IF Surface Wind Speed and Direction exceed cross wind component of the aircraft OR IF wind Speed and Direction will not permit a safe landing THEN the landing point is not suitable and will not be considered.

Repeat For each landing point Until

i. Wind Speed / Direction < Maximum Cross Wind Component OR

ii. No landing points remain

IF no Landing Points THEN Airport is not suitable and will not be considered.

- In evaluating landing point, if the cross wind component is greater than the maximum stated for the aircraft the airport would be parsed away as unusable. However, this could be used in the selection criteria. In this case, the cross wind component could be calculated resulting in a vector. The vectors could then be ranked from low to high and given numbers (e.g., 10 for the lowest, 9 for the next lowest,...). This could then be weighted with a multiplier depending on its importance. Landing point selection could then utilize this information.

b. Low Level Turbulence

- IF low level turbulence is severe AND turbulence will not allow for a safe landing, THEN the airport is unsuitable and will not be considered.

- The level of forecast turbulence could be assigned a number. In this case

LEVEL OF TURBULENCE	RANKING NUMBER
None	10
Light	9
Moderate	8
Severe	7
Extreme	6

for each airport. The airports would then be ranked and a multiplier utilized in determining the importance of turbulence in landing point selection.

This overall ranking number could then have a multiplier attached indicating importance in landing point / airport selection.

c. Runway Surface Conditions

- IF landing point conditions due to rain, snow, ice will not permit a safe landing THEN the landing point is not suitable and will not be considered.

- This factor will interact with landing surface type (see runway attributes). This is the reason why landing surface type is merely a binary ranking while the effects of the interaction with weather factors creating a this attribute will be ranked to determine importance in landing point selection. The best measure for this would be from break action advisories or calculated breaking distance. In this case:☺

BREAK ACTION ADVISORY	RANKING NUMBER
No advisory	10
Good	9
Fair	8
Poor	7
Nil	6

Landing points would then be ranked based on the ranking of the break action advisory.

Again, multipliers could be utilized to reflect the importance of breaking action based on different types / needs for diversion.

Repeat for each landing point until

i. weather related runway conditions will permit a safe landing or

ii. no landing points remain

- IF no landing points remain THEN airport is unsuitable and will not be considered.

d. Runway Closure

- IF Notams, ATC, FSS, etc. advise a landing point is closed due to weather THEN the landing point is not suitable and will not be considered.

Repeat for each landing point Until

i. Non Closed landing point or

ii. No landing points remain

- IF No landing points remain then airport is unsuitable and will not be considered.

- This would only be utilized as a binary decision as to whether the airport or landing point is available. No weighting would be required or appropriate.

e. Wind Shear

- IF Notams, ATC, FSS, etc. advises severe wind shear conditions that would not permit a safe landing THEN the landing point is not suitable and will not be considered.

Repeat for each landing point Until

i. no wind shear detected or

ii. level or windshear would permit a safe approach

iii. no landing points remain

- IF no landing points remain THEN the airport is unsuitable and will not be considered.

- At this point in time the report of wind shear indicates where on the airport the windshear was reported and the effects on aircraft performance. Given this data, it would not really be possible to rank severity and choose a landing point based on this weather attribute. As such, it will only be used to parse landing points from the list of options. In the future, as recording technology increases and the attribute is assigned levels of intensity; this could become a selection criterion.

D. Air Traffic Control Directives

1. Traffic Directives

- IF ATC advises that traffic will not permit Landing THEN landing point and / or airport is unsuitable and will not be considered.

- IF ATC advises that the landing point is closed THEN the landing point is not suitable and will not be considered.

- IF ATC advises that the airport is closed THEN the airport is not suitable and will not be considered.

- IF airport is military and no permission THEN airport is unsuitable and will not be considered.

- IF airport has special operating hours AND NOT during operation period THEN airport unsuitable and will not be considered.

- This information is of a binary selection nature and would not be used in the ranking of landing points or airports.

E. Airport Facilities at Landing Point

1. Emergency Equipment

- IF Certified Fire and Rescue (CFR) does not meet aircraft size and weight standards or if CFR does not meet company standards THEN the airport is unsuitable and will not be considered.

- This could be quantified. There is a certain minimal level based on the types and sizes of aircraft using the facility. This could be utilized as a selection factor if the situation was an emergency which might require large amounts of such equipment. If this was the case, the ranking could be based on the difference between the actual equipment available and that required of the particular aircraft. For instance:

Aircraft Index *	Equipment Required	Difference
A	B	-2
AA	B	-1
B	B	+1
C	B	+2
D	B	+3
E	B	+4

* from Airport / Facility Directories.

In this case the negative numbers would indicate that the equipment level was not sufficient for the needs and that, if the level of preparedness is important that the airport is inadequate and should not be considered. The "1" for 'B - B' indicates that the level of equipment is adequate and that the airport can be considered. Any additional equipment would be beneficial. This weighting scheme does not reflect a deficit in facilities for larger aircraft requirements where there is not airport index beyond the maximum of 'E'. Still, it allows for ranking of equipment. Then each airport could be ranked based on these rankings of equipment and a multiplier could be used to increase the importance of any particular variable in airport selection. Since no emergency exists for a weather diversion, it would either be given no weight (0 multiplier) or minimal weight reflecting the need to have such equipment available "just in case".

2. Fuel, Oxygen & Maintenance

- IF fuel will be required for departure and flight to next destinations THEN IF type of fuel utilized is not available THEN the airport is unsuitable and will not be considered.

- IF Oxygen will be required for departure or if Oxygen will be required for continued flight and IF Oxygen is not available THEN the airport is unsuitable and will not be considered.

- IF Maintenance will be required for continued flight and Maintenance facilities not available THEN Airport is unsuitable and will not be considered.

- IF a Power Cart is required for aircraft restart AND Power Cart not available THEN airport Not suitable and will not be considered.

- The availability would determine if the airport is suitable or not. They could be quantified based on the number of attributes available. Rank the one with all of the above highest and give that a '10', the second '9', etc.; or perhaps maintenance manpower, etc. could be rated. Again, use a multiplier to determine the reflect importance during selection.

3. Passenger Facilities

- IF passenger terminal facilities are not available THEN airport is not suitable and will not be considered.

- IF nc hotel facilities exist within commuting distance OR IF no ground transportation is available THEN the airport is unsuitable and will not be considered.

- Again, this is a binary decision as to existence or not. A weight could be used based on that (10 of exist, 0 if they don't) to reflect importance in decision to select landing point. Conversely, ranking could be based on number of facilities (motels, hotels, restaurants, car rental, taxi, bus, limo,etc.) and distance from the airport terminal. In the hotel category, the number of rooms might be a quantification variable too. The individual facilities could use a multiplier to reflect their importance in the final figure (i.e., motels are initially multiplied by 10, taxi service 8, limo 2, ...). A total sum could then be calculated and a general weighting based on importance of this attribute in airport selection based on the weighted rankings. This, no doubt, will be an important variable as customer satisfaction is becoming increasingly important to airline management. On the other hand, if it is an emergency and it doesn't matter (i.e., the airplane is on fire, who cares if rooms are available) then a weighting of 0 could be applied removing this from consideration.

4. Gate Facilities

- IF No gate available, THEN airport not suitable and will not be considered.

- Airports could be ranked on the time expected delay times for a gate. In this case 10 would reflect the location with the least wait, 9 the next shortest wait,... A multiplier again could be used to reflect attribute importance in airport selection.

- IF No suitable stairs are available OR deplaning is not possible with gate facilities THEN landing point is not suitable and will not be considered.

F. Company Communication or Policy

- IF Company policy does not allow use of airport (unknown reason) OR if company policy does not allow use of approach procedure for landing point THEN landing point or airport is unsuitable and will not be considered.

**(Note : this could include considerations of landing fees, location of other aircraft and need to utilize current aircraft in further scheduling. It is assumed that this information would be from the company in the form of a "Don't use this airport because" statement that will be rated as to the nature of the cause and the urgency of the situation.

- IF Company does not have gate rights or reciprocity rights with another airline, THEN Consult with company.

    - weight this to help make decision for airport usage.

- IF Company response is no use THEN airport not suitable, dropped from consideration. (Pilot in command can over - ride this decision based on the circumstances).

- IF Crew complement required for continuation of flight and No crew available THEN Consult with Company

    - IF Company response is no use THEN airport not suitable, dropped from consideration.

- IF NO airline flight continuation reciprocity available THEN consult with company

    - IF Company response is no use THEN airport not suitable, dropped from consideration.

*** The goal of this section has been to parse any and all airfields from the list of those within the diversion operational area being considered. The goal is to reduce the number of airports to only those that would provide the level of serve needed for a landing point diversion due to weather factors. It is realized that if an emergency situation exists, if equipment in the aircraft has occurred, or if the flight is in a dangerous condition that another type of diversion would be followed and these considerations would be weighted to allow for inappropriate facilities but expeditious movement of the flight into a safe status.

6.1.1.2 Determine Probable Route to Each Landing Point.

**(Note: It is expected at this point that through Function 6.1.1.1 "Determine All Viable Landing Points in (200) NM Radius" a list of airports that would be appropriate for landing has be compiled and any airport from this analysis of facilities is suitable for continued consideration.

6.1.1.2.1 Assume Direct Course to Each Alternate Landing Point

It is assumed that for each viable landing point in a 200 NM radius of the aircraft, a direct route will first be considered. The major goal is to determine whether a direct routing to each of the selected landing points is possible. A direct route, over a short distance, minimizes fuel consumption and time to the destination. It would be the preferred route if its completion could be made in a safe manner.)

6.1.1.2.2 Determine Probable Descent (Normal or Emergency)

-IF NOT an emergency (would be defined in later definitions for emergency reasons for diversions) AND No ATC directive for emergency letdown THEN normal letdown.

-IF Emergency OR ATC directive for Emergency letdown THEN Emergency descent.

** Note - it is expected that the aircraft will be operated under normal flight conditions and not under acrobatic flight or in any way which would endanger the well-being of the aircraft or passengers contained therein. Drastic or extreme flight maneuvers must be minimized because they are unsafe.

6.1.1.2.3 Assess Route Viability

6.1.1.2.3.1 Assess Possible Traffic Conflicts

1. Enroute Traffic Conflicts

- IF enroute traffic will cause holds of greater than 60 Minutes OR (expected times in holds > time on fuel - 45 minutes) THEN Route not suitable and will not be considered.

- IF ATC directives will not permit usage of direct route due to traffic conflicts THEN

  - IF ATC will permit planned hold and continuation THEN route is suitable ELSE route is unsuitable and will not be considered.

6.1.1.2.3.2 Assess Possible Weather Conflicts

**(Note: It is expected that the flight is under, or may proceed under Instrument flight rules if necessary. As such, weather conditions concerning clouds and visibility are not important as they would have no bearing on the continuation of the flight. The following weather factors will be considered:)

1. Thunderstorms

**(Note: Most of this information came from the Airman's Information Manual, Paragraph 525.

- IF thunderstorm cells are expected be within 20 miles of the flight path preventing passage along a direct route unless flight continues into the thunderstorm THEN a direct route is not possible AND an indirect route circumnavigating the thunderstorms is required.

- IF thunderstorm cells are embedded in a cloud mass which is across or will be across the path if a direct route THEN an indirect route or different landing point should be utilized.

- IF on - board or ground weather radar detects strong radar echoes separated by less than 20 - 30 miles along proposed flight path THEN area is possibly extremely turbulent AND no direct course though this weather should be attempted.

- IF (Temp > -5 Celsius) AND (Temp < 5 Celsius) AND (Distance to Thunderstorm < 10 - 20 NM) THEN possibility of Lightning strike AND Flight should not continue in the area.

2. Severe Icing

- IF severe icing in clouds along route or in areas expected to be penetrated by direct navigation to landing point THEN an altitude with less icing should be utilized.

    - IF utilization of different altitude with less than moderate icing not available THEN flight though area should not be attempted AND direct route not feasible.

- IF no deicing equipment OR deicing equipment inoperative THEN navigation though areas of moderate to severe icing should not be attempted.

3. Severe Turbulence

- IF severe Turbulence OR Extreme Turbulence along direct route is forecast during flight though area THEN Indirect Route to avoid turbulence.

- IF turbulence is encountered OR Turbulence is forecast along route THEN airspeed should be reduced to the maximum maneuvering airspeed for turbulent conditions.

**(Note : This will have an effect on the cruise airspeed and also the time to destination and fuel used. Therefore, this factor should be considered in further flight planning.

4. Clear Air Turbulence (CAT)

- IF **Pilot Reports (Pireps)** Indicate Severe OR Extreme Clear Air Turbulence along route to landing point THEN indirect routing to avoid the area and altitude where CAT was experienced is suggested.

**(Note : It has been suggested that Clear Air Turbulence occurs primarily at altitudes in excess of 15000 feet.

5. Company Weather Directives

- IF company weather directives (company specific) do not permit operations into certain weather conditions AND these conditions are forecast along direct route THEN indirect routing.

  - IF indirect routing not possible THEN landing point not suitable and should not be considered.

6.1.1.2.3.3 Assess Possible Terrain / Aerospace Conflicts

1. Enroute Terrain Altitude Conflicts

- IF **Minimum Safe (Sector) Altitude (MSA)** > maximum altitude THEN route is not suitable and will be dropped from consideration. This is the minimum altitude for each sector that will ensure FAR part 91 obstacle clearance minima. This altitude is really for emergency purposes only and does not ensure navigational aid reception.

- IF **Minimum Obstacle Clearance Altitude (MOCA)** < Maximum performance altitude THEN route is not suitable and will be dropped from consideration.

- IF the approach or navigation is under radar control then the **Minimum Vectoring Altitude (MVA)** must be met. The MVA is the lowest Mean Sea Level (MSL) altitude which an IFR aircraft will be vectored by a radar controller. IF because of performance or weather factors the MVA cannot be attained THEN route is not suitable and will not be considered.

- IF the enroute navigation will require a hold THEN IF **Minimum Holding Altitude (MHA)** > Maximum altitude the aircraft can attain because of performance or weather THEN route is not suitable and will not be considered.

2. Enroute Airspace Conflicts

- Prohibited Airspace

  - IF direct route requires flight through prohibitive areas THEN route is not acceptable and will not be considered unless authorization has been granted by the using agency.

  **(Note : Special Use airspace is generally governed by the rules in FAR Part 71; 73.3, 73.13, 73.83.)

- Restricted Areas

  - IF direct route requires flight though restricted airspace during duration of restriction THEN route is not suitable and will not be considered unless prior authorization is given by using authority.

- Warning Areas

  - IF direct route requires flight through warning areas during the duration of the warning THEN the route is not suitable and will not be considered unless prior authorization is given by using authority.

  **(Note : Warning is the same as restricted airspace except that warning areas cannot be legally designated as restricted areas because they are over international waters.

- **Military Operations Areas (MOA)**

  IF direct route requires flight through MOA's AND IFR apply AND IF IFR separation can and will be provided by ATC THEN flight is permitted though the MOA ELSE route is not suitable and will not be considered.

  - IF direct route requires flight through MOA AND VFR AND in contact with controlling agency THEN overflight is permitted.

  - IF direct route requires flight through MOA and MOA NOT active THEN overflight permitted, route is viable.

- IF the direct route requires an **Minimum Crossing Altitude (MCA)** and the aircraft cannot attain that altitude because of weather or performance THEN that route is not suitable and will not be considered.

6.1.1.2.3.4 Assess Route

1. Navigation

- IF aids to navigation will allow for direct routing from current location to selected landing point THEN a direct route will be used.

** (Note : Most direct routing of aircraft utilizes VOR transmitters. Since these transmitters have a limited range, which depends on the type of facility and altitude of the aircraft, their usefulness can be defined by these parameters. Further, if they are not usable, then either RNAV, Loran, Inertial Navigation Systems or Radar Vectoring would have to be used to provide a direct routing.)

- IF VOR is Standard High Altitude Type AND

  - IF (Altitude > 1000') AND (Altitude < 14,500') AND (Distance from VOR < 40 NM) Then VOR Usable

  - IF (Altitude > 14500') AND (Altitude < 18,000') AND (Distance From VOR < 100 NM) THEN VOR Usable

  - IF (Altitude > 18000') AND (Altitude < 45000') AND (Distance From VOR < 130 NM) THEN VOR Usable

  - IF (Altitude > 45000') AND (Altitude < 60000') AND (Distance From VOR < 100 NM) THEN VOR Usable

- IF VOR is Standard Low Altitude Type AND

  - IF (Altitude > 1000') AND (Altitude < 18000') AND (Distance from VOR < 40 NM) THEN VOR Usable

- IF VOR is Terminal Type AND

    - IF (Altitude > 1000') AND (Altitude < 12000') And (Distance from VOR < 25 NM) THEN VOR Usable

- IF VOR Usable, THEN evaluate direct route for other conflicts ELSE

- IF **Loran C** available THEN enter position of landing point AND navigate direct to landing point.

    - IF Loran Navigation AND VOR at landing point THEN enter position of VOR AND navigate direct to VOR AND when VOR usable THEN utilize VOR.

    ** Note : The goal of utilizing loran is usually to navigate to a position where a VOR is usable as VOR is utilized extensively in an IFR approach.

- IF **Inertial Navigation System (INS)** available THEN enter position of landing point AND navigate direct to landing point.

- IF **Area Navigation (RNAV)** available THEN enter position of landing point AND navigate direct to landing point.

- IF Not VOR AND Not LORAN AND Not INS AND Not RNAV AND IF radar vectoring available THEN Request Radar Vectoring direct to landing point form ATC.

- IF Not VOR AND Not Loran AND Not INS AND Not RNAV AND Not Radar Vectoring THEN Direct Route not possible AND Indirect Route.

- IF using ground based Navigation aids (VOR) THEN IF aircraft cannot attain Minimum Enroute IFR Altitude (MEA) because of performance limitations or weather THEN the route is not suitable and will not be considered.

- IF no applicable minimum altitude is prescribed in FAR part 95 or 97, THEN

  - IF in designated mountainous areas THEN MEA = 2000' above the highest obstacle within a horizontal distance of 5 SM from planned course

  - IF other than mountainous areas THEN MEA = 1000' above the highest obstacle within a horizontal distance of 5 SM from planned course

  - Other authorization by ATC

2. Performance Limitations

- IF the aircraft cannot (attain altitude due to weather OR the effects of weather on performance OR aircraft performance limitations) OR (hold due to fuel requirements) OR (Cannot abide by any clearance required of the route) THEN the route is not feasible and will not be considered.

- IF weather, aircraft performance / status, ATC directives permit THEN the higher the altitude the greater the fuel economy.

- IF enroute winds at altitude enhance ground speed AND ATC clearance permits use of higher altitude AND aircraft performance enables higher altitudes AND gain by higher altitudes is not offset by time to climb or time to descend AND if maneuvering to altitude provides less 1 g maneuvering THEN Utilize higher altitude.

3. Altitude Selection

-IF Altitude < 18000 feet MSL then if 0 < magnetic course < 179, then cruise altitude = odd thousands, ELSE even thousands.

-Select an altitude that minimizes enroute time. This will be predicated on several factors including performance at altitude, climb and descent performance, winds at altitude, and fuel burn. Generally, increased altitude means reduced fuel burn. Winds tend to increase with altitude. IF a tail wind exists, this usually results in increased ground speed and reduced enroute time. However, the time to climb and descend must also be considered. If the proposed landing point is close to the point of diversion, it might be the case that the time saved by increased altitude and favorable winds is outweighed by time to climb and descend. For this reason, any calculation must include all of this information and a decision must be made to minimize the entire enroute time. So, once again, altitude is determined by time if no emergency exists, aircraft performance will allow operations at the selected altitude, weather permits usage of altitude, and other traffic at the altitude does not cause added delays.

- Selection of an altitude should also consider maximum airspeed permitted. IF aircraft altitude < 10000 feet MSL AND

IF aircraft not in airport traffic area THEN maximum airspeed >= 250 kts. (FAR 91.70)

IF aircraft has turbine power plant THEN

IF aircraft in airport traffic area THEN maximum airspeed <= 200 kts. (FAR 91.70)

IF aircraft has reciprocating power plant THEN

IF aircraft in airport traffic area THEN maximum airspeed <= 156 kts. (FAR 91.70)

- IF aircraft is turbine powered or large aircraft THEN minimum altitude >= 1500 AGL until further descent required for safe approach.

- IF Noise abatement procedures require minimum altitude AND Not Emergency THEN selected altitude >= Minimum noise abatement altitude.

- IF NO ATC assigned altitude and Aircraft in Airport Traffic area THEN selected altitude = pattern altitude until altitude decrease for safe descent for landing.

6.1.1.2.4 Revise Route

(Note: The major goal is to determine viable non - direct routes to the proposed landing points. It is assumed at this point that a direct route is not possible due to enroute weather, availability / status of navigation equipment, enroute terrain or airspace limitations, or performance limitations. Further, it is expected that there are several possible indirect routes to each landing point, each with it's own attributes and limitations. Therefore, the non - direct route will be evaluated by route segments. If a segment cannot be completed, the evaluation will look for other segment. If no other segments can be completed then the evaluation will retrace back one segment and evaluate alternatives. In this case, the task would be analogous to traversing a tree structure to get to a point.)

**(Note: A segment is defined as the minimum distance between two fixes, waypoints, intersections, or navigation aids.

6.1.1.2.4.1 Make "Minimal" Route Change

- Each possible route deviation from a direct route results in increased total distance and total time. Resultant increases in fuel used (and consequent cost), missed connections (and consequent customer dissatisfaction), flight time on the aircraft (and consequent maintenance), crew costs, etc. make the direct route the most advantageous if traffic and terrain considerations permit. If these do not, then the other available routes should be ranked on the basis of estimated time enroute and length of the route.

6.1.1.2.4.2 Assess Revised Route

The assessment of the revised route must consider the same variables as those pertinent for the previously discussed direct route. An assessment of each route segment should be made to determine the suitability of each segment.

1. Navigation

- IF navigation facilities will permit a direct flight between segment end points THEN segment is usable if other constraints do not apply.

**(Note: It is expected, due to the nature of segments, that this condition will most often be met.

- IF VOR is Standard High Altitude Type AND VOR's are end points of segment AND

    - IF (Altitude > 1000') AND (Altitude < 14,500') AND (Distance from VOR < 40 NM) OR (Half Segment Distance < 40 NM) Then VOR Usable AND Segment is usable

    - IF (Altitude > 14500') AND (Altitude < 18,000') AND (Distance From VOR < 100 NM) OR (Half Segment Distance < 100 NM) THEN VOR Usable AND Segment is Usable

    - IF (Altitude > 18000') AND (Altitude < 45000') AND (Distance From VOR < 130 NM) OR (Half Segment Distance < 130 NM) THEN VOR Usable AND Segment is Usable.

    - IF (Altitude > 45000') AND (Altitude < 60000') AND (Distance From VOR < 100 NM) OR (Half Segment Distance < 100 NM) THEN VOR Usable AND Segment is Usable.

- IF VOR is Standard Low Altitude Type AND VOR's are end points of segment AND

  - IF (Altitude > 1000') AND (Altitude < 18000') AND (Distance from VOR < 40 NM) OR (Half Segment Distance < 40 NM) THEN VOR Usable and Segment is Usable.

- IF VOR is Terminal Type AND VOR's are end points of segment AND

  - IF (Altitude > 1000') AND (Altitude < 12000') And (Distance from VOR < 25 NM) OR (Half Segment Distance < 25 NM) THEN VOR Usable and Segment is Usable.

- IF VOR Usable, THEN evaluate segment for other conflicts ELSE

  - IF **Loran C** available THEN enter position of next fix AND navigate direct to next fix.

    - IF Loran Navigation AND VOR is end point of segment THEN enter position of VOR AND navigate direct to VOR AND when VOR usable THEN utilize VOR.

    ** Note : The goal of utilizing loran is usually to navigate to a position where a VOR is usable as VOR is utilized extensively in an IFR approach.

  - IF **Inertial Navigation System (INS)** available THEN enter position of next fix AND navigate direct to next fix.

  - IF **Area Navigation (RNAV)** available THEN enter position of next fix AND navigate direct to next fix

  - IF Not VOR AND Not LORAN AND Not INS AND Not RNAV AND IF radar vectoring available THEN Request Radar Vectoring direct to next fix from ATC.

- IF Not VOR AND Not Loran AND Not INS AND Not RNAV AND Not Radar Vectoring THEN navigation along segment not possible

- IF using ground based Navigation aids (VOR) THEN IF aircraft cannot attain Minimum Enroute IFR Altitude (MEA) because of performance limitations or weather THEN the segment is not suitable and will not be considered.

- IF no applicable minimum altitude is prescribed in FAR part 95 or 97, THEN

    - IF in designated mountainous areas THEN MEA = 2000' above the highest obstacle within a horizontal distance of 5 SM from planned course

    - IF other than mountainous areas THEN MEA = 1000' above the highest obstacle within a horizontal distance of 5 SM from planned course

    - Other authorization by ATC

2. Enroute Weather Conflicts

A. Thunderstorms

**(Note: Most of this information came from the Airman's Information Manual, Paragraph 525

- IF thunderstorm Cells are expected to be within 20 miles of the flight path thereby preventing passage along segment unless flight continues into the thunderstorms THEN segment is not feasible and a different segment that circumvents the thunderstorms is required.

- IF thunderstorm cells are embedded in a cloud mass which is across or will be across the flight path during passage THEN segment is not feasible

- IF on - board or ground weather radar detects strong radar echoes separated by less than 20 - 30 miles along proposed segment flight path THEN area of segment is possibly extremely turbulent AND no direct course through this weather should be attempted AND segment is not feasible.

- IF (Temp > - 5 Celsius) AND (Temp < 5 Celsius) AND (Distance to Thunderstorms < 10 - 20 NM) THEN possibility of lightening strike AND flight should not continue into the area AND segment no feasible.

B. Severe Icing

- IF severe icing in clouds along route segment or in areas expected to be penetrated during navigation along segment THEN an altitude with less icing should be utilized

- IF utilization of different altitude with less than moderate icing not available THEN flight along segment should not be attempted AND segment not feasible.

- IF no deicing equipment OR deicing equipment inoperative THEN navigation through areas of moderate to severe icing along segment should not be attempted and segment not feasible.

C. Severe Turbulence

- IF severe Turbulence OR extreme Turbulence along segment OR forecast along segment during flight through the area THEN segment not viable AND choose segment to avoid turbulence.

- IF turbulence is encountered OR turbulence is forecast along route THEN airspeed should be reduced to the maximum maneuvering airspeed for turbulent conditions.

D. Clear Air Turbulence

- IF Pireps indicate severe or extreme clear air turbulence along the segment THEN segment not feasible and must select segment with no clear air turbulence.

E. Company Weather Directives

- IF company weather directives (company specific) do not permit operations into certain weather conditions AND these conditions are forecast along segment during flight THEN segment not feasible.

3. Enroute Terrain Conflicts

- IF MSA > Maximum altitude THEN segment is not suitable and will not be considered.

- IF MOCA > Maximum altitude THEN segment is not suitable and will not be considered.

- IF navigation is under radar control THEN altitude > MVA ELSE segment not feasible and will not be considered.

- IF enroute navigation during segment will require a hold THEN IF MHA > maximum altitude the aircraft can attain because of performance or weather then segment is not suitable and will not be considered.

4. Enroute Traffic Conflicts

-IF traffic along segment will cause holds so that total hold time is greater than 60 minutes for all segments OR expected time in holds exceeds endurance time minus 45 minutes THEN segment is not suitable and will not be considered.

-IF ATC directives will not permit usage of segment due to traffic conflicts THEN

-IF ATC will permit planned hold and continuation AND if revised planned holding time < 60 minutes AND total enroute time with holds < total endurance - 45 minutes) THEN segment is usable with hold ELSE segment is unsuitable and will not be considered

5. Enroute Airspace Conflicts

a. Prohibited Airspace

- IF segment requires flight through prohibitive areas THEN segment is not acceptable and will not be considered unless authorization has been granted by using agency.

b. Restricted Areas

- IF segment requires flight through restricted airspace during duration of restriction (from ATC, Charts, and Notams) THEN segment is not viable and will not be considered unless prior authorization has been secured.

c. Warning Areas

IF segment requires flight through warning areas during duration of warning THEN segment is not suitable and will not be considered unless prior authorization has been secured from using authority.

d. Military Operations Areas

- IF segment requires flight through MOA's and IFR apply AND IF IFR separation can or will be provided by ATC THEN flight along segment through MOA is permitted ELSE segment is not suitable and will not be considered.

- IF segment requires flight through MOA AND VFR AND in contact with controlling agency AND agency approval THEN overflight permitted and segment suitable.

- IF segment requires flight though MOA and MOA NOT active THEN overflight permitted and segment is viable.

- IF segment has MCA and aircraft cannot attain that altitude because of weather or performance limitations THEN segment is not suitable and will not be considered.

F. Performance Limitations

- IF the aircraft cannot (attain altitude due to weather OR the effects of weather on performance OR aircraft performance limitations) OR (hold due to fuel requirements) OR (Cannot abide by any clearance required of the segment) THEN the segment is not feasible and will not be considered.

6.1.1.2.4.3 Iterate a Number of Times until Route Acceptable

If a segment is found not to be suitable, then the segment should not be considered and the evaluation should consider other segments of the same level. Selection of successive segments should be made on the basis of minimal route change in terms of bearing and distance (6.1.1.2.4.1). If no segments are found to be suitable at a particular level, evaluation should be made of the next higher level. This evaluation, selection and backing up to a higher level segment will allow consideration of all suitable routes. If minimum distance and bearing deviation are used as ranking variables, such an evaluation will culminate in a ranked list of suitable routes.

(I consider the route selection process to be something like a tree structure. The point at which a diversion is required is the highest level. Successive segments form lower level branches. This is continued until a segment to the destination is determined. This same structure would work for the direct route as the route would be a single segment from diversion point to the selected landing point.)

Iteration should continue until all alternative routes have been ranked on the basis of distance and estimated time enroute.

6.1.1.2.4.4 Accept Route for Alternate

It is assumed at this point that there will be a ranked list of acceptable routes to the planned landing point. At this point, the highest ranking route will be selected, course will be transmitted to ATC and company for approval and will be presented to the pilot on the pertinent navigational display.

6.1.1.2.4.5 Abandon Alternate

IF no acceptable route to destination, then landing point is not suitable and will not be considered.

6.1.1.3 Assess Fuel Requirements for Routes / Approach

**(Note: It is assumed at this point that several alternates are available and one or more routes to each alternate can be utilized given weather, aircraft performance, and ATC directives.

1. Assess Fuel Requirements for direct route

- IF direct route, assess fuel required for navigation to and approach and landing at each landing point. Assessment should include weather consideration such as winds and temperature at altitudes. At this point, if fuel limitations are such that direct route to the landing point can not be completed within endurance - 45 minutes THEN the landing point is not suitable and will not be considered. (FAR 91.23)

- IF weather at landing point for at least 1 hour before and 1 hour after estimated time of arrival at landing point indicate that the ceiling will be at least 2000′ AGL AND visibility will be at least 3 miles THEN IF direct route to landing point can be completed within endurance limits the landing point is viable and can be considered. (FAR 91.23)

- If non - direct route, assess fuel requirements to complete route to landing point. IF fuel limitations are such that indirect route to landing point cannot be completed within endurance - 45 minutes THEN the route is not suitable and will not be considered. (FAR 91.23).

- IF weather at landing point for at least 1 hour before and 1 hour after estimated time of arrival at landing point indicate that the ceiling will be at least 2000′ AGL AND visibility will be at least 3 miles THEN IF direct route to landing point can be completed within endurance limits the landing point is viable and can be considered. (FAR 91.23)

- Calculate amount of fuel required to fly to each proposed divert destination then, subtract this amount from the total amount of fuel onboard. Calculate endurance based on current fuel flow to determine endurance range beyond planned diversion alternate.

**(Note: The goal here is to parse away any routes that are not within distances available given a certain level of endurance and fuel reserves. The goal here is to select routes that are feasible given fuel quantity available, fuel usage, and time to destination.

6.1.1.4 Determine IF Secondary Alternates are Available with Remaining Fuel

**(Note: The goal of this function is to determine if there are available alternates to the planned diversion alternate. Since the diversion alternate must be above minimums in order to be considered this evaluation might be considered somewhat unimportant. In the event of an unexpected change in weather or equipment status, however, this might have considerable impact.

6.1.1.4.1 Determine Available Range Given Fuel Remaining after Missed Approach at Primary

Range will be a function of the weight of the aircraft, fuel usage per hour, fuel quantity, selected power setting, aircraft performance (this might include airspeed in climb, missed approach procedure, ATC clearances, etc.) and weather criteria (winds, and perhaps temperature). Given the volatility of most of this information, range should first be calculated based on weight, remaining fuel available, and best economy fuel usage. Given this range, expressed in hours, only aircraft performance (as listed above) and weather will be considerations. Because this secondary is an alternate, 45 minute fuel reserve regulations would apply and the maximum range in hours would have to be decreased by 45 minutes to allow for this consideration. Calculation of ground speed based on power setting, aircraft performance, and weather (winds) will result in a maximum range, in nautical miles, around the planned landing point.

6.1.1.4.2 Determine all Viable Secondary Landing Points Given Fuel Remaining

This determination will be the same as the determination of alternate landing points (6.1.1). The previously discussed material would again be iterated for all landing points within the area defined by maximum range given fuel (see 6.1.1.4.1). The only exceptions will be the alternate weather minimums (see below).

- IF Alternate Minimums THEN use alternate minimums ELSE

    - IF Non-Precision Approach (NDB, VOR, LOC, TACAN, LDA, VORTAC, VOR/DME, or ASR) THEN

        i. Minimum Ceiling = 800' AGL AND
        ii. Minimum Visibility = 2 NM

- IF Precision Approach (ILS, PAR, MLS) THEN

  i. Minimum Ceiling = 600' AGL AND
  ii. Minimum Visibility = 2 NM

- FOR all possible landing points and routes iterate as was done in 6.1.1.2 to determine acceptable landing points, routing, and airport facilities AND assess fuel requirements to each (6.1.1.3).

- IF acceptable landing point and fuel endurance + 45 minutes THEN landing point is acceptable as an alternate to the diversion destination.

6.1.1.5 Iterate for all Landing Points / Routes

Inherent in the previous rules is the notion that all landing points within the 200 NM radius are to be considered. All of these rules must be iterated so as to complete several actions. First, all unsuitable landing points must be parsed from the list of possible landing points. Further, if all landing points at a particular location (airport) have been parsed, then the airport is unsuitable and should not be considered. In this way the parsing is from a specific to a global level. In a similar manner, all possible routes to the suitable landing points are evaluated and a parsing of these is done to reduce the list of routes to those that are suitable. If a suitable route to a landing point cannot be attained then the landing point is not considered and is parsed from the list. This parsing of a landing point due to route problems is probably not too common given the multiplicity of available routes but might be the case if equipment failure or traffic in conjunction with weather makes a route unsuitable. Again, the iteration is from specific to global.

Ranking of routes should be done on the basis of distance and estimated time enroute. Such variables will inherently include attributes of the routes such as traffic conflicts, planned ATC holds, etc., as such information will have been considered in 6.1.1.2.4.2. Once the routes are ranked, numbers can be attached to each ranking as per prior discussing, and an evaluation of the best route can be made

6.1.2 Select Best Alternative Landing Point

*(Note: This section is going to vary relative to factors affecting the situation. Any assessment here would be utilized to determine the multipliers to apply to the attributes already discussed. To a large degree they are going to rely on company policy and air traffic control restrictions. Safety issues should always be considered first. Facilities and routing are very important as the affect the type of approach available, certainty of approach completion, and overall safety. Economy will most likely be of utmost concern to companies but should not detract from the aforementioned variables. Included hereafter are some examples although I am unsure of the importance and weighting to be given.

**(Note: It is assumed at this point that the group of all landing points within the 200 NM operational radius have been parsed to include only those landing points with physical characteristics that would allow usage given the weather, those that have the required airport facilities and passenger accommodations, those that have weather expected to be above minimums for the published instrument approach procedure. In addition, each landing point has been assessed to determine whether there is a secondary alternate within fuel endurance range of the planned diversion point.

1. Distance and Estimated Time Enroute:

One of the major variables to consider is distance. It is assumed that the diversion due to weather is such that no emergency situations exist requiring rapid action to ensure safety of passengers. Further, the list of airports, given these assumptions, has been parsed to contain only those airports with runway and approach facilities to handle the aircraft, facilities to handle maintenance, fuel and other expendables requirements, terminal facilities to accommodate passengers and hotel accommodations, weather at or above published approach or alternate approach minima, enroute navigation facilities to allow safe navigation to the landing point, enroute weather that will allow safe navigation. As such, what is left to consider is distance and estimated time enroute. Weighting in the selection of landing points should minimize distance and estimated time enroute given the previously discussed constraints. It is further expected that the minimization of distance will minimize time enroute, and hence fuel used.

2. Secondary Alternate

If the assumed that the weather at the proposed diversion landing point is forecast to be within 100' ceiling and 1/4 SM visibility at expected time of arrival AND ceiling and visibility are decreasing so at a rate that within 1 hour after expected time of arrival the destination would or could be below minimums, THEN a primary diversion point with a secondary alternate available within the maximum endurance distance for the expected fuel to be remaining at primary landing point ETA would be selected in place of the a primary airfield that is closer but with no secondary alternate. In this case, then, having a secondary to the primary diversion landing point will be more important than distance as a single variable. Therefore, weighting should emphasize both secondary distances and primary distances, especially if it is possible that the primary diversion could go below minimums.

IF several primary diversion landing points are available after parsing, each with a suitable secondary landing point and weather within the above mentioned criteria, THEN select the landing point with the minimum distance to both primary and secondary landing points.

3. Approach Type

It is assumed that the landing points available are above published instrument minima.

- Weigh landing points with precision approach procedures higher than approaches with non precision procedures.

- IF weather at minima THEN weigh MLS > ILS > PAR

4. Airfield Condition

- IF landing point is free from snow, slush, or rain THEN weigh landing point greater THAN if snow, slush, or rain.

5. Facilities

- IF facilities for connections with further flights to original destinations THEN weigh this factor greater than if no such facilities (other airlines or same airline with other flights)

- IF Accommodations are greater at one landing point AND probability of extended layover due to weather THEN weigh those with accommodations greater than those with none.

6.1.3 Confer with ATC and Company

-IF ATC does not authorize route or landing point, THEN route or landing point not suitable and will not be considered. The landing point or route with the next highest rank will be considered and all pertinent information will be transmitted to ATC and Company.

-Since pilot in command is directly responsible for , and the the final authority as to the operation of the aircraft, it is his decision to utilize a route or landing point. IF safety dictate such a use THEN pilot may utilize landing point even if ATC does not authorize usage. However, since the diversion under consideration is not an emergency, pilot should follow ATC authorizations. (FAR 91.4)

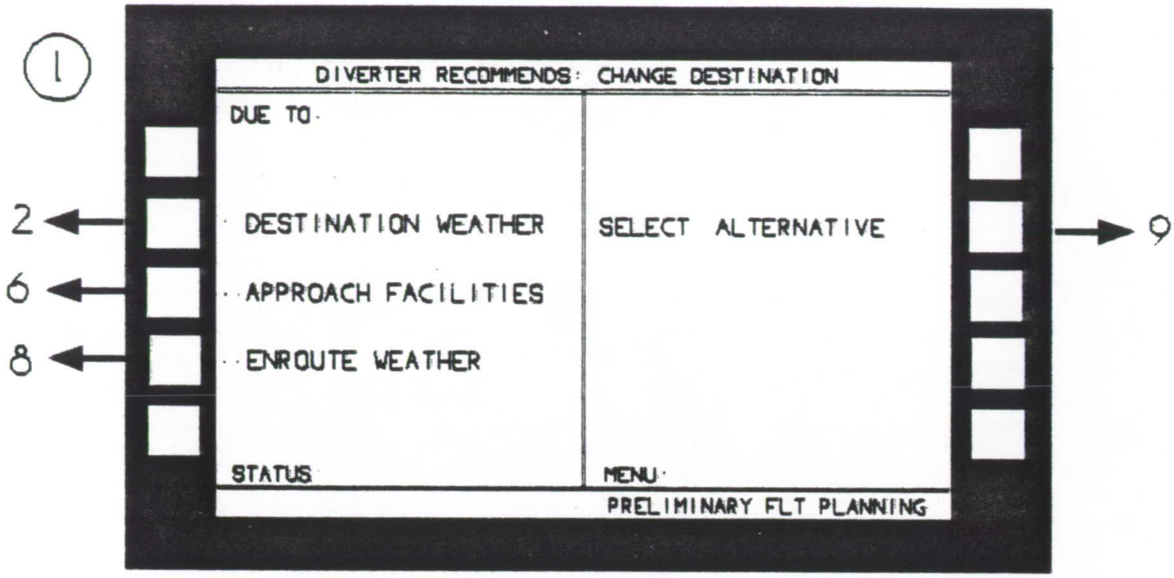
-Since pilot in command has final decision, IF company does not authorize route or landing point AND emergency (or pilots feels action is warranted to effect safe continuation of the flight), THEN landing point or route may be used. Again, this is not an emergency diversion so such usage of non - authorized routes or landing points would be unlikely.

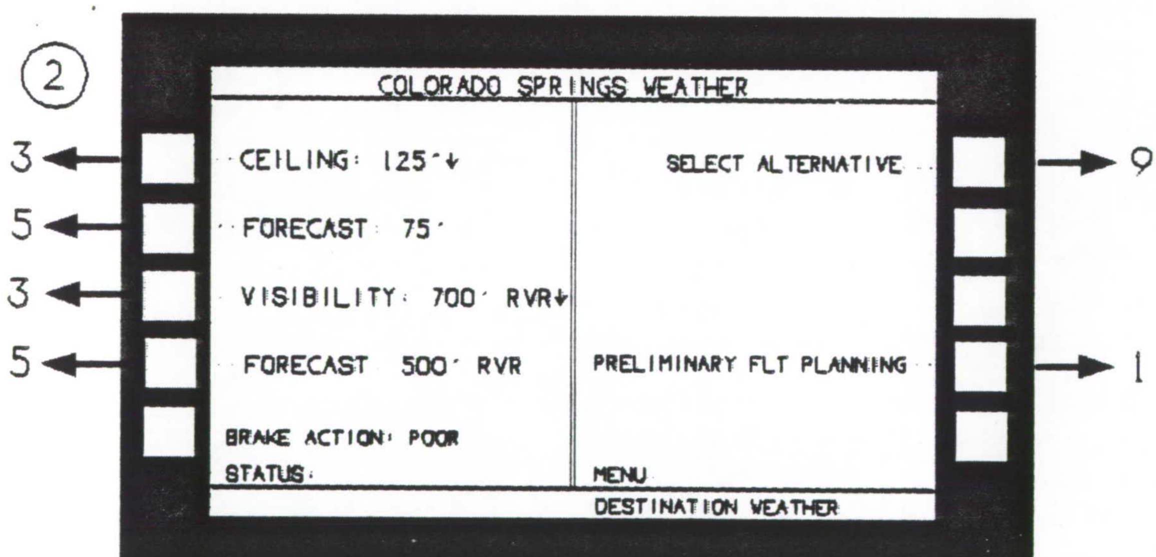
Basically, the idea here is that the pilot in command is responsible for his aircraft and the safety of his passengers. All final decisions rest with the pilot in command. Diverter is assumed to be only a decision aid, with ultimate selection of landing points or routes lying with the pilot. Further, ATC authorizations may not be adhered to if the pilot feels that such adherence would be detrimental to the safety of the flight. Finally, the same considerations exist with respect to company policy or authorizations. Beyond this responsibility lying with the pilot, if alternate is not acceptable to ATC or company AND pilot agrees, THEN select landing point and route with the next highest ranking (6.1.2).

APPENDIX C

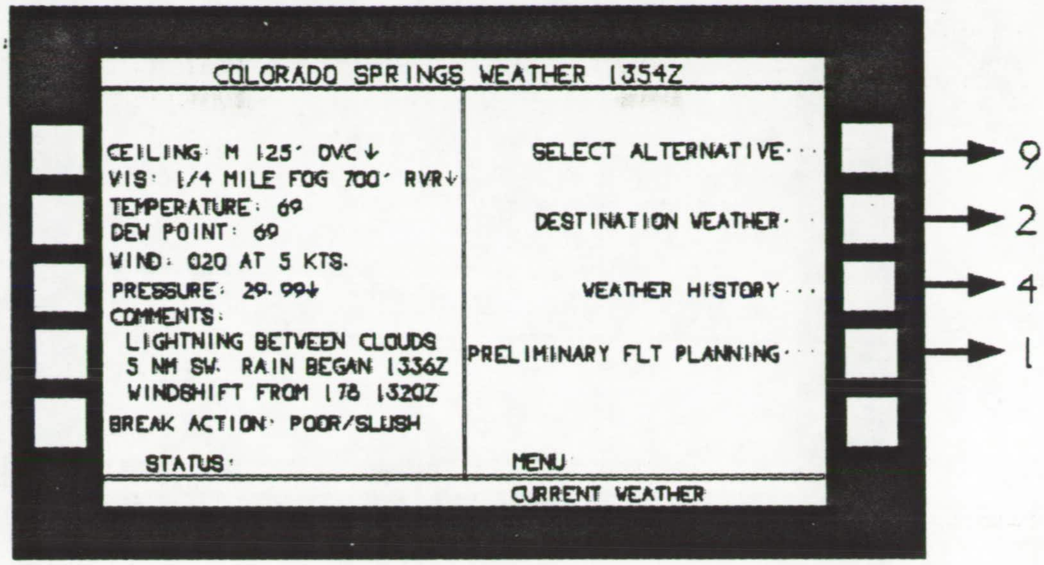
Pilot-Vehicle Interface CDU Display Formats and Logic

The appendix illustrates the Pilot-Vehicle Interface (PVI) CDU display formats. The illustrations also provide information about system logic for manipulation of information presented on displays as well as system control. The logic tree for operation of the CDU is quite extensive with numerous routes and loops. It was not feasible, therefore, to present it as one figure. In order to allow the reader to follow the logic, a system of numbering the display page formats was developed. The format page being viewed corresponds to the circled number at the upper left corner of each page. The numbers adjacent to the arrows and line switches indicate the display format that would appear if that line switch is pressed.

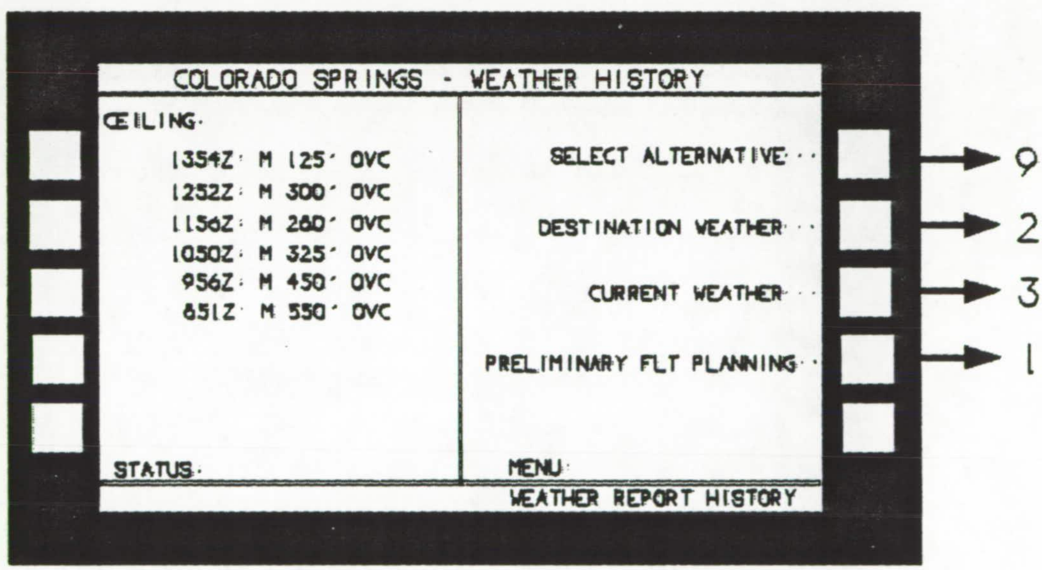

1
DIVERTER RECOMMENDS: CHANGE DESTINATION
DUE TO:
DESTINATION WEATHER
APPROACH FACILITIES
ENROUTE WEATHER
SELECT ALTERNATIVE
STATUS:
MENU:
PRELIMINARY FLT PLANNING
2
6
8
9


2
COLORADO SPRINGS WEATHER
CEILING: 125'↓
FORECAST: 75'
VISIBILITY: 700' RVR↓
FORECAST 500' RVR
BRAKE ACTION: POOR
STATUS:
SELECT ALTERNATIVE
PRELIMINARY FLT PLANNING
MENU
DESTINATION WEATHER
3
5
3
5
9
1

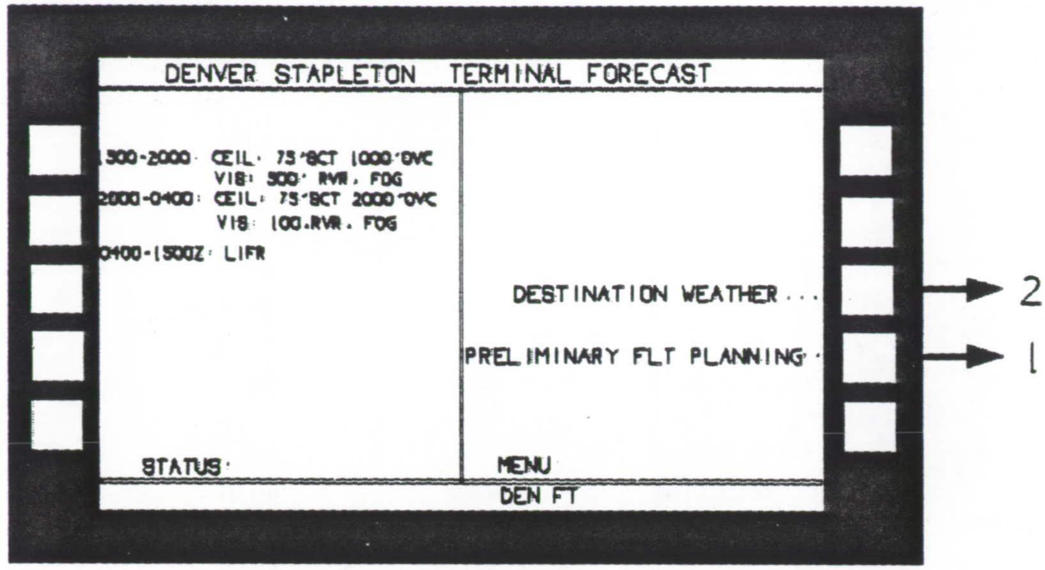
3


COLORADO SPRINGS WEATHER 1354Z
CEILING: M 125' OVC↓
VIS: 1/4 MILE FOG 700' RVR↓
TEMPERATURE: 69
DEW POINT: 69
WIND: 020 AT 5 KTS.
PRESSURE: 29.99↓
COMMENTS:
LIGHTNING BETWEEN CLOUDS
5 NM SW. RAIN BEGAN 1336Z
WINDSHIFT FROM 178 1320Z
BREAK ACTION: POOR/SLUSH
STATUS:
SELECT ALTERNATIVE···
DESTINATION WEATHER··
WEATHER HISTORY···
PRELIMINARY FLT PLANNING···
MENU:
CURRENT WEATHER
9
2
4
1

4

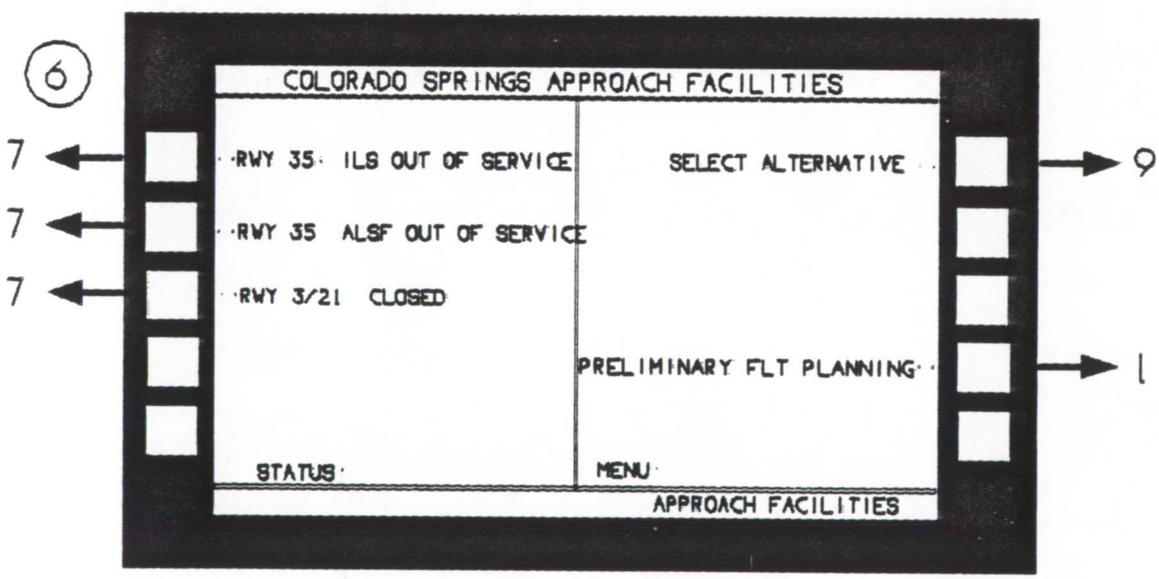

COLORADO SPRINGS - WEATHER HISTORY
CEILING:
1354Z: M 125' OVC
1252Z: M 300' OVC
1156Z: M 280' OVC
1050Z: M 325' OVC
956Z: M 450' OVC
851Z: M 550' OVC
STATUS:
SELECT ALTERNATIVE··
DESTINATION WEATHER··
CURRENT WEATHER··
PRELIMINARY FLT PLANNING··
MENU:
WEATHER REPORT HISTORY
9
2
3
1

5



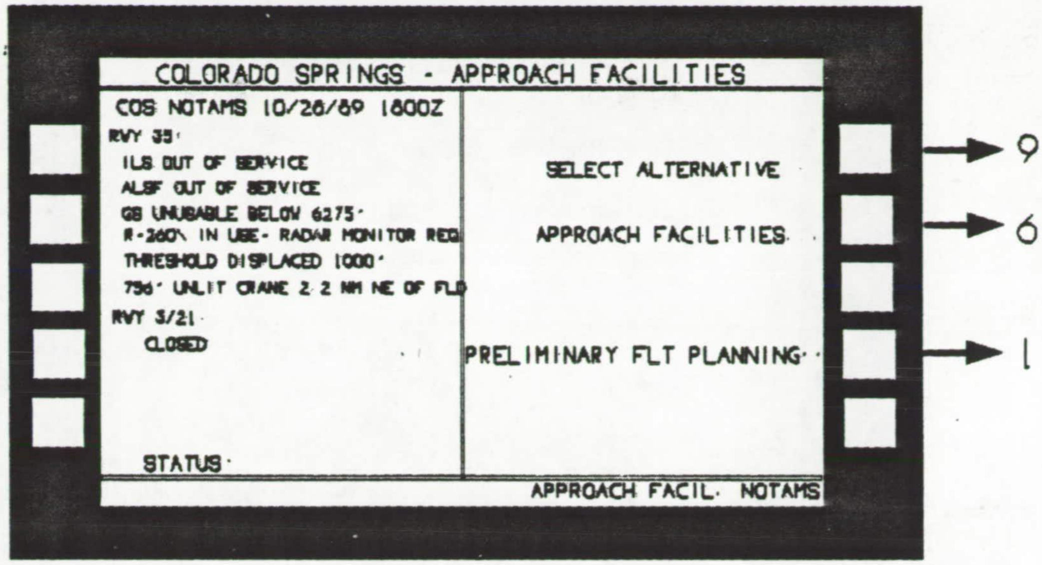
DENVER STAPLETON TERMINAL FORECAST
1300-2000: CEIL: 75'SCT 1000'OVC
VIS: 500' RVR, FOG
2000-0400: CEIL: 75'SCT 2000'OVC
VIS: 100.RVR, FOG
0400-1500Z: LIFR
DESTINATION WEATHER...
PRELIMINARY FLT PLANNING
STATUS
MENU
DEN FT
2
1

6

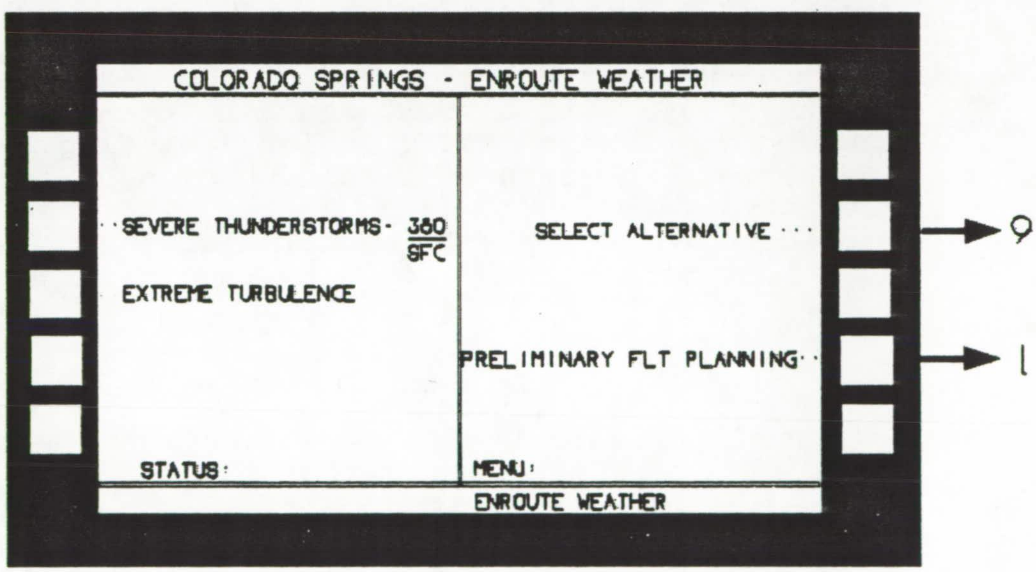


COLORADO SPRINGS APPROACH FACILITIES
RWY 35 ILS OUT OF SERVICE
RWY 35 ALSF OUT OF SERVICE
RWY 3/21 CLOSED
SELECT ALTERNATIVE
PRELIMINARY FLT PLANNING
STATUS
MENU
APPROACH FACILITIES
7
7
7
9
1

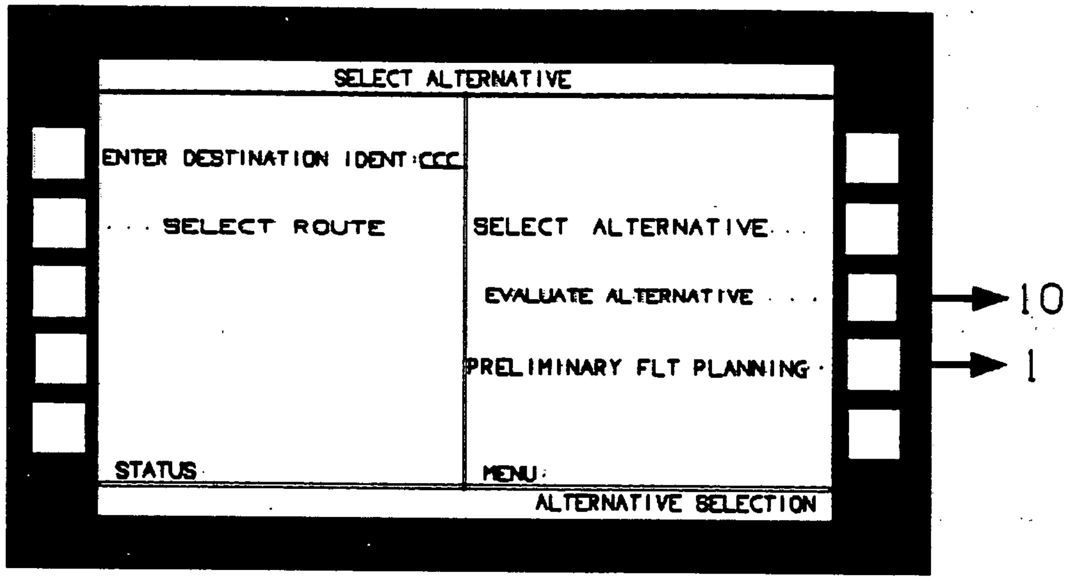
7


COLORADO SPRINGS - APPROACH FACILITIES
COS NOTAMS 10/26/89 1800Z
RWY 35:
ILS OUT OF SERVICE
ALSF OUT OF SERVICE
GS UNUSABLE BELOW 6275'
R-260\ IN USE- RADAR MONITOR REQ
THRESHOLD DISPLACED 1000'
756' UNLIT CRANE 2.2 NM NE OF FLD
RWY 3/21:
CLOSED
STATUS:
SELECT ALTERNATIVE
APPROACH FACILITIES
PRELIMINARY FLT PLANNING
APPROACH FACIL. NOTAMS
9
6
1

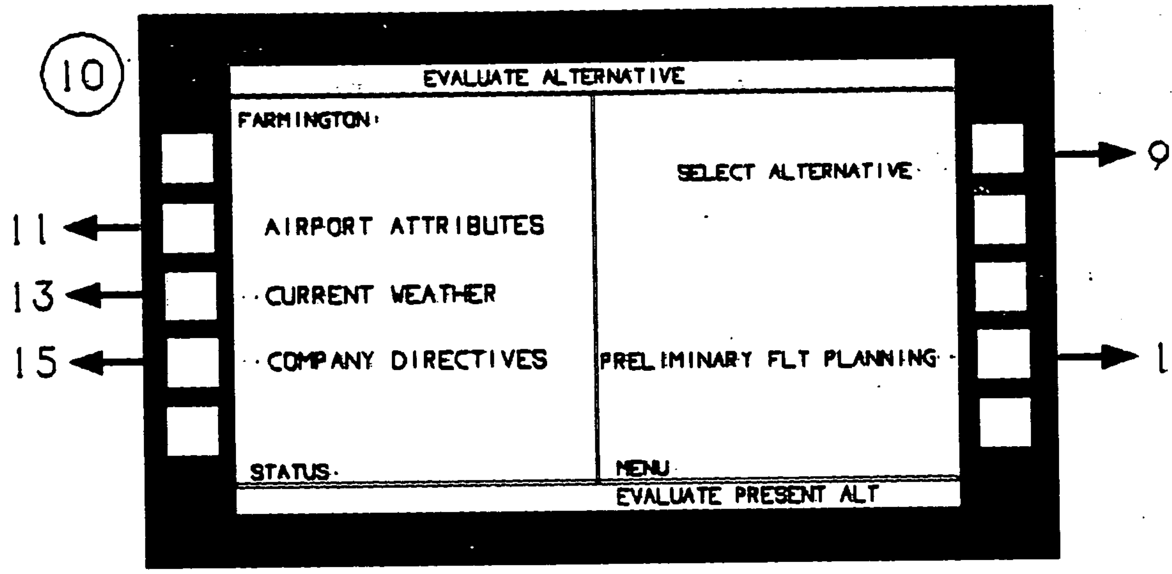
8

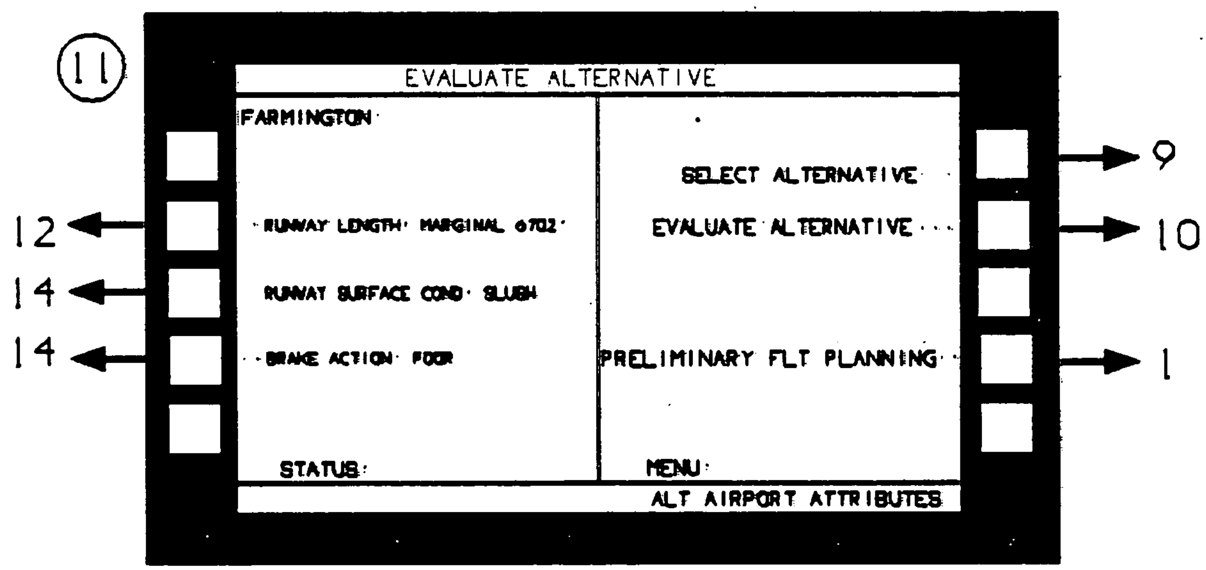

COLORADO SPRINGS - ENROUTE WEATHER
SEVERE THUNDERSTORMS- 380/SFC
EXTREME TURBULENCE
STATUS:
SELECT ALTERNATIVE
PRELIMINARY FLT PLANNING
MENU:
ENROUTE WEATHER
9
1

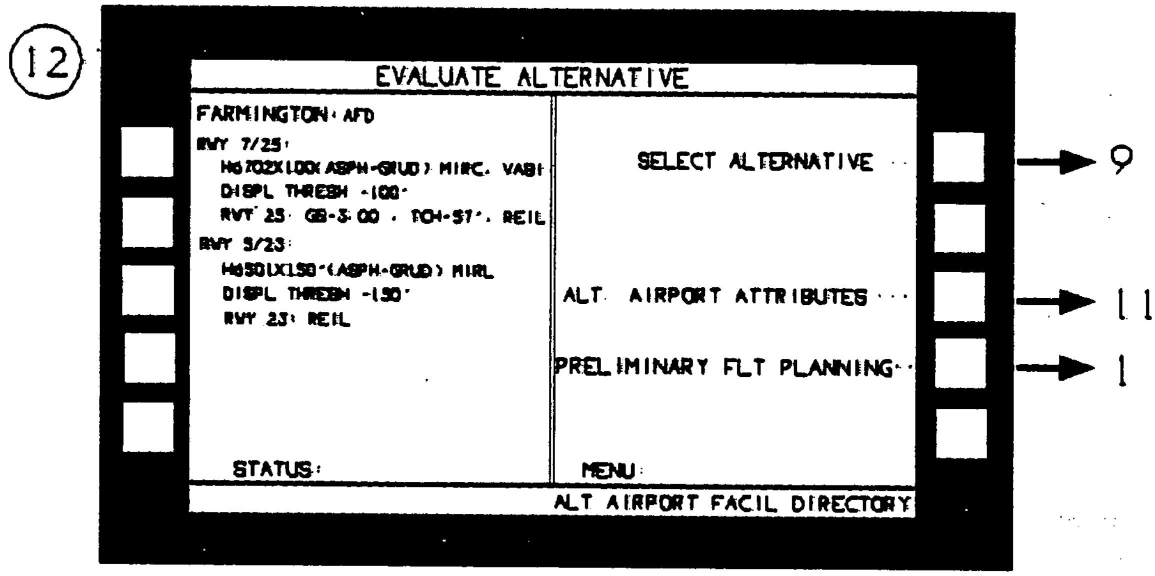
9

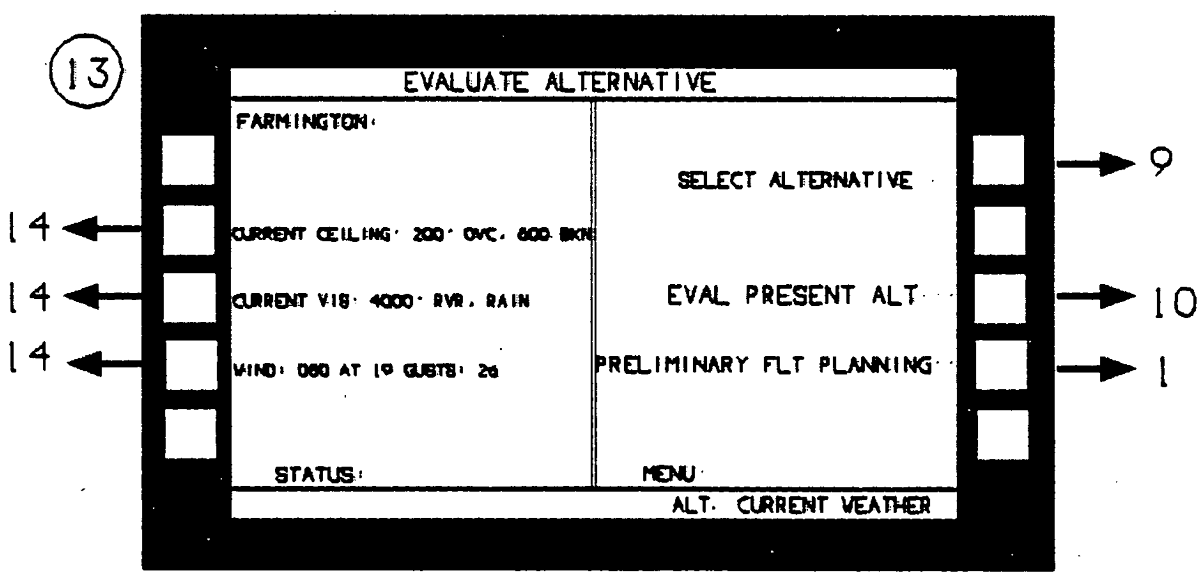


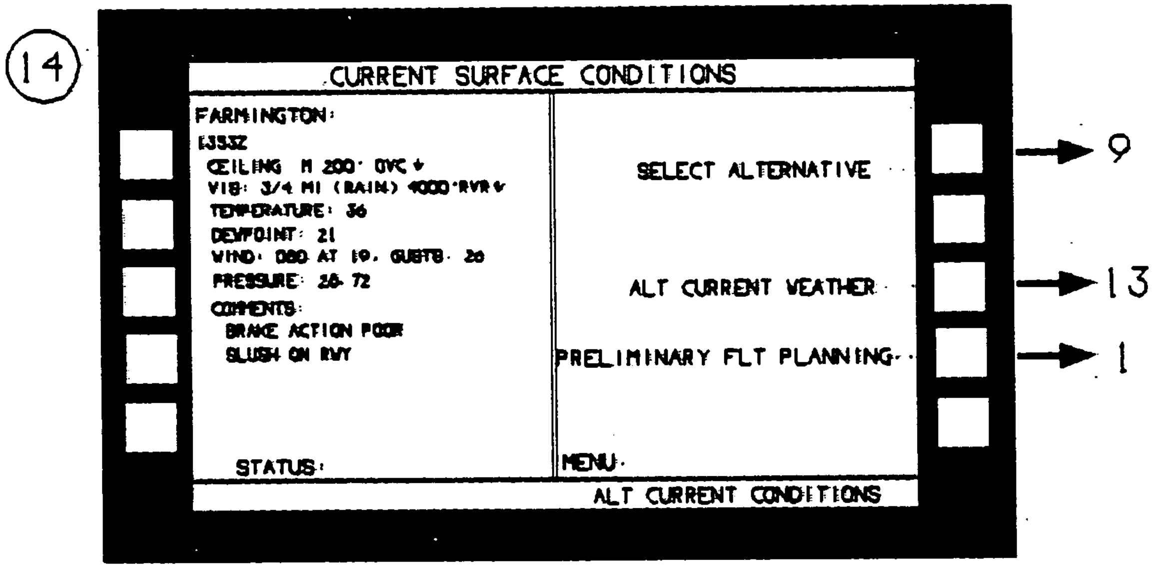
9 When entering information defining the selection of an alternative destination and route, the pilot would press the button next to "enter destination ident". This would change the function of the Diverter moving map display to provide direct input through its touch screen. Upon touching a destination point, the point would change color to magenta and the three letter identifier would be entered in the field are next to "enter destination ident". This button would again be pressed, thereby confirming the selection, entering the identifier, and returning the function of the moving map display to output only. The same procedure would apply to route selection. In addition, either entry could be made via the CDU.


10
EVALUATE ALTERNATIVE
FARMINGTON
AIRPORT ATTRIBUTES
CURRENT WEATHER
COMPANY DIRECTIVES
STATUS
SELECT ALTERNATIVE
PRELIMINARY FLT PLANNING
MENU
EVALUATE PRESENT ALT
11
13
15
9
1

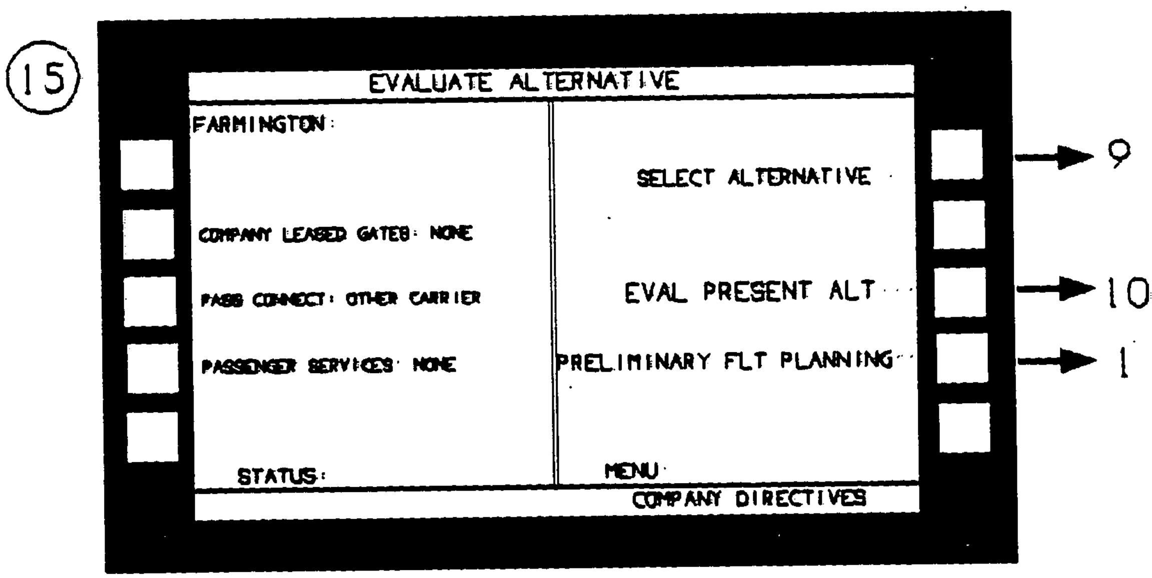

11
EVALUATE ALTERNATIVE
FARMINGTON
RUNWAY LENGTH: MARGINAL 6702
RUNWAY SURFACE COND: SLUSH
BRAKE ACTION: POOR
STATUS
SELECT ALTERNATIVE
EVALUATE ALTERNATIVE
PRELIMINARY FLT PLANNING
MENU
ALT AIRPORT ATTRIBUTES
12
14
14
9
10
1


12
EVALUATE ALTERNATIVE
FARMINGTON: AFD
RWY 7/25:
DISPL THRESH -100'
RWY 5/23:
DISPL THRESH -150'
RWY 23: REIL
STATUS:
SELECT ALTERNATIVE
ALT AIRPORT ATTRIBUTES
PRELIMINARY FLT PLANNING
MENU:
ALT AIRPORT FACIL DIRECTORY
9
11
1


13
EVALUATE ALTERNATIVE
FARMINGTON:
CURRENT CEILING: 200' OVC, 600 BKN
CURRENT VIS: 4000' RVR, RAIN
WIND: 060 AT 19 GUSTS: 26
STATUS:
SELECT ALTERNATIVE
EVAL PRESENT ALT
PRELIMINARY FLT PLANNING
MENU:
ALT. CURRENT WEATHER
14
14
14
9
10
1

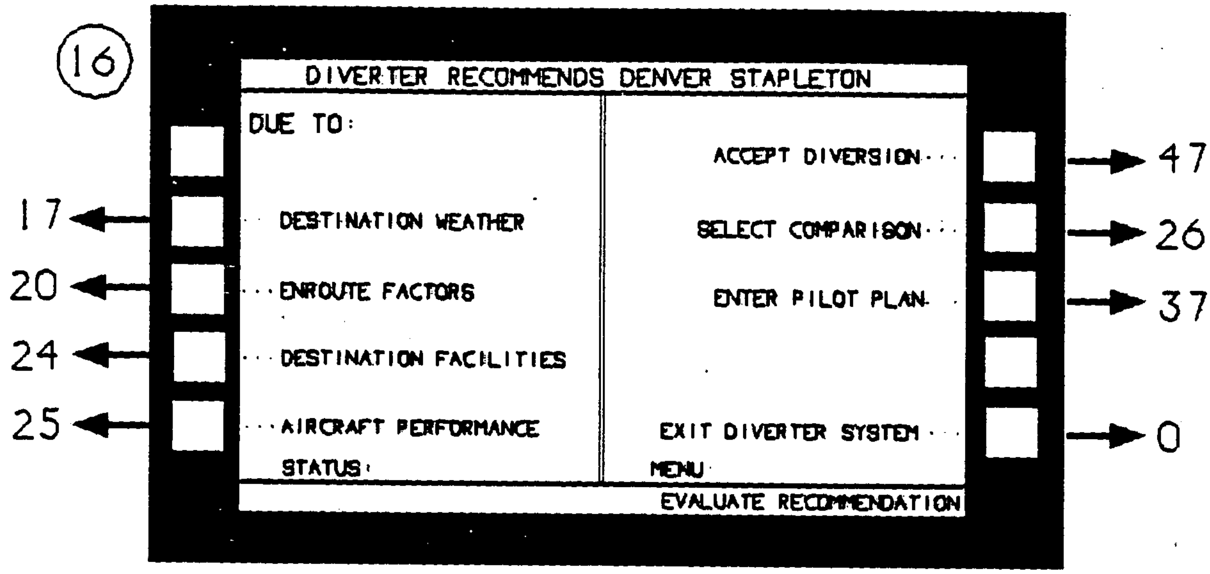


14
CURRENT SURFACE CONDITIONS
FARMINGTON:
1353Z
CEILING M 200' OVC
VIS: 3/4 MI (RAIN) 4000'RVR
TEMPERATURE: 36
DEWPOINT: 21
WIND: 080 AT 19, GUSTS 26
PRESSURE: 28.72
COMMENTS:
BRAKE ACTION POOR
SLUSH ON RWY
STATUS:
SELECT ALTERNATIVE
ALT CURRENT WEATHER
PRELIMINARY FLT PLANNING
MENU:
ALT CURRENT CONDITIONS
9
13
1

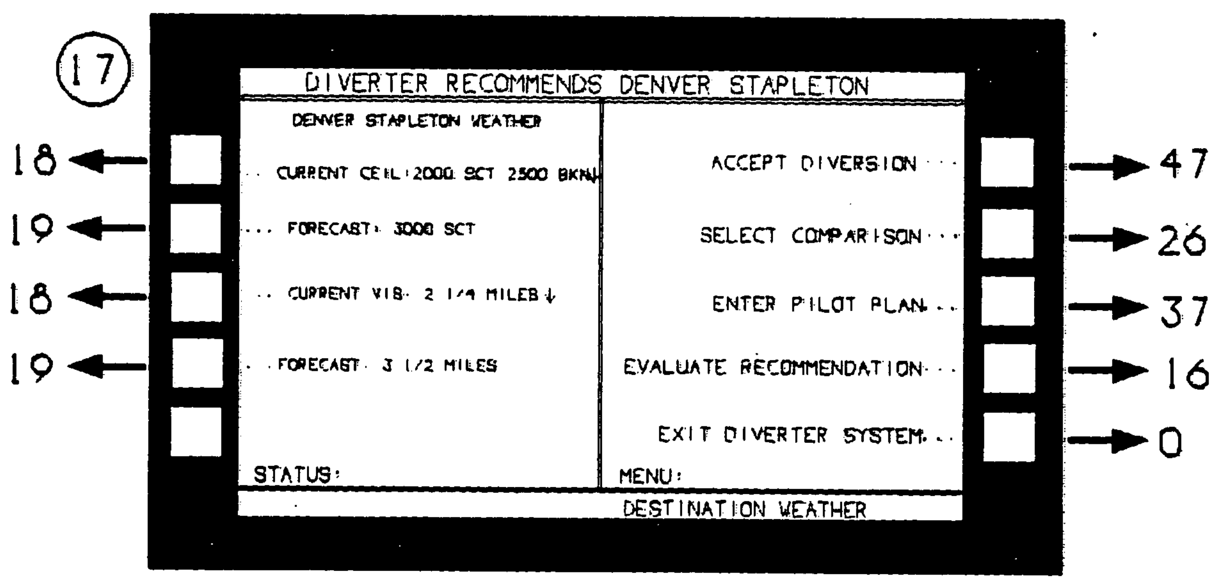


15
EVALUATE ALTERNATIVE
FARMINGTON:
COMPANY LEASED GATES: NONE
PASS CONNECT: OTHER CARRIER
PASSENGER SERVICES: NONE
STATUS:
SELECT ALTERNATIVE
EVAL PRESENT ALT
PRELIMINARY FLT PLANNING
MENU:
COMPANY DIRECTIVES
9
10
1

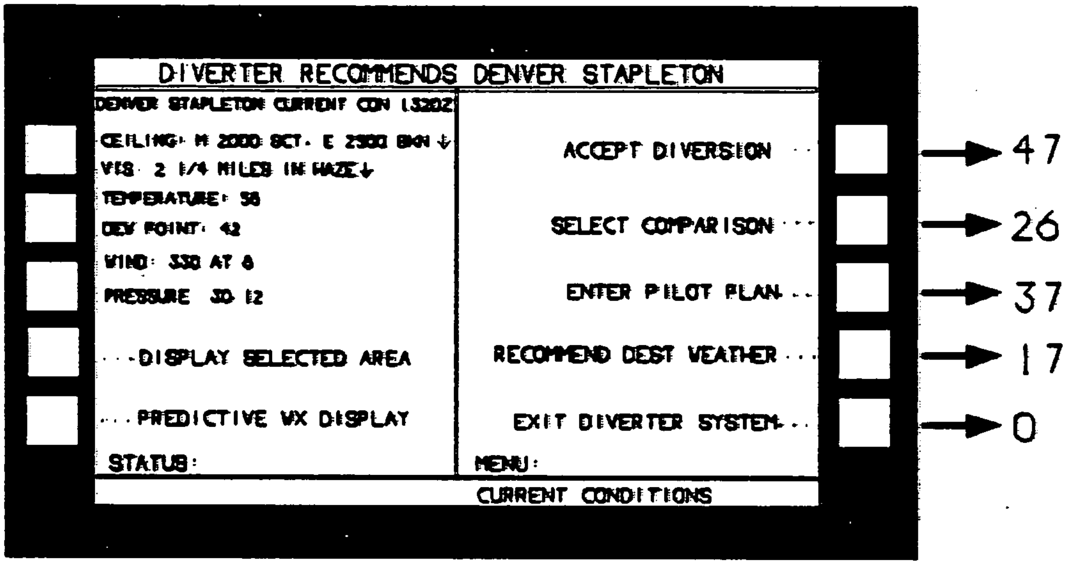
16


DIVERTER RECOMMENDS DENVER STAPLETON
DUE TO:
DESTINATION WEATHER
ENROUTE FACTORS
DESTINATION FACILITIES
AIRCRAFT PERFORMANCE
ACCEPT DIVERSION
SELECT COMPARISON
ENTER PILOT PLAN
EXIT DIVERTER SYSTEM
STATUS:
MENU:
EVALUATE RECOMMENDATION
17
20
24
25
47
26
37
0

17

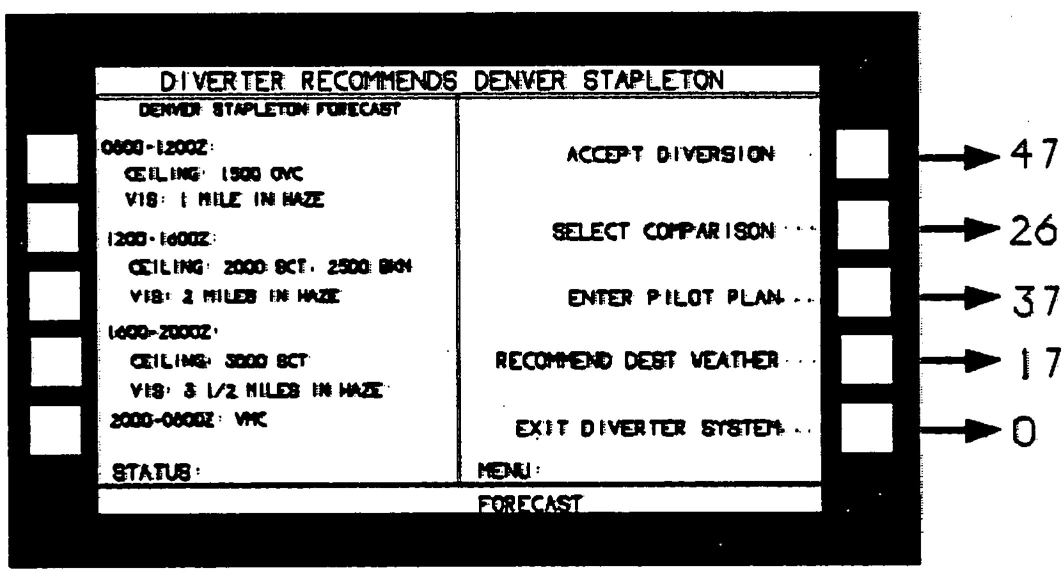

DIVERTER RECOMMENDS DENVER STAPLETON
DENVER STAPLETON WEATHER
CURRENT CEIL: 2000 SCT 2500 BKN
FORECAST: 3000 SCT
CURRENT VIS: 2 1/4 MILES
FORECAST: 3 1/2 MILES
ACCEPT DIVERSION
SELECT COMPARISON
ENTER PILOT PLAN
EVALUATE RECOMMENDATION
EXIT DIVERTER SYSTEM
STATUS:
MENU:
DESTINATION WEATHER
18
19
18
19
47
26
37
16
0

18



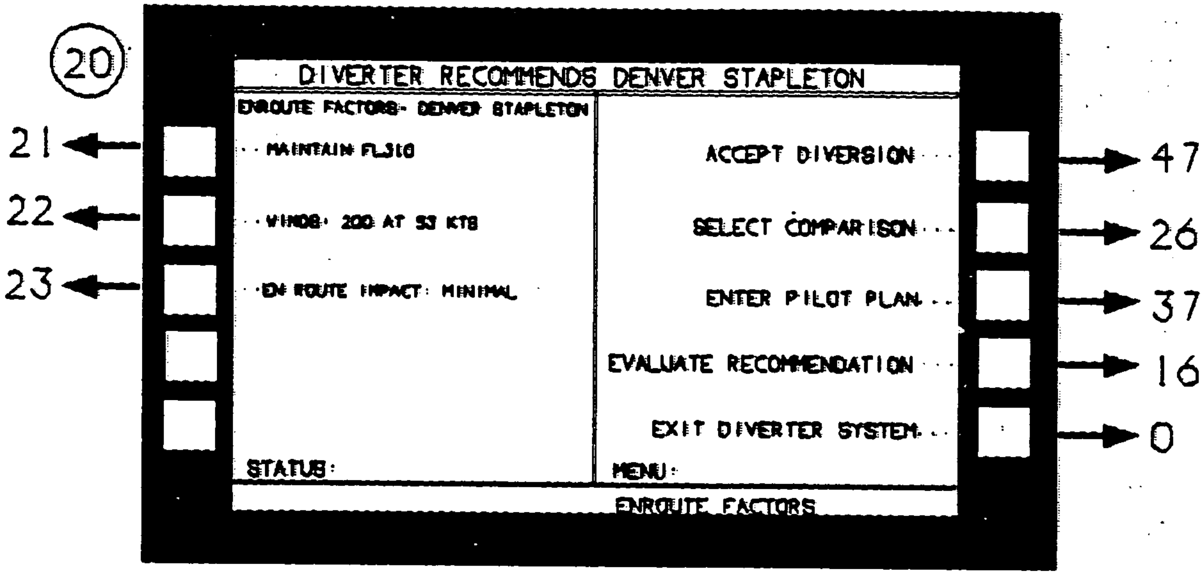
DIVERTER RECOMMENDS DENVER STAPLETON
DENVER STAPLETON CURRENT CON 1320Z
CEILING: M 2000 SCT, E 2500 BKN ↓
VIS: 2 1/4 MILES IN HAZE ↓
TEMPERATURE: 58
DEW POINT: 42
WIND: 330 AT 6
PRESSURE 30.12
DISPLAY SELECTED AREA
PREDICTIVE WX DISPLAY
STATUS:
ACCEPT DIVERSION
SELECT COMPARISON
ENTER PILOT PLAN
RECOMMEND DEST WEATHER
EXIT DIVERTER SYSTEM
MENU:
CURRENT CONDITIONS
47
26
37
17
0

19

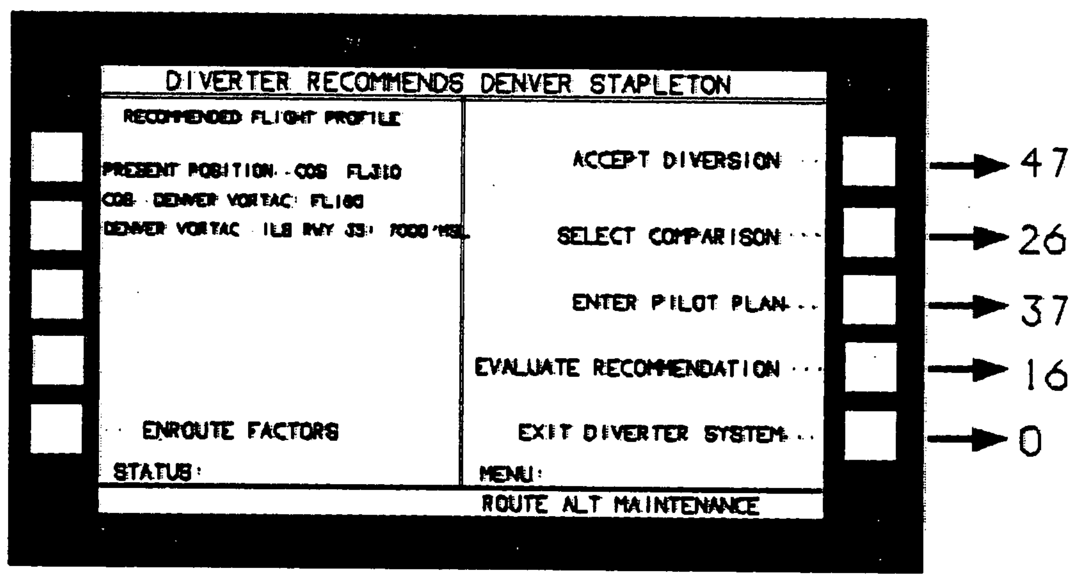


DIVERTER RECOMMENDS DENVER STAPLETON
DENVER STAPLETON FORECAST
0800-1200Z:
CEILING: 1500 OVC
VIS: 1 MILE IN HAZE
1200-1600Z:
CEILING: 2000 SCT, 2500 BKN
VIS: 2 MILES IN HAZE
1600-2000Z:
CEILING: 3000 SCT
VIS: 3 1/2 MILES IN HAZE
2000-0800Z: VMC
STATUS:
ACCEPT DIVERSION
SELECT COMPARISON
ENTER PILOT PLAN
RECOMMEND DEST WEATHER
EXIT DIVERTER SYSTEM
MENU:
FORECAST
47
26
37
17
0

20



21



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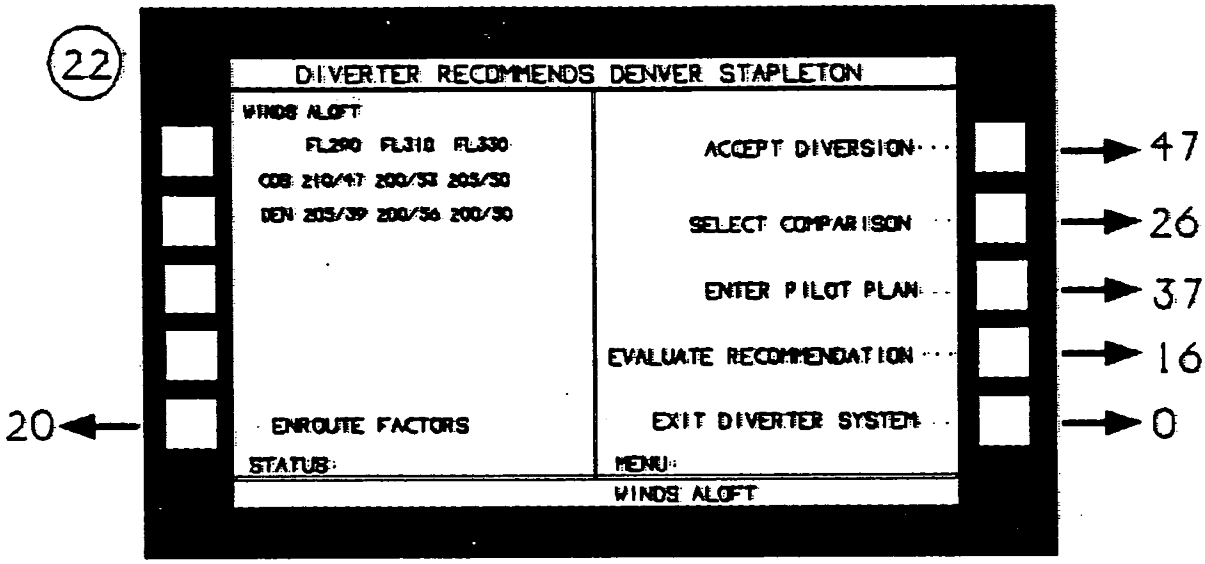
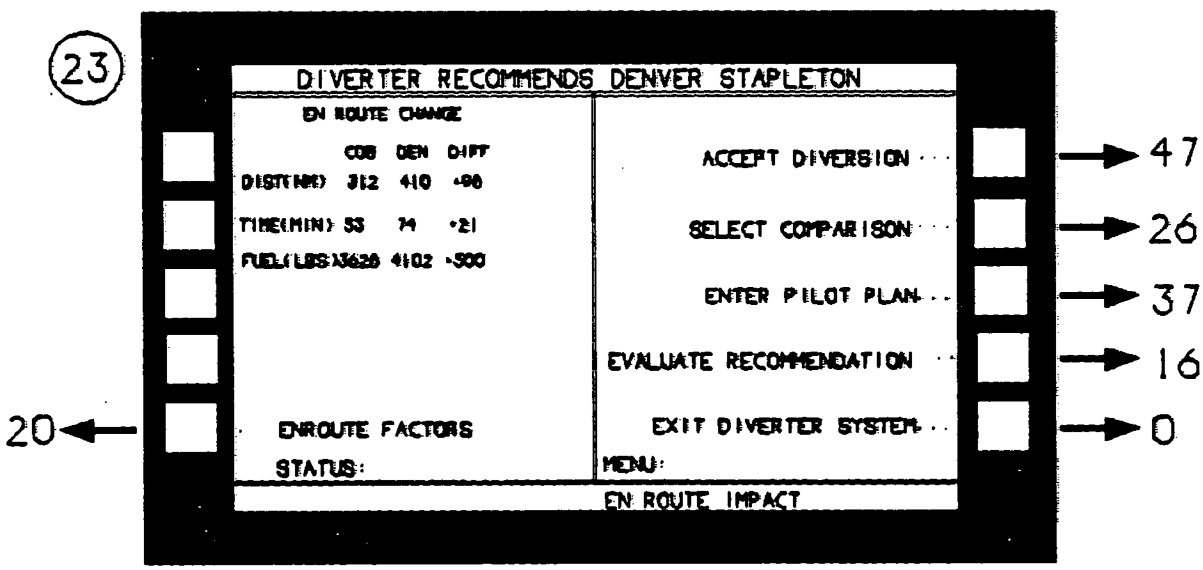
22



23



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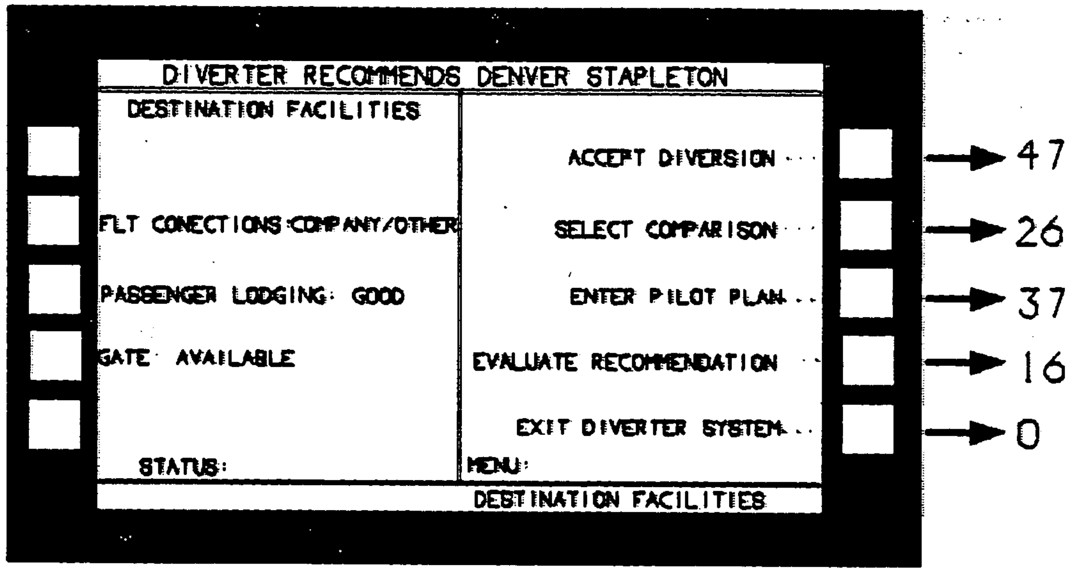
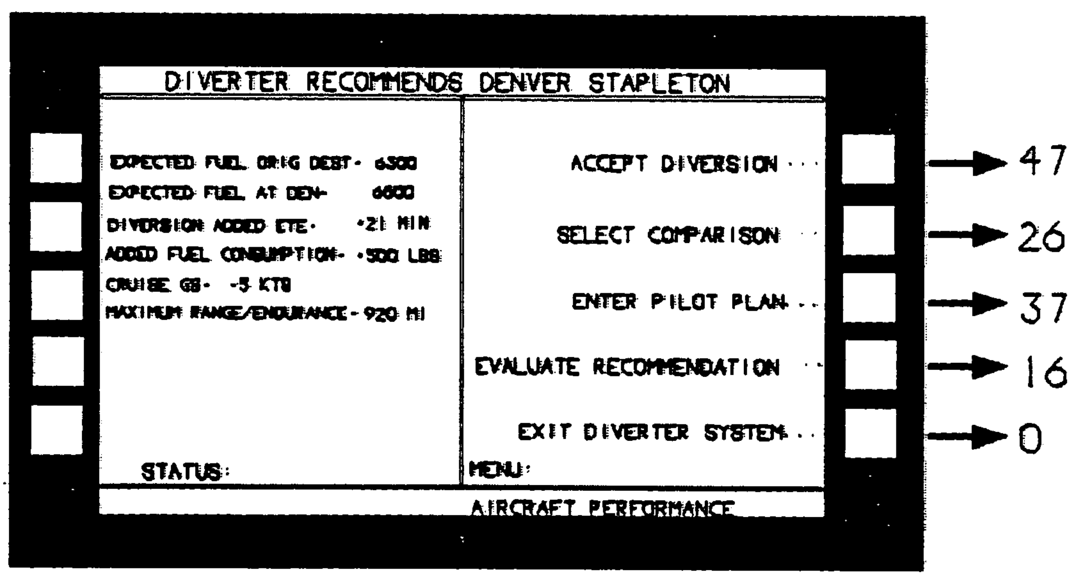
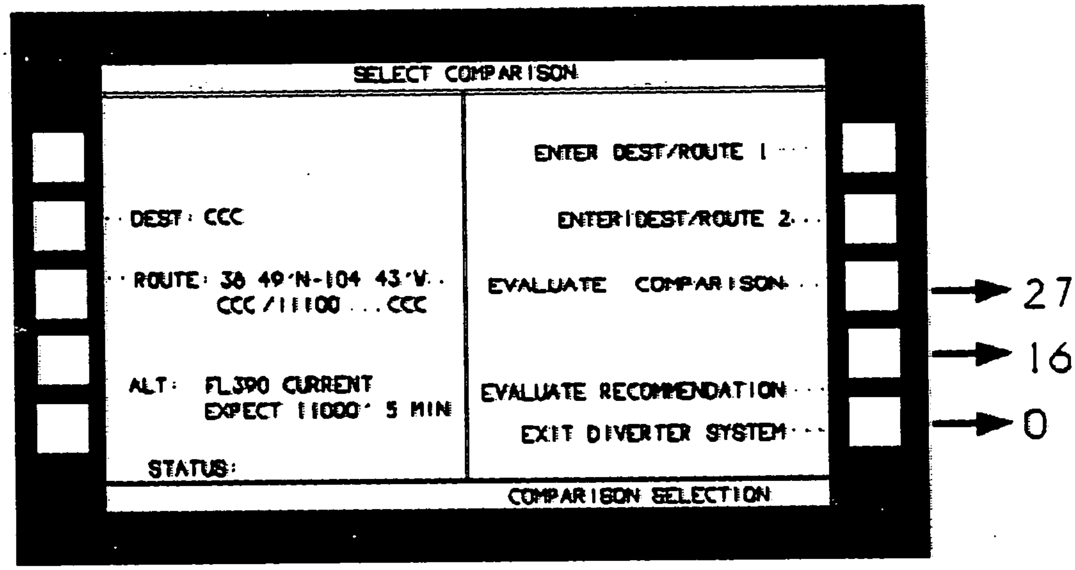
24


DIVERTER RECOMMENDS DENVER STAPLETON
DESTINATION FACILITIES
FLT CONECTIONS:COMPANY/OTHER
PASSENGER LODGING: GOOD
GATE: AVAILABLE
STATUS:
ACCEPT DIVERSION
SELECT COMPARISON
ENTER PILOT PLAN
EVALUATE RECOMMENDATION
EXIT DIVERTER SYSTEM
MENU:
DESTINATION FACILITIES
47
26
37
16
0

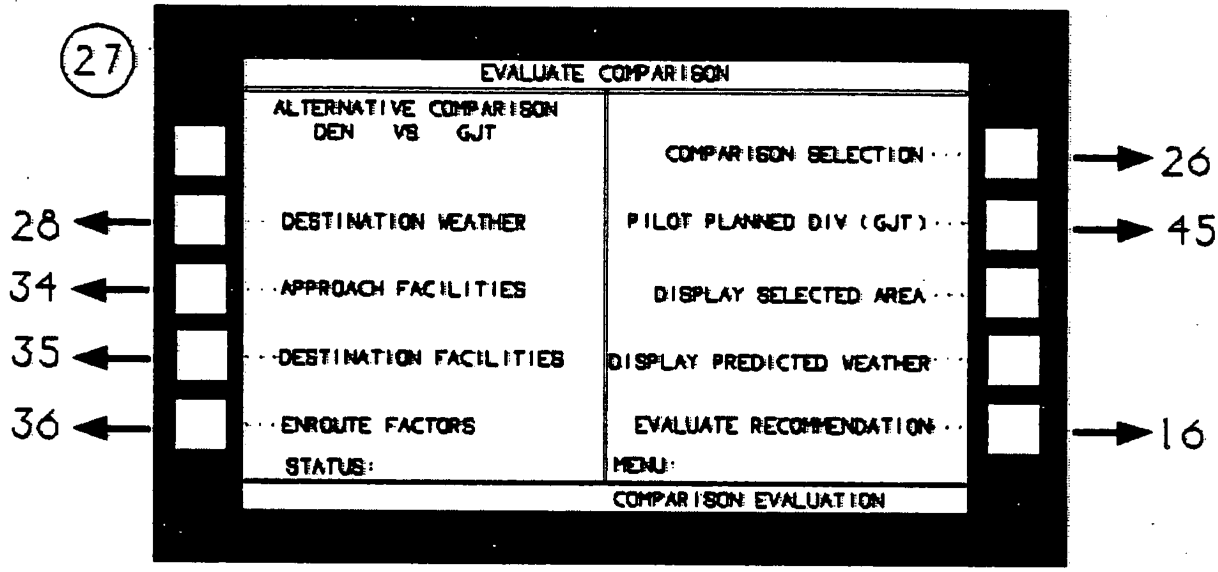
25


DIVERTER RECOMMENDS DENVER STAPLETON
EXPECTED FUEL ORIG DEST- 6300
EXPECTED FUEL AT DEN- 6600
DIVERSION ADDED ETE- +21 MIN
ADDED FUEL CONSUMPTION- +500 LBS
CRUISE GS- -5 KTS
MAXIMUM RANGE/ENDURANCE - 920 MI
STATUS:
ACCEPT DIVERSION
SELECT COMPARISON
ENTER PILOT PLAN
EVALUATE RECOMMENDATION
EXIT DIVERTER SYSTEM
MENU:
AIRCRAFT PERFORMANCE
47
26
37
16
0

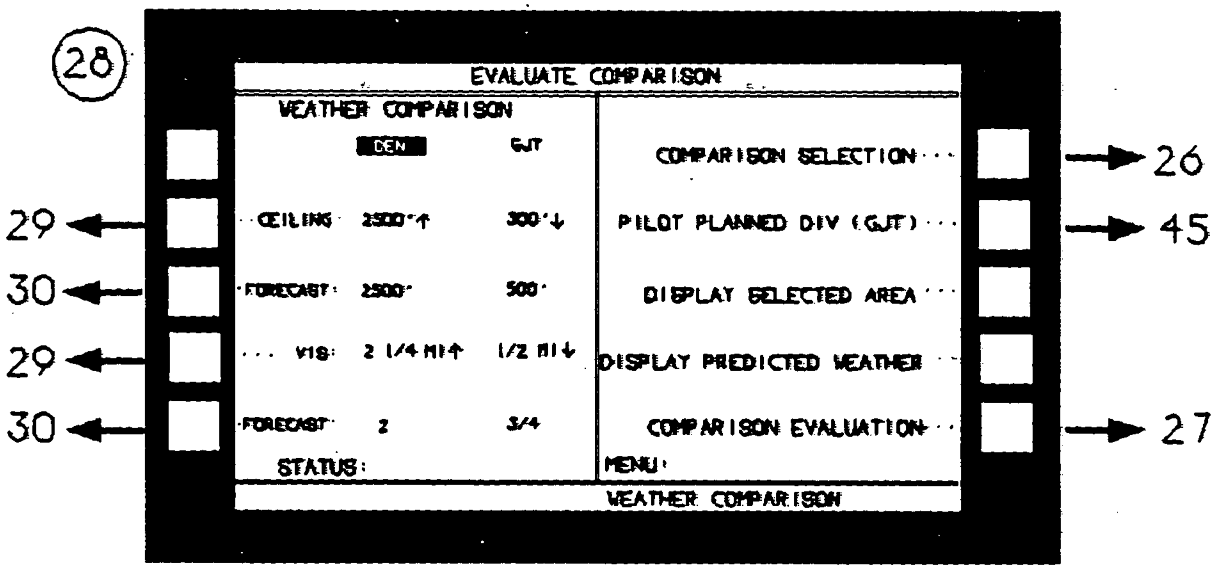
26

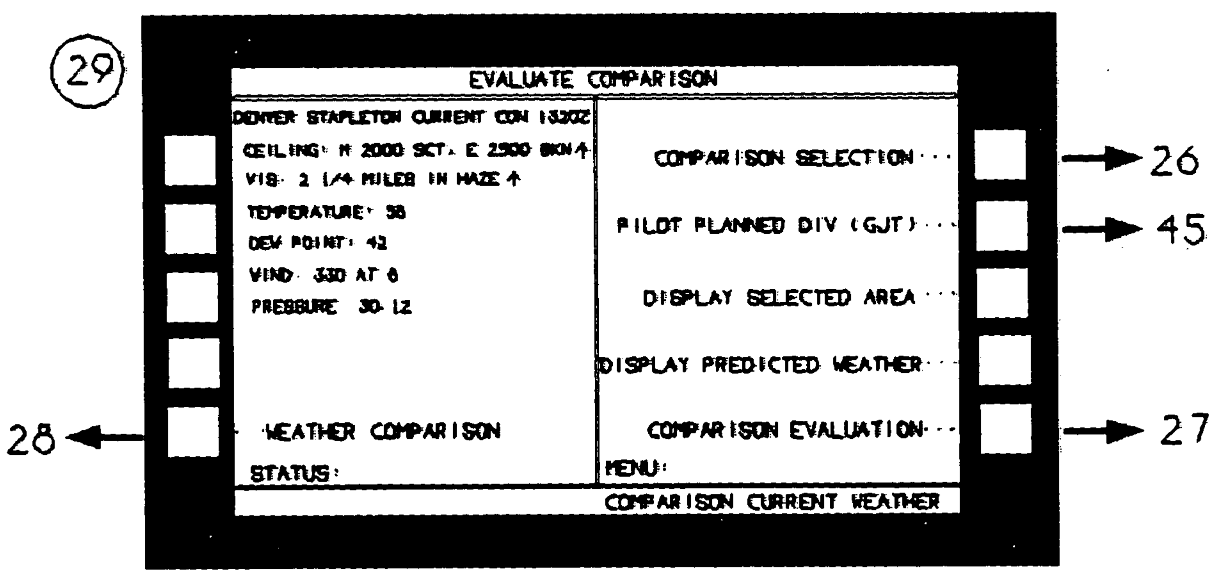


26 This display menu permits the entry of destinations and routes for comparison. The pilot would press the "enter dest/route 1" button. This would present a cue for destination on the left. The pilot could enter the waypoint/destination through either the CDU or touch screen moving map display. The pilot would confirm by pressing the "dest" key. The route would be specified by pressing "route". The system would automatically enter the latitude/longitude of the current position. The pilot would then enter, via touch screen or CDU, the waypoints selected. After entry, the route would be confirmed by pressing the "route" key again. Altitude would be entered using the same scheme, although altitude values would be entered using the CDU keyboard whereas application to a route segment could utilize the moving map display. The "enter dest/route 2" would require the same control inputs.



27-36 When the pilot presses the "display predicted weather" the function of the Diverter moving map would switch to allow touch screen input. The pilot would then touch the screen at the position representing his ownship symbol and slew that to the place where he expects the aircraft to be at a particular point in time. A color "ghost" image of the predicted weather would be presented compensating for time for navigation and expected weather movement. After pressing "display predicted weather" the associated button command would be changed to "display actual weather". Pressing this button would return the moving map display to its normal function, disabling the touch screen, and would remove the "ghost" of the weather.





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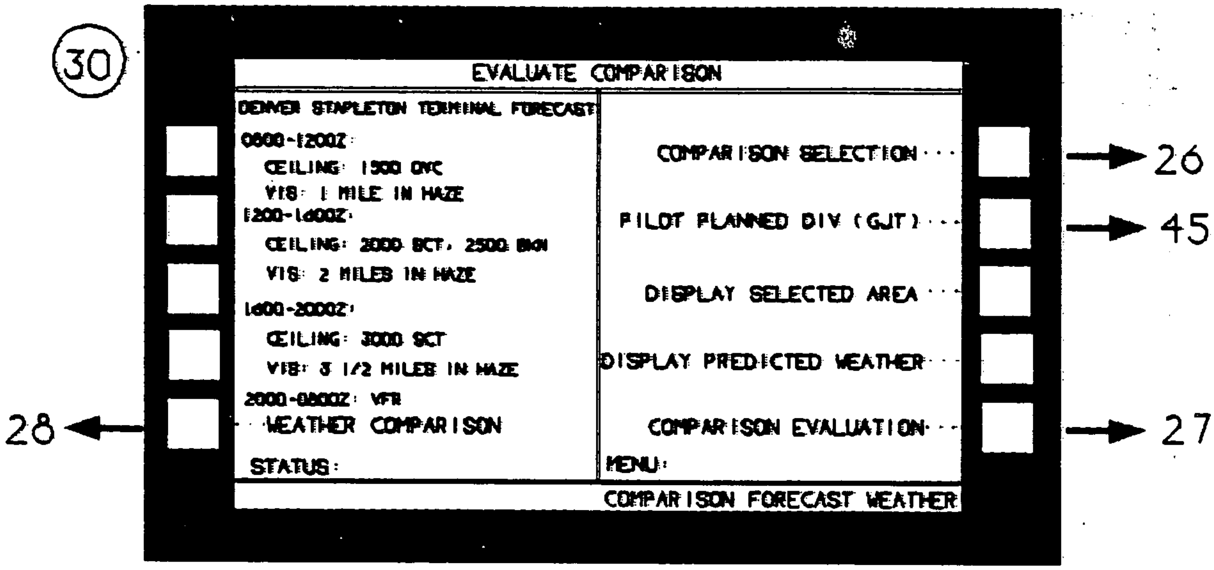

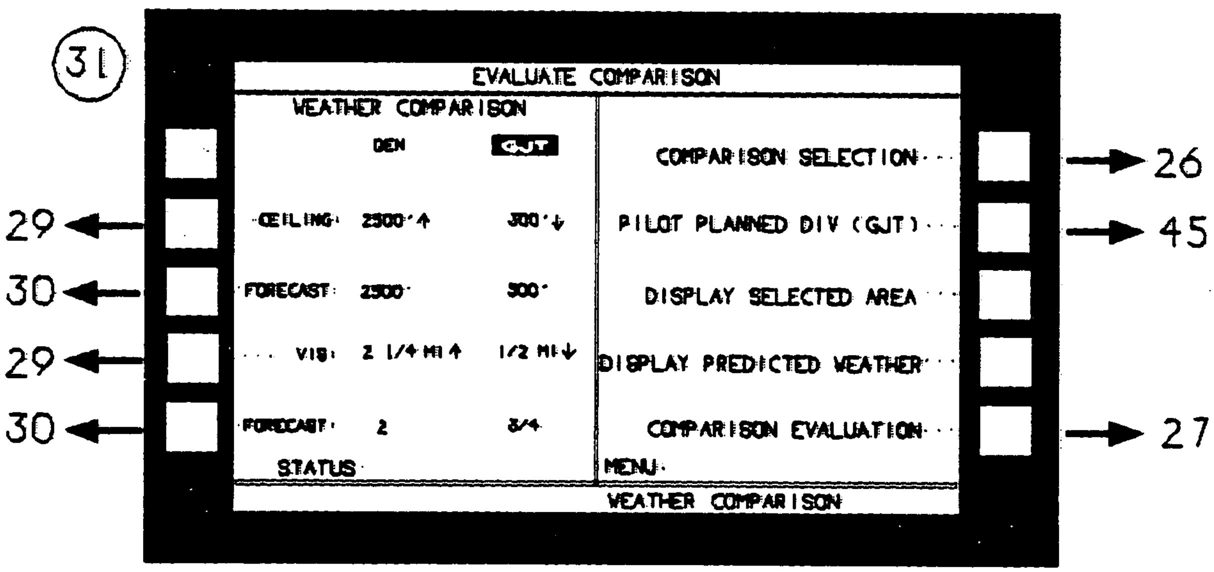

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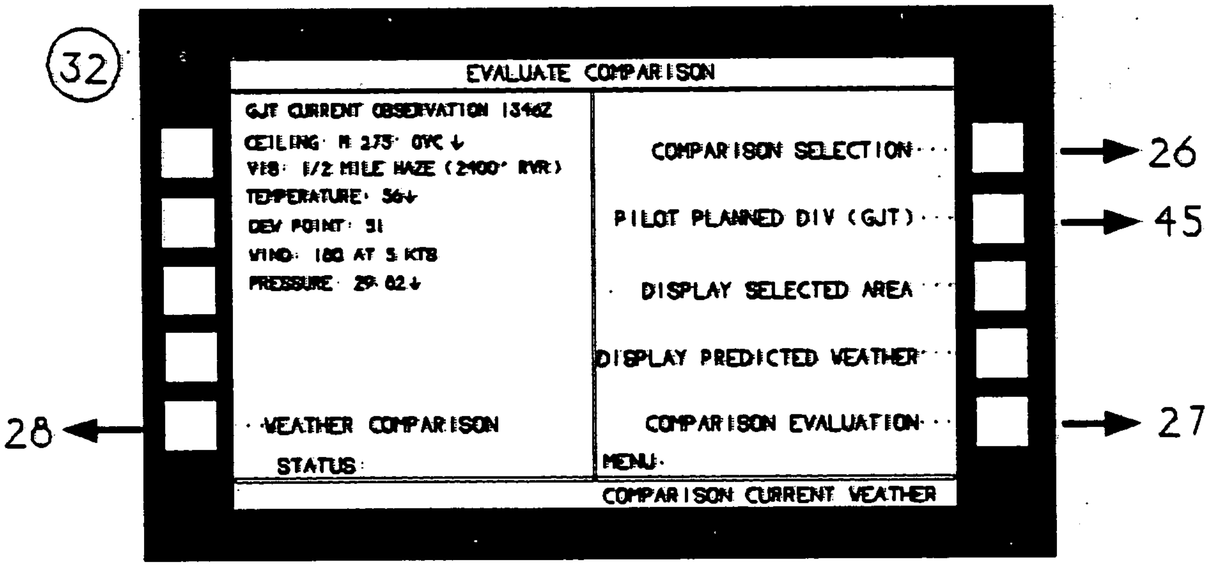
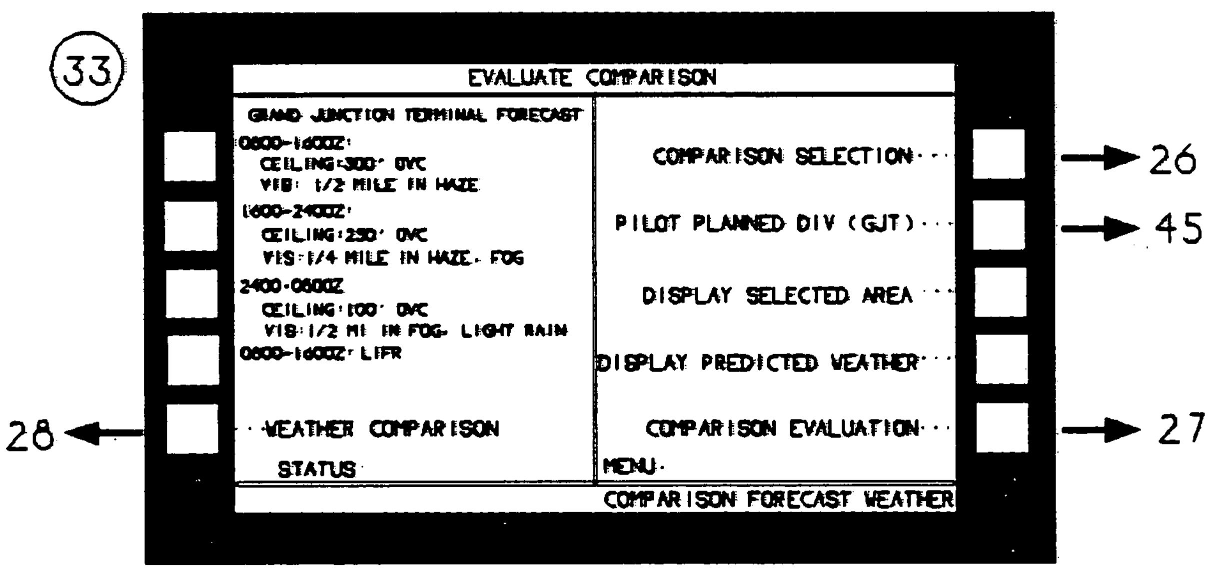
(32)



(33)



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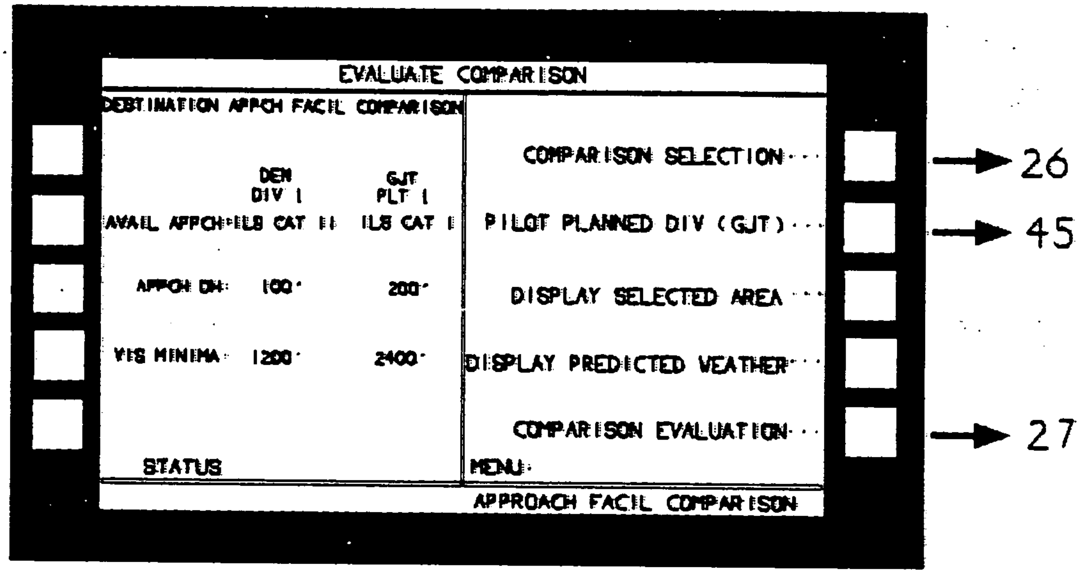
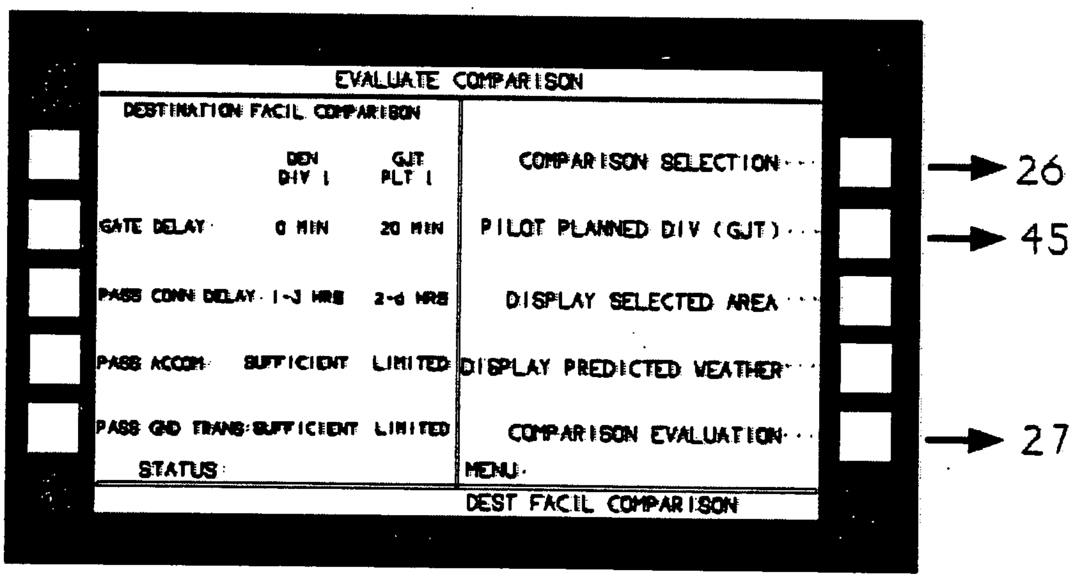
34



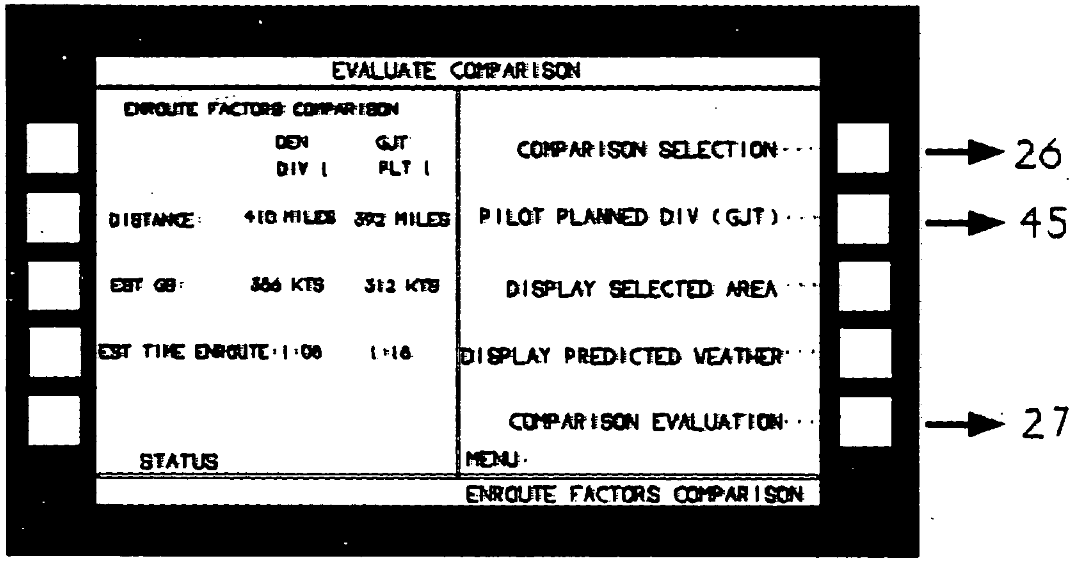
EVALUATE COMPARISON
DESTINATION APPCH FACIL COMPARISON
DEN DIV 1
GJT PLT 1
AVAIL APPCH: ILS CAT II ILS CAT I
APPCH DH: 100' 200'
VIS MINIMA: 1200' 2400'
STATUS
COMPARISON SELECTION
PILOT PLANNED DIV (GJT)
DISPLAY SELECTED AREA
DISPLAY PREDICTED WEATHER
COMPARISON EVALUATION
MENU:
APPROACH FACIL COMPARISON
26
45
27

35

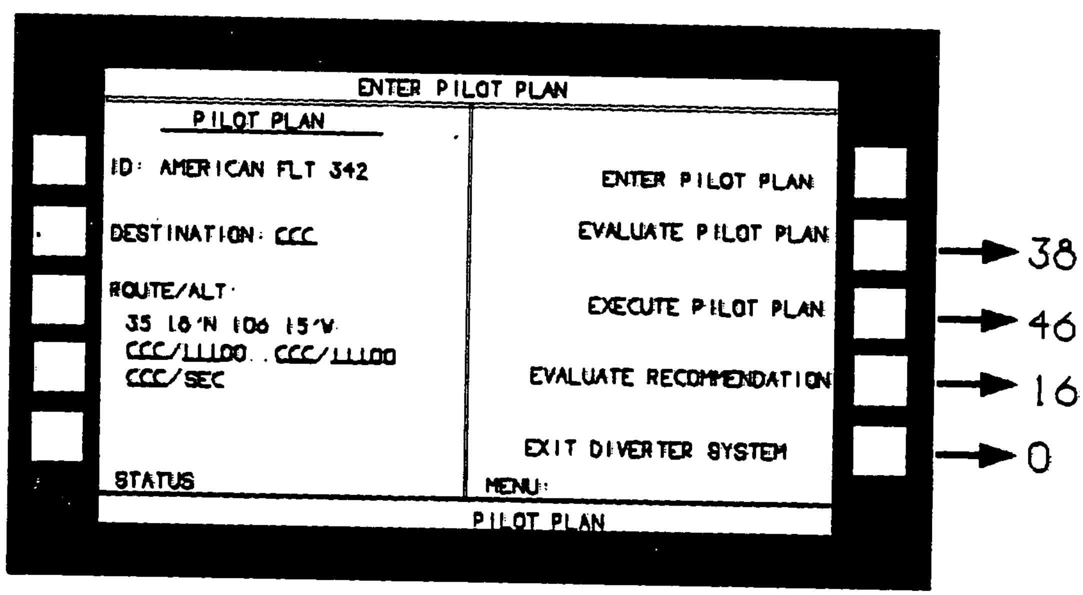


EVALUATE COMPARISON
DESTINATION FACIL COMPARISON
DEN DIV 1
GJT PLT 1
GATE DELAY: 0 MIN 20 MIN
PASS CONN DELAY: 1-3 HRS 2-4 HRS
PASS ACCOM: SUFFICIENT LIMITED
PASS GND TRANS: SUFFICIENT LIMITED
STATUS:
COMPARISON SELECTION
PILOT PLANNED DIV (GJT)
DISPLAY SELECTED AREA
DISPLAY PREDICTED WEATHER
COMPARISON EVALUATION
MENU:
DEST FACIL COMPARISON
26
45
27

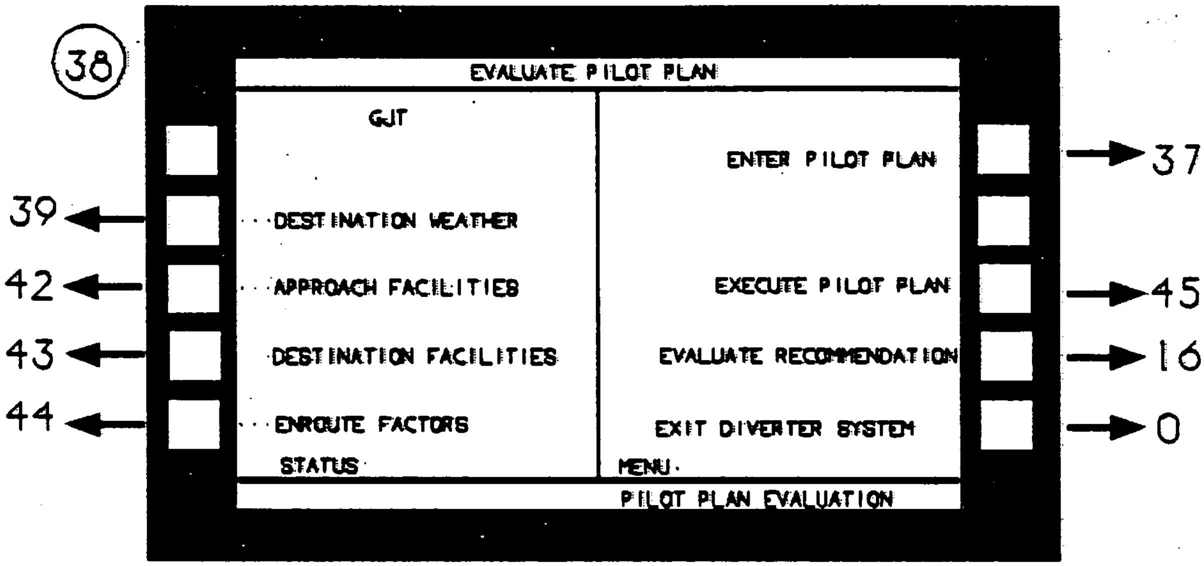
36

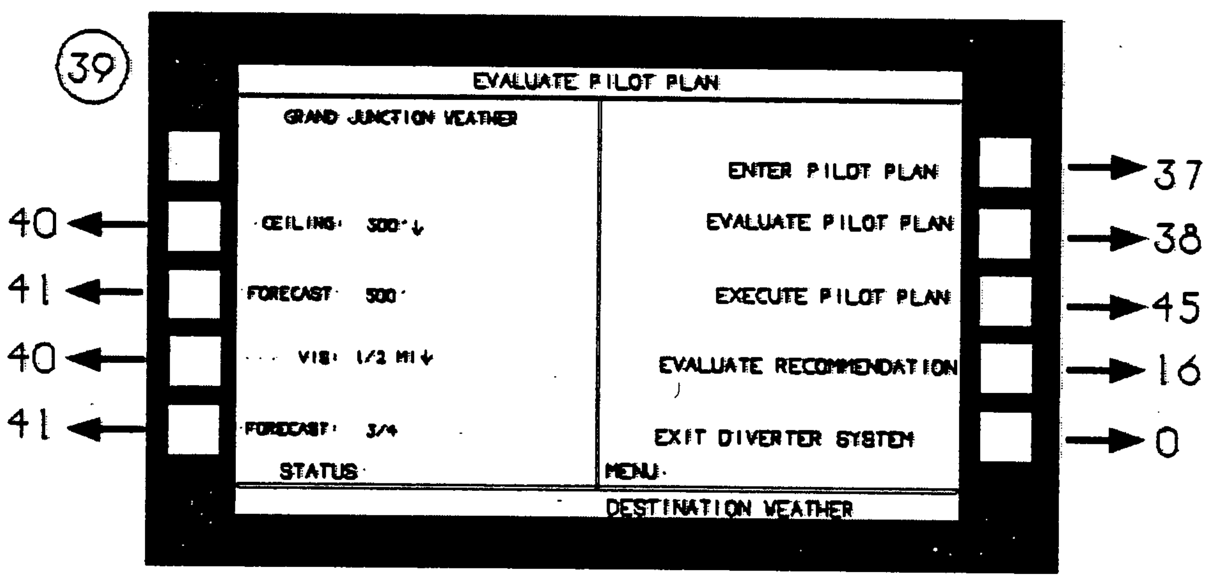


37

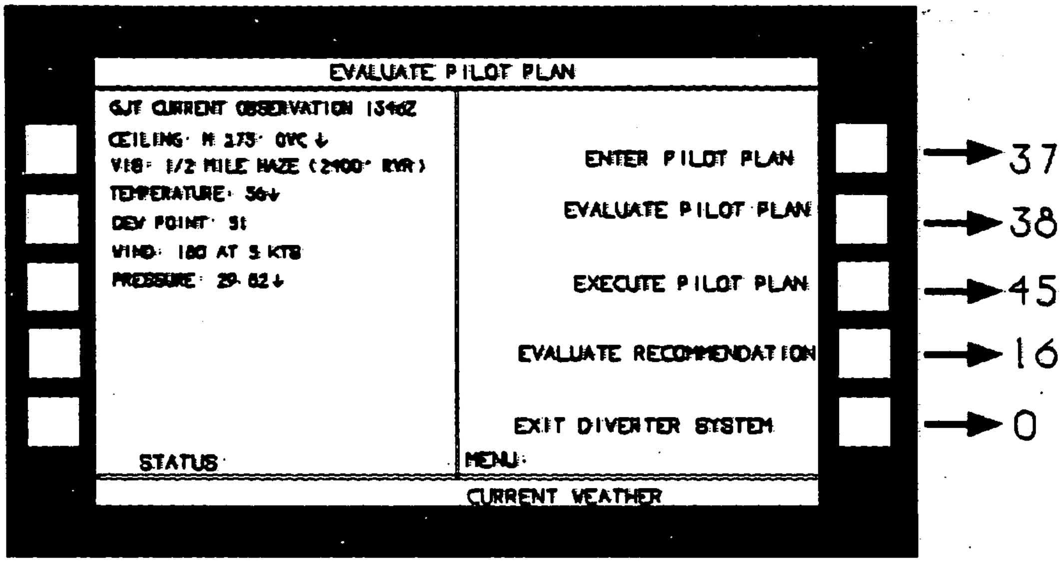


37 Pressing the "enter pilot plan" would activate the left side of the display to allow definition of both a destination and a route/altitude for pilot diversion planning. The data input could be made from the CDU or moving map display. Field selections would be confirmed by pressing their associated key.

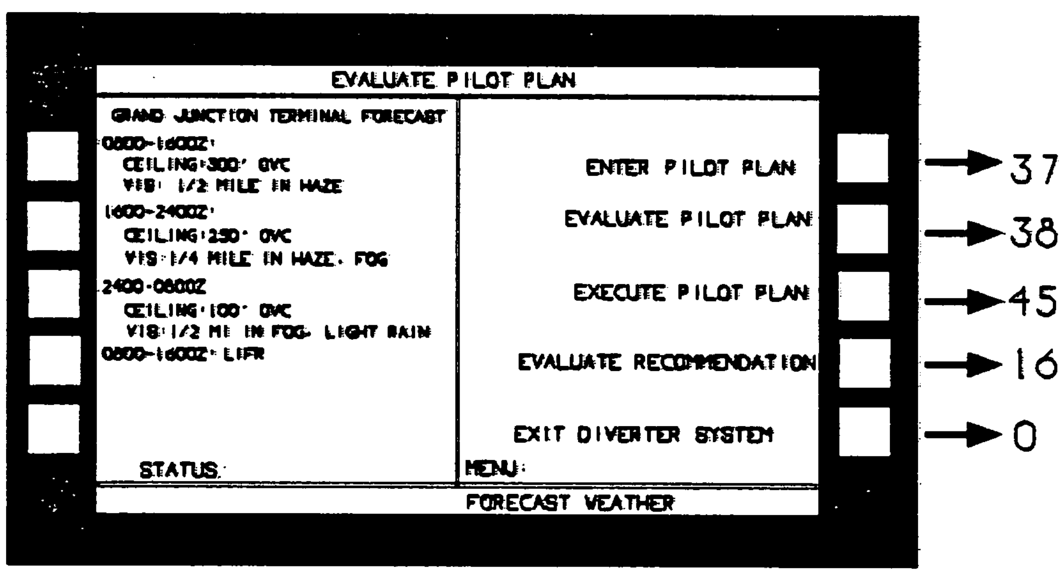

38
EVALUATE PILOT PLAN
GJT
DESTINATION WEATHER
APPROACH FACILITIES
DESTINATION FACILITIES
ENROUTE FACTORS
STATUS
ENTER PILOT PLAN
EXECUTE PILOT PLAN
EVALUATE RECOMMENDATION
EXIT DIVERTER SYSTEM
MENU
PILOT PLAN EVALUATION
39
42
43
44
37
45
16
0


39
EVALUATE PILOT PLAN
GRAND JUNCTION WEATHER
CEILING: 300'↓
FORECAST 500
VIS: 1/2 MI↓
FORECAST: 3/4
STATUS
ENTER PILOT PLAN
EVALUATE PILOT PLAN
EXECUTE PILOT PLAN
EVALUATE RECOMMENDATION
EXIT DIVERTER SYSTEM
MENU
DESTINATION WEATHER
40
41
40
41
37
38
45
16
0

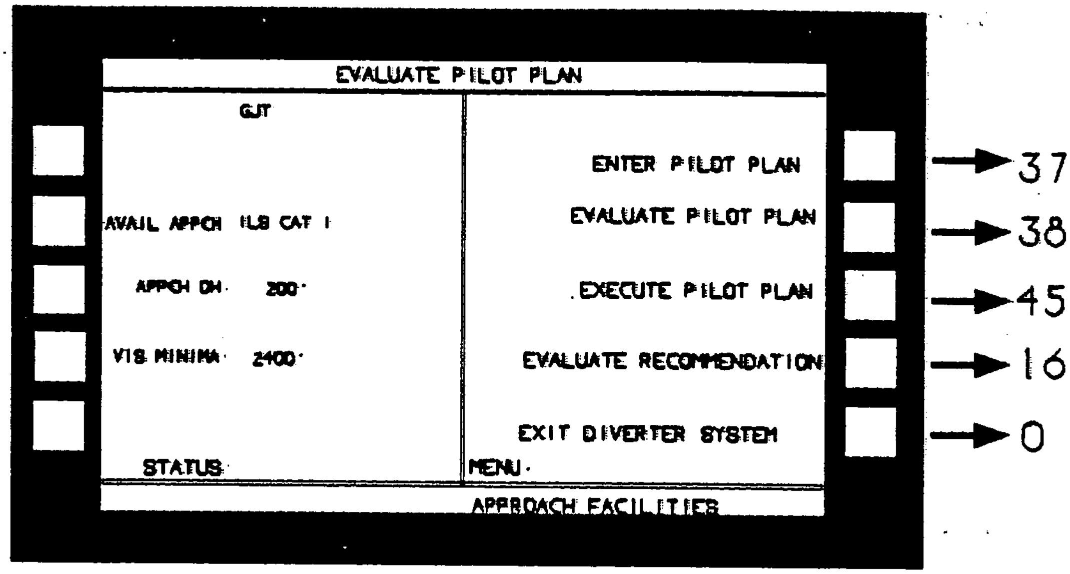
40


EVALUATE PILOT PLAN
GJT CURRENT OBSERVATION 1346Z
CEILING: M 275' OVC ↓
VIS: 1/2 MILE HAZE (2400' RVR)
TEMPERATURE: 56↓
DEW POINT: 51
WIND: 180 AT 5 KTS
PRESSURE: 29.82↓
STATUS:
ENTER PILOT PLAN
EVALUATE PILOT PLAN
EXECUTE PILOT PLAN
EVALUATE RECOMMENDATION
EXIT DIVERTER SYSTEM
MENU:
CURRENT WEATHER
37
38
45
16
0

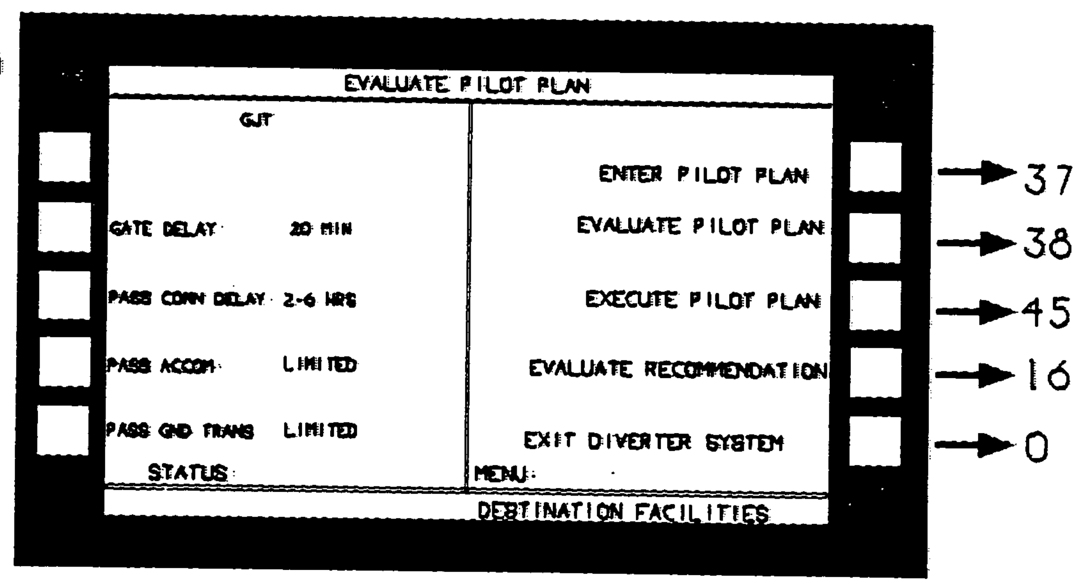
41


EVALUATE PILOT PLAN
GRAND JUNCTION TERMINAL FORECAST
0800-1600Z:
CEILING:300' OVC
VIS: 1/2 MILE IN HAZE
1600-2400Z:
CEILING:250' OVC
VIS:1/4 MILE IN HAZE, FOG
2400-0800Z
CEILING:100' OVC
VIS:1/2 MI IN FOG, LIGHT RAIN
0800-1600Z: LIFR
STATUS:
ENTER PILOT PLAN
EVALUATE PILOT PLAN
EXECUTE PILOT PLAN
EVALUATE RECOMMENDATION
EXIT DIVERTER SYSTEM
MENU:
FORECAST WEATHER
37
38
45
16
0

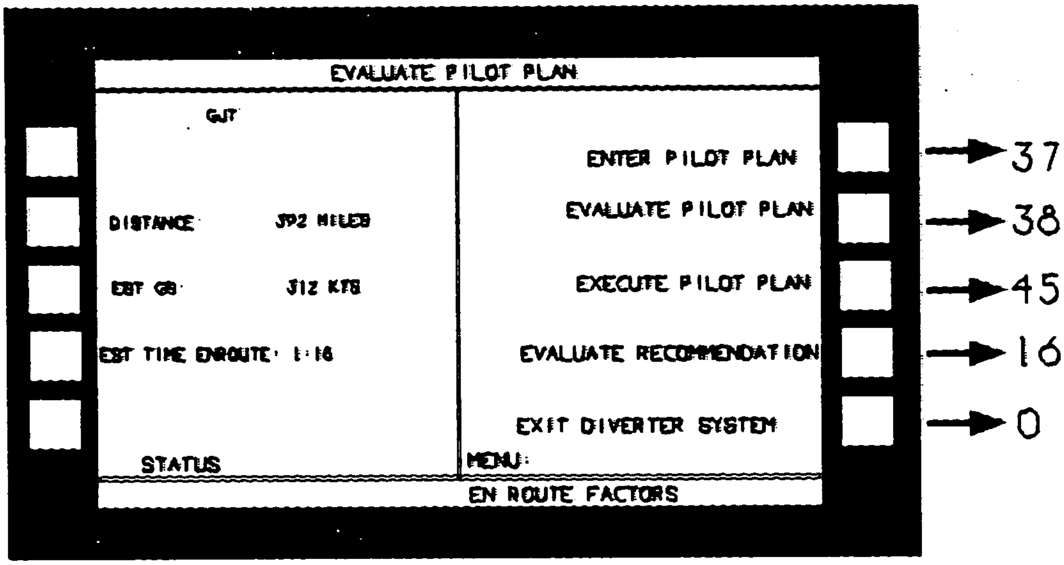
42


EVALUATE PILOT PLAN
GJT
AVAIL APPCH ILS CAT I
APPCH DH 200'
VIS MINIMA 2400'
STATUS
ENTER PILOT PLAN
EVALUATE PILOT PLAN
EXECUTE PILOT PLAN
EVALUATE RECOMMENDATION
EXIT DIVERTER SYSTEM
MENU
APPROACH FACILITIES
37
38
45
16
0

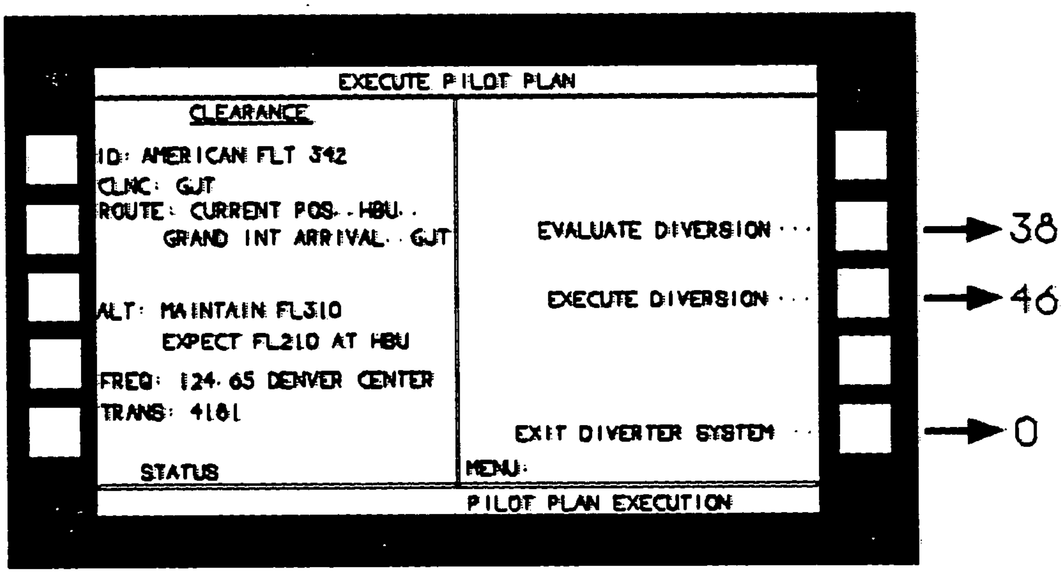
43


EVALUATE PILOT PLAN
GJT
GATE DELAY 20 MIN
PASS CONN DELAY 2-6 HRS
PASS ACCOM LIMITED
PASS GND TRANS LIMITED
STATUS
ENTER PILOT PLAN
EVALUATE PILOT PLAN
EXECUTE PILOT PLAN
EVALUATE RECOMMENDATION
EXIT DIVERTER SYSTEM
MENU
DESTINATION FACILITIES
37
38
45
16
0

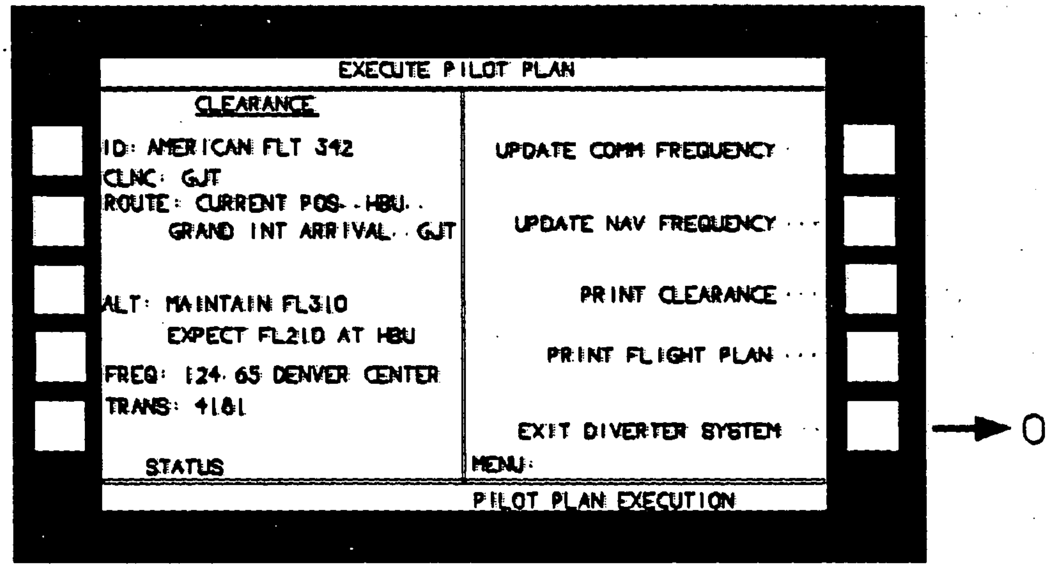
44


EVALUATE PILOT PLAN
GJT
DISTANCE 392 MILES
EST GS 312 KTS
EST TIME ENROUTE 1:16
STATUS
ENTER PILOT PLAN
EVALUATE PILOT PLAN
EXECUTE PILOT PLAN
EVALUATE RECOMMENDATION
EXIT DIVERTER SYSTEM
MENU:
EN ROUTE FACTORS
37
38
45
16
0

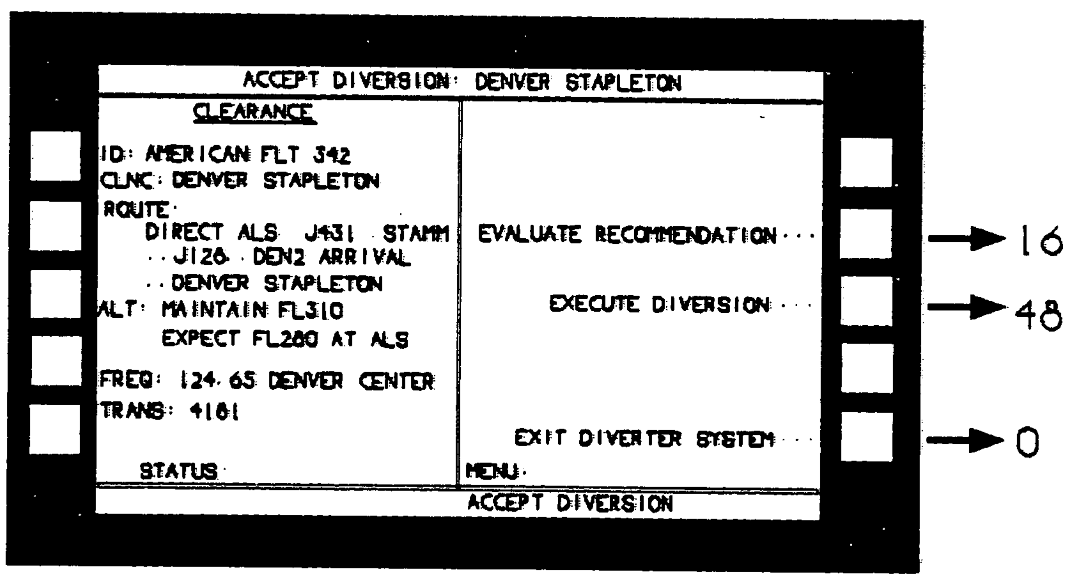
45


EXECUTE PILOT PLAN
CLEARANCE
ID: AMERICAN FLT 342
CLNC: GJT
ROUTE: CURRENT POS..HBU..
GRAND INT ARRIVAL..GJT
ALT: MAINTAIN FL310
EXPECT FL210 AT HBU
FREQ: 124.65 DENVER CENTER
TRANS: 4161
STATUS
EVALUATE DIVERSION...
EXECUTE DIVERSION...
EXIT DIVERTER SYSTEM ..
MENU:
PILOT PLAN EXECUTION
38
46
0

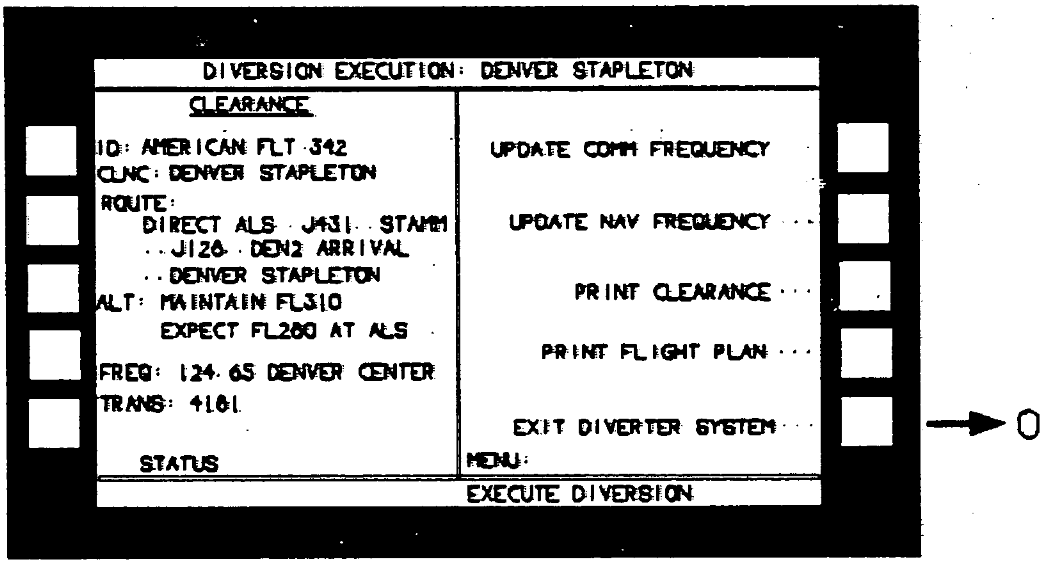
46


EXECUTE PILOT PLAN
CLEARANCE
ID: AMERICAN FLT 342
CLNC: GJT
ROUTE: CURRENT POS..HBU..
GRAND INT ARRIVAL..GJT
ALT: MAINTAIN FL310
EXPECT FL210 AT HBU
FREQ: 124.65 DENVER CENTER
TRANS: 4161
STATUS
UPDATE COMM FREQUENCY
UPDATE NAV FREQUENCY
PRINT CLEARANCE
PRINT FLIGHT PLAN
EXIT DIVERTER SYSTEM
MENU:
PILOT PLAN EXECUTION
0

47


ACCEPT DIVERSION: DENVER STAPLETON
CLEARANCE
ID: AMERICAN FLT 342
CLNC: DENVER STAPLETON
ROUTE:
DIRECT ALS J431 STAMM
..J126..DEN2 ARRIVAL
..DENVER STAPLETON
ALT: MAINTAIN FL310
EXPECT FL280 AT ALS
FREQ: 124.65 DENVER CENTER
TRANS: 4161
STATUS
EVALUATE RECOMMENDATION
EXECUTE DIVERSION
EXIT DIVERTER SYSTEM
MENU:
ACCEPT DIVERSION
16
48
0

48



DIVERSION EXECUTION: DENVER STAPLETON
CLEARANCE
ID: AMERICAN FLT 342
CLNC: DENVER STAPLETON
ROUTE:
DIRECT ALS . J431 . . STAMM
. . J128 . DEN2 ARRIVAL
. . DENVER STAPLETON
ALT: MAINTAIN FL310
EXPECT FL280 AT ALS
FREQ: 124.65 DENVER CENTER
TRANS: 4161
STATUS
UPDATE COMM FREQUENCY
UPDATE NAV FREQUENCY
PRINT CLEARANCE
PRINT FLIGHT PLAN
EXIT DIVERTER SYSTEM
MENU:
EXECUTE DIVERSION
0

APPENDIX D

Sample Diverter Display Screen Images

This appendix contains a sample of Symbolics display screen images taken from the diverter demonstration showing the type and format of information presented by the simulation tool. The scenario for this demonstration is included in the body of the report in the section titled "Demonstration."

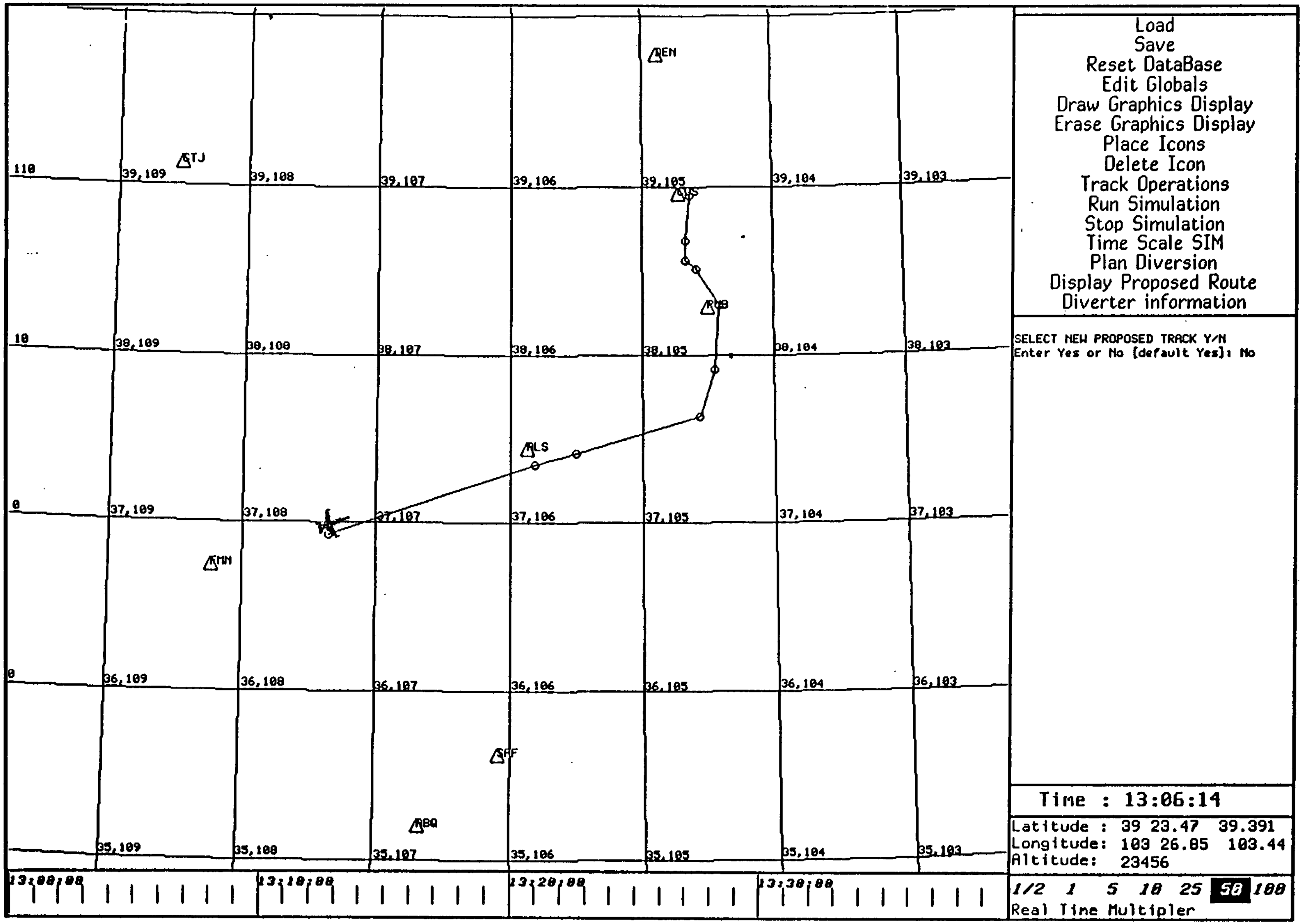


Figure D-1. Original Flight Plan. Aircraft is 70 NM SW of Alamosa En Route from Los Angeles to Colorado Springs.

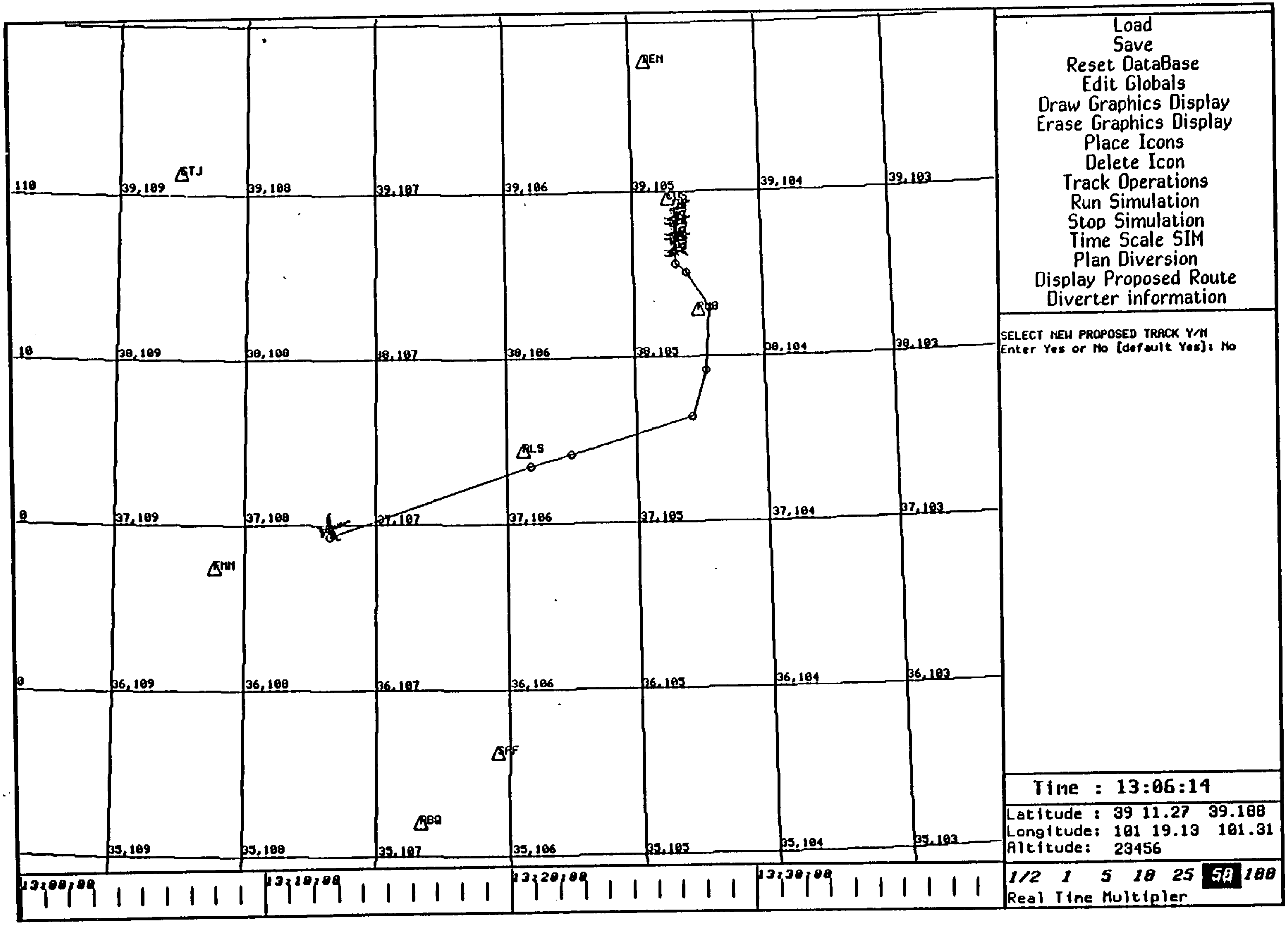


Figure D-2. Diverter Receives Notification of Line of Thunderstorms Presently in the Colorado Springs Area.

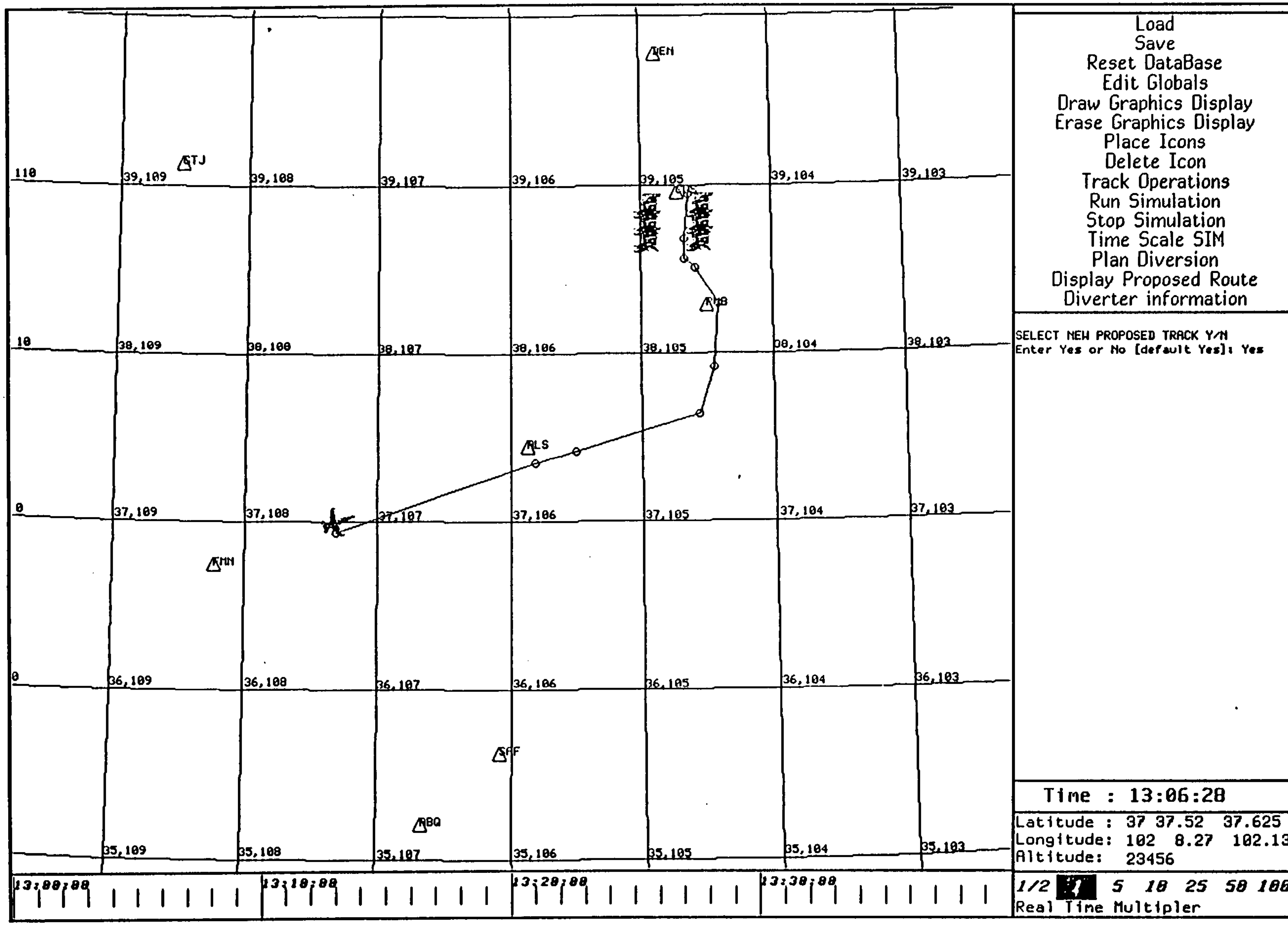


Figure D-3. Diverter Receives Notification of a Second Line of Thunderstorms West of Colorado Springs Moving Eastward.

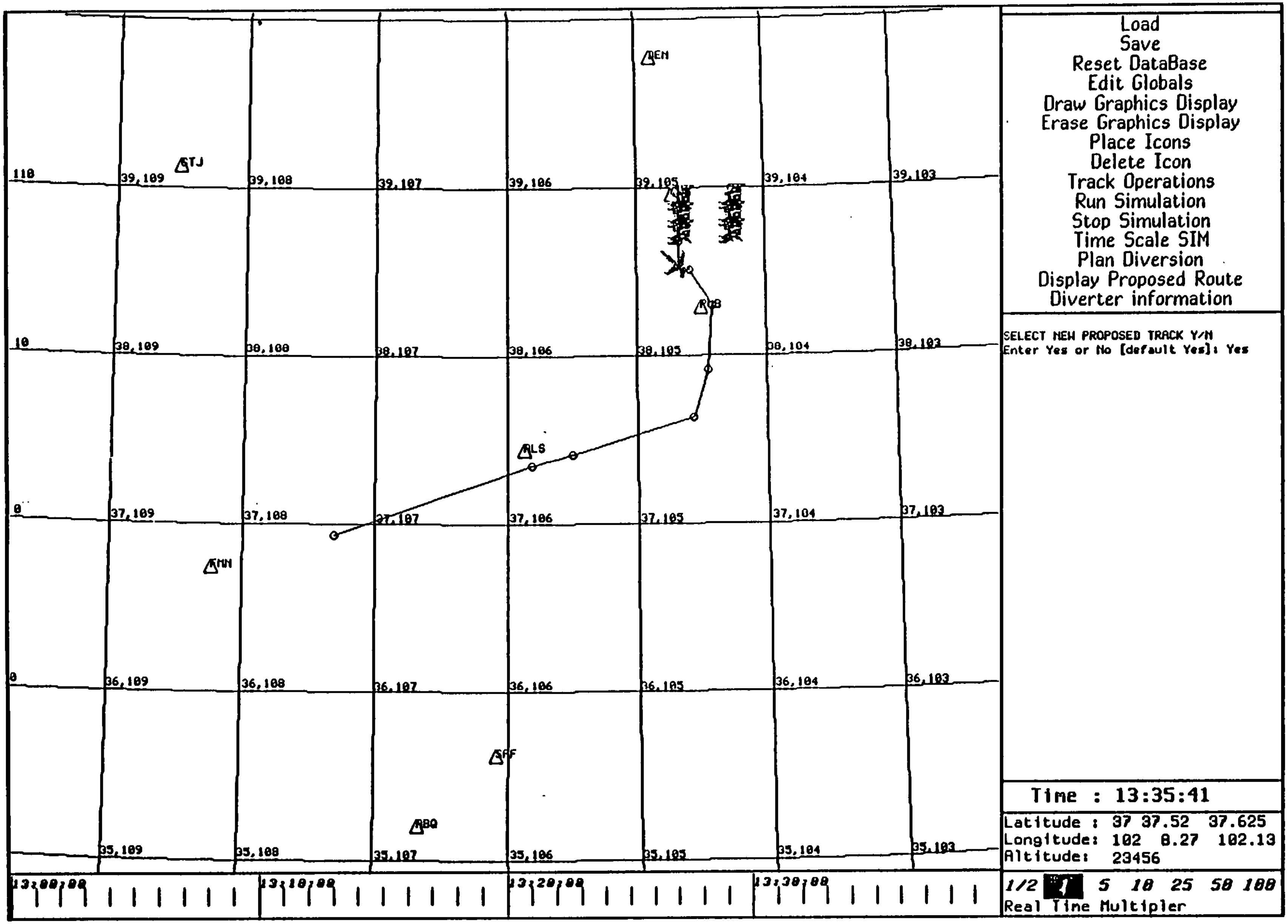


Figure D-4. Pilot Asks Diverter to Predict Relative Movement of the Aircraft and the Thunderstorms. Diverter Predicts Conflict in the Colorado Springs Area.

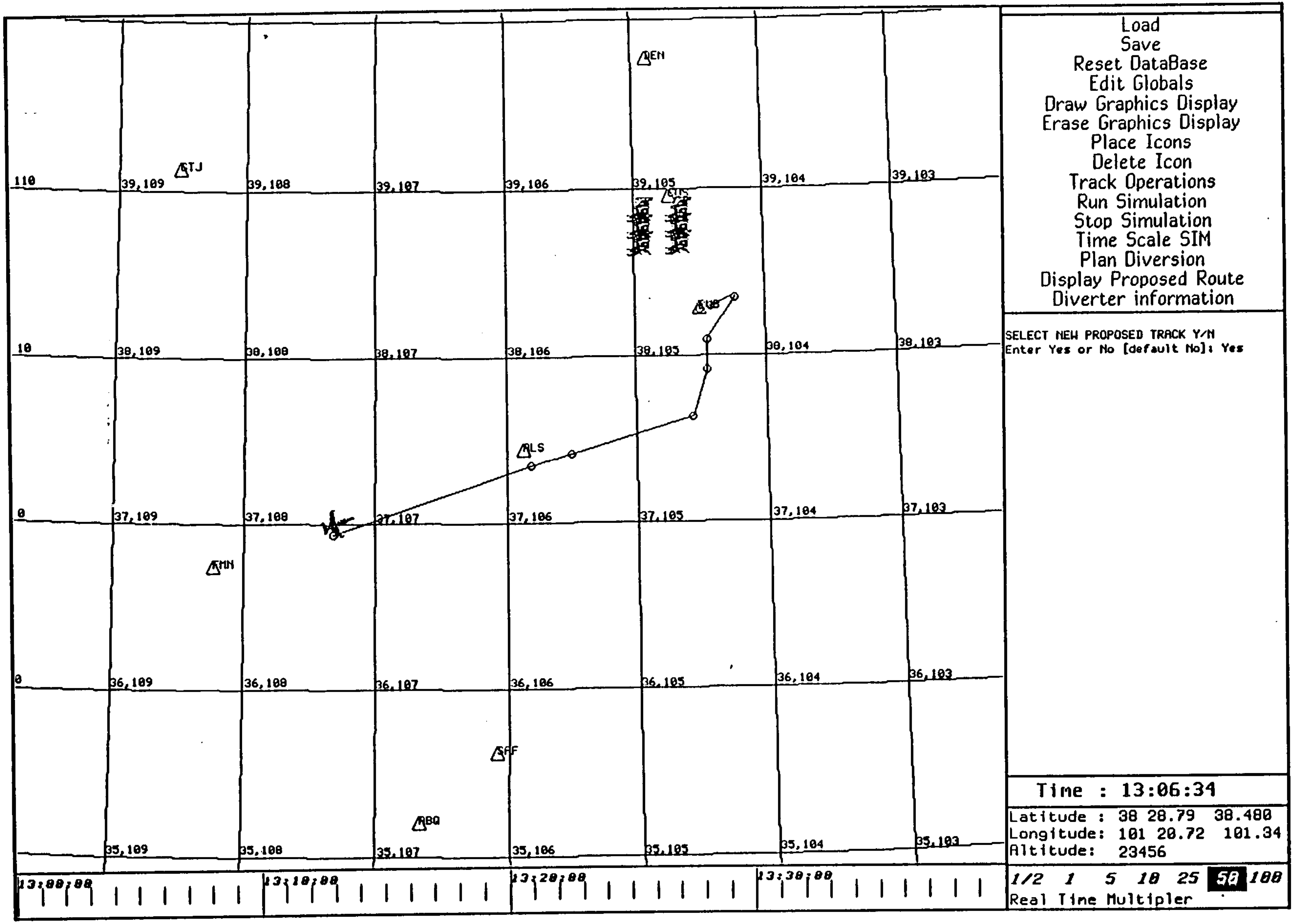


Figure D-5. Diverter Replans and Recommends Diversion to Pueblo.

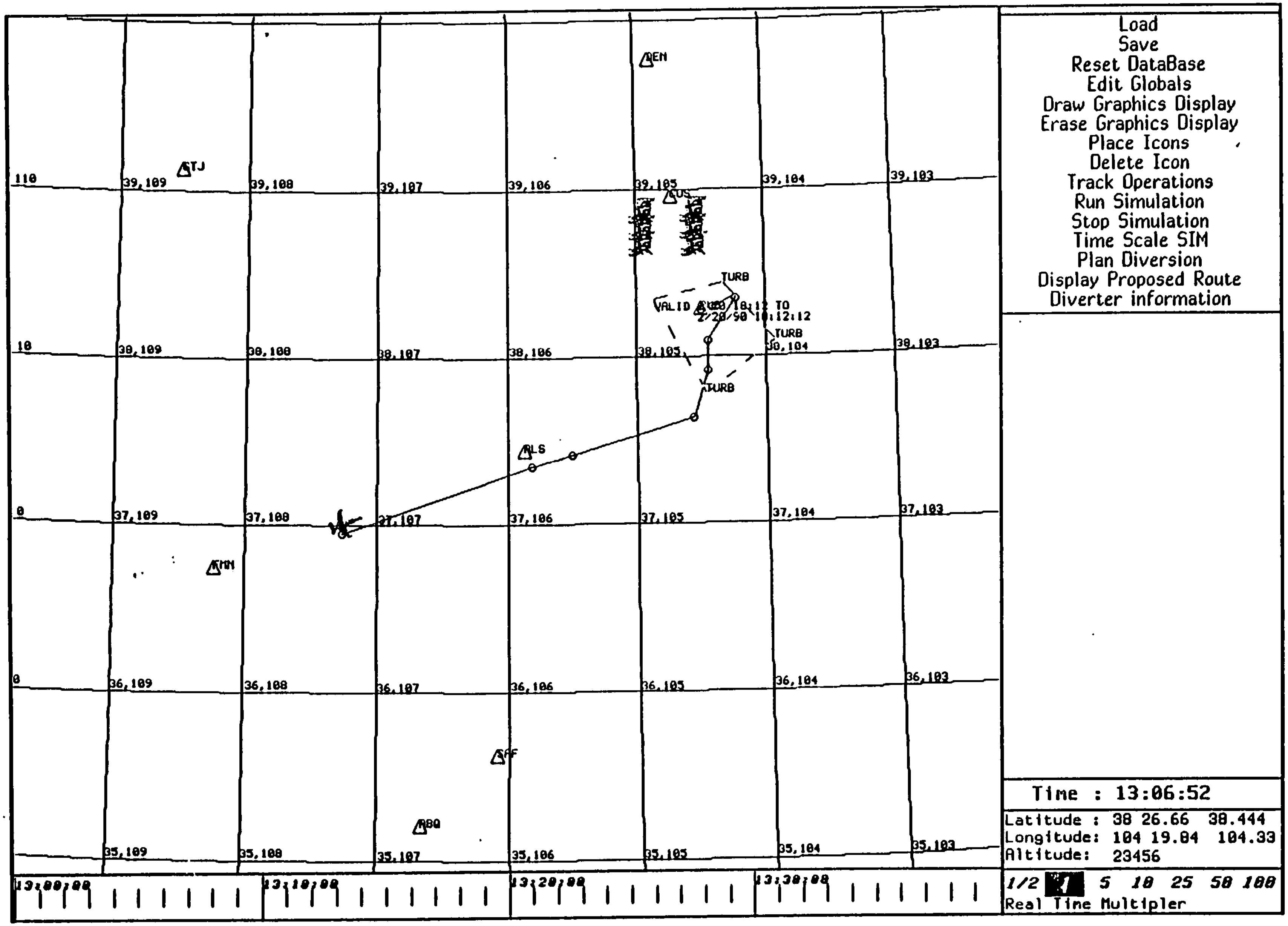


Figure D-6. Diverter is Notified of an Area of Severe Turbulence Around Pueblo.

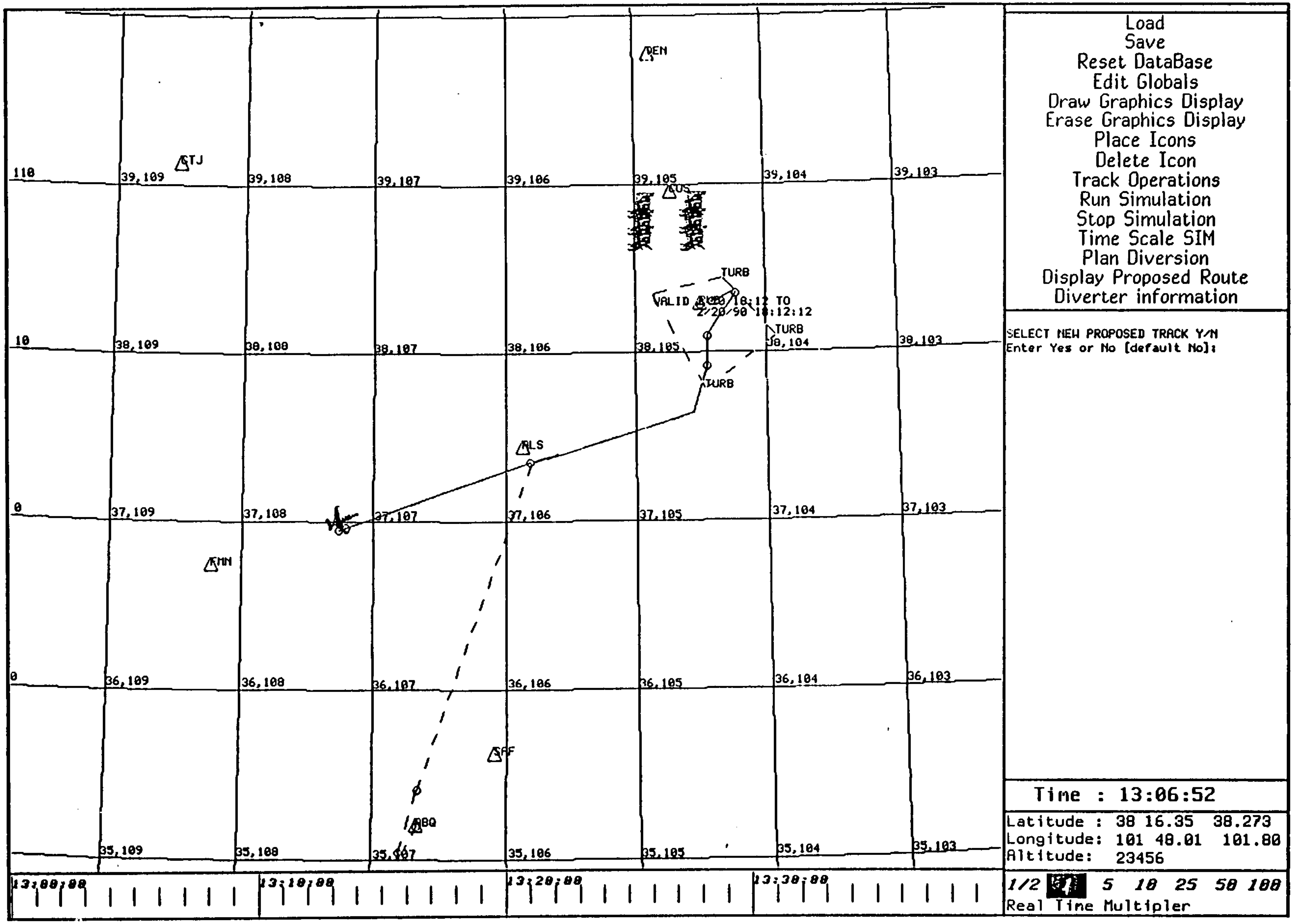


Figure D-7. Diverter Replans and Recommends a New Route to a New Destination of Albuquerque.

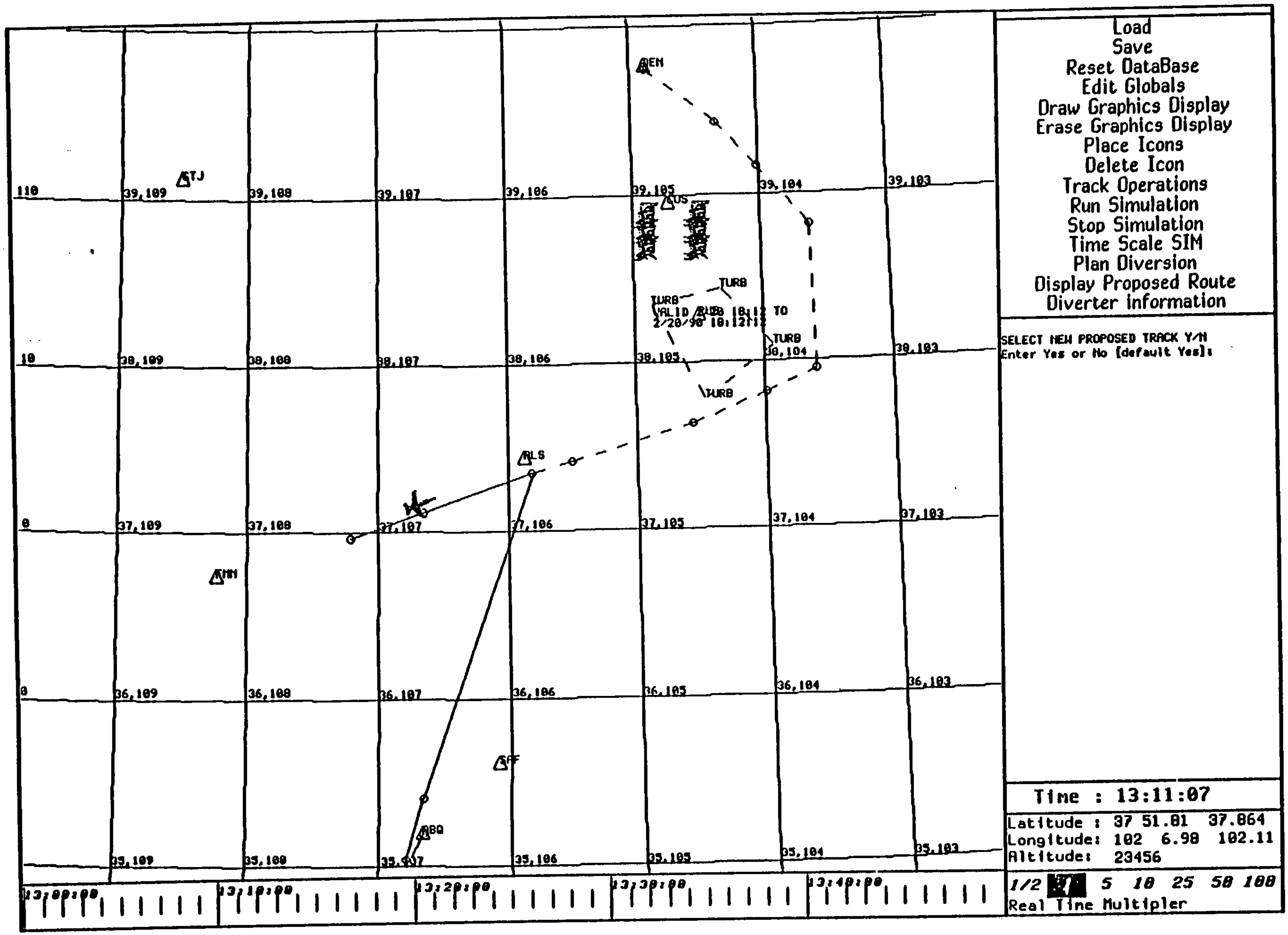


Figure D-8. After Change to Albuquerque has been Accepted, the Cabin Pressurization System Fails, and Diverter Replans and Recommends a New Route to a New Destination of Denver.

APPENDIX E

Information Analysis Database

The information contained in this appendix represents the results of an information analysis to determine the sources of information utilized by pilots in planning an in-flight diversion. The format of the database follows the functional flow diagrams contained in Appendix A. Pertinent system allocation is identified as well as the information used from the source.

The database then contains information as to what the sources of information for a given system are. These sources are enumerated in detail. They are divided among sources for the pilot and the Diverter system. This, to some degree, also specifies the route by which Diverter would receive the information. Generally this is through onboard communications links with systems or through either data link or manual input by the pilot.

Both current displays and controls as well as suggested Diverter displays and controls are also included in the database. The Diverter displays center on the functional requirements of presenting the information rather than the type of display to be used. Diverter control of systems is illustrated to a lesser degree in earlier sections of the database where the primary function is related to systems monitoring.

Finally, Pilot-Vehicle Interface concepts are included in the database, referencing both the expected and required displays as well as the availability. The latter is ascribed to the display of the information to the pilot through conventional flight displays as well as by Diverter separately.

Diverter Information Analysis

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.0	Mon. Sys. for Chg	None			
1.1	Acft Sys Status	Hydraulic	Fluid Quantity	Fluid Quant. Indicator Master Annunciator Decr. Control Effect.	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Hydraulic	Fluid Pressure	Fluid Pres. Indicator Master Annunciator Decr. Control Effect.	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Hydraulic	System Failure	Cockpit Displays Master Annunciator Inoperable Controls	Digital Interface Manual Pilot Input

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Fluid Quant. Display	None	Pilot Logic Query Fault Annunciation	None
Fluid Pres. Display	Boost Pump	Pilot Logic Query Fault Annunciation	None
Fluid Pres. Display Fluid Quant. Display Master Annunciator	Acknolwledge Annunciation	Pilot Logic Query Fault Annunciation	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
Info for pilot logic query Fault annunciation Info source disparity Pilot input	Continuous	Pilot Cmd.
Info for pilot logic query Fault annunciation Info source disparity Pilot input	Continuous	Pilot Cmd.
Info for pilot logic query Fault annunciation Info source disparity Pilot input	Available on Failure	Auto Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.1	Acft Sys Status	Electrical	Generator Voltage	Gen. Volt. Indicator Master Annunciator Dimming Lights Decr. Radio Range Part. Loss Elect. Sys.	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Electrical	Generator Oil Quant.	Gen. Oil Quant. Indicator Master Annunciator Incr. Gen. Oil Temp.	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Electrical	Generator Oil Temp.	Gen. Oil Temp. Indicator Master Annunciator	Digital Interface Manual Pilot Input

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Generator Voltage Display Master Annunciator	Cir. Break. - Master Bus.	Pilot Logic Query Fault Annunciation	None
Gen. Oil Quant. Display Master Annunciator	None	Pilot Logic Query Fault Annunciation	None
Gen. Oil Temp. Display Master Annunciator	None	Pilot Logic Query Fault Annunciation	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
Info for pilot logic query	Continuous	Pilot Cmd.
Fault Annunciation		
Info Source Disparity		
Pilot input		
Info for pilot logic query	Continuous	Pilot Cmd.
Fault Annunciation		
Info Source Disparity		
Pilot input		
Info for pilot logic query	Continuous	Pilot Cmd.
Fault Annunciation		
Info Source Disparity		
Pilot input		

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.1	Acft Sys Status	Electrical	Alternator Voltage	Alt. Volt. Indicator Master Annunciator	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Electrical	Alternator Amp.	Alt. Amp. Indicator Master Annunciator	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Electrical	Alternator Failure	Alt. Volt. Indicator Alt. Amp. Indicator Master Annunciator	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Electrical	Generator Failure	Gen. Volt. Indicator Master Annunciator	Digital Interface Manual Pilot Input

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Alt. Volt. Display Master Annunciator	Alt. Select. - Elect. Bus.	Pilot Logic Query Fault Annunciation	None
Alt. Amp. Display Master Annunciator	Alt. Select. - Elect. Bus.	Pilot Logic Query Fault Annunciation	None
Alt. Volt. Display Alt. Amp. Display Master Annunciator Power Bus.	Alt. Failure	Pilot Logic Query Fault Annunciation Loss of Elect. Instruments	None
Gen. Volt. Display Master Annunciator Power Bus.		Pilot Logic Query Fault Annunciation	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
Info for pilot logic query Fault Annunciation Info Source Disparity Pilot input	Continuous	Pilot Cmd.
Info for pilot logic query Fault Annunciation Info Source Disparity Pilot input	Continuous	Pilot Cmd.
Info for pilot logic query Fault Annunciation Info Source Disparity Pilot input	Available on Failure	Auto Pilot Cmd.
Info for pilot logic query Fault Annunciation Info Source Disparity Pilot input	Available on Failure	Auto Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.1	Acft Sys Status	Electrical	APU Status	Cockpit Display Master Annunciator	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Power Plant	N1 Ind.	N1 Indicators	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Power Plant	N2 Ind.	N2 Indicators	Digital Interface Manual Pilot Input

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
unknown		Pilot Logic Query Fault Annunciation	None
N1 Engine Display	Engine Start Settings Engine Power Settings	Pilot Logic Query Fault Annunciation	None
N2 Engine Display	Engine Start Settings Engine Power Settings	Pilot Logic Query Fault Annunciation	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
Info for pilot logic query Fault Annunciation Info Source Disparity Pilot input	Continuous	Auto if Fault Pilot Cmd.
	Continuous Engine Start	Auto if Fault Pilot Cmd.
	Continuous Engine Start	Auto if Fault Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.1	Acft Sys Status	Power Plant	Engine Press. Ratio	EPR Indicators Engine Noise	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Power Plant	RPM	Tachometer Engine Noise Vibration	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Power Plant	Cylinder Head Temp.	CHT Indicators	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Power Plant	Exhaust Gas Temp.	EGT Indicators Engine Roughness (too lean)	Digital Interface Manual Pilot Input

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
EPR Displays	Engine Throttle Settings	Pilot Logic Query Fault Annunciation	None
Engine Tachometers	Engine Power Settings	Pilot Logic Query Fault Annunciation	None
Engine CHT Gauges	Engine Power Settings Engine Cooling Settings	Pilot Logic Query Fault Annunciation	None
Engine EGT Gauges	Engine Power Settings Fuel Mixture Settings	Pilot Logic Query Fault Annunciation	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous	Auto if Fault Pilot Cmd.
	Continuous	Auto if Fault Pilot Cmd.
	Continuous	Auto if Fault Pilot Cmd.
	Continuous	Auto if Fault Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.1	Acft Sys Status	Power Plant	Manifold Press.	Manifold Pres. Guage	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Power Plant	Oil Quantity	Oil Quant. Indicators Engine Roughness RPM Loss	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Power Plant	Oil Pressure	Oil Pres. Indicators	Digital Interface Manual Pilot Input

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
	Engine Power Settings	Pilot Logic Query Fault Annunciation	None
Oil Quantity Gauges	None	Pilot Logic Query Fault Annunciation	None
Oil Pressure Gauges	Activate Boost Pump	Pilot Logic Query Fault Annunciation	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous	Auto if Fault Pilot Cmd.
	Continuous	Auto if Fault Pilot Cmd.
	Continuous	Auto if Fault Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.1	Acft Sys Status	Fuel	Fuel Quantity	Fuel Quant. Indicators. Master Annunciator FMC	Digital Interface Manual Pilot Input FMC
1.1	Acft Sys Status	Fuel	Fuel Pressure	Fuel Pres. Indicators Master Annunciator	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Fuel	Fuel Temp.	Fuel Temp. Indicators	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Press.	Cabin Altitude	Cabin Pres. Indicator	Digital Interface Manual Pilot Input

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Fuel Quant. Gauges FMC Display FMC Printout	Switch Tanks Chg. Consumption (power) Chg. Altitude Dump Fuel	Pilot Logic Query Low Fuel Annunciation Over Max. Ldg. Wt. Annunc. Range Allow. / Limit.	Instructions to FMC Auto Throttle Settings
Fuel Pres. Gauges	Fuel Boost Pump Fuel Cross Feed Red. Fuel Pump Activation	Pilot Logic Query Low Press Annunciation Pilot Command	None
Fuel Temp. Gauges	Act./Reset Fuel Heaters	Pilot Logic Query Fault Annunciation	None
Cabin Pres. Alt. Gauge	Adj. Cabin Alt. Controls Set Ctrl. Auto / Man. Decrease Actual Altitude Depressurize Aircraft	Pilot Logic Query Fault Annunciation	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous	Auto if Fault Pilot Cmd. Flight Planning
	Continuous	Auto if Fault Pilot Cmd.
	Continuous	Auto if Fault Pilot Cmd.
	Continuous	Auto if Fault Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.1	Acft Sys Status	Press.	System Failure	Cabin Pres. Indicator Master Annunciator	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Airframe Component	Trim	Trim Control Knob Display Ease of Control Movement	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Airframe Component	Access Doors	Annunciator Panel Master Annunciator	Digital Interface Manual Pilot Input

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Cabin Pres. Alt. Gauge Failure Annunciator	Reset Press. Sys. Decrease Altitude	Pilot Logic Query Fault Annunciation	None
Trim Control Position	Adjust Trim Amt.	Pilot Logic Query	None
Annunciator Panel Master Annunciator	None	Pilot Logic Query Fault Annunciation	None

C.3

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Available on Failure	Auto if Fault Pilot Cmd.
	Continuous	Pilot Cmd.
	Available on Failure	Auto if Fault Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.1	Acft Sys Status	Airframe Component	Spoilers	Control Position Annunciator	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Airframe Component	Flaps	Flap Handle Position Flap Position Display Aircraft Vibration	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Airframe Component	Slats	Slat Handle Position Control Surface Display Aircraft Vibration	Digital Interface Manual Pilot Input
1.1	Acft Sys Status	Airframe Component	Landing Gear	Landing Gear Position Lights Aircraft vibration Aircraft Noise Landing Gear Handle Position	Digital Interface Manual Pilot Input

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Control Position Display Annunciator Display	Adjust Spoilers	Pilot Logic Query Fault Annunciation	None
Flap Handle Position Position Display	Adjust Flaps Reduce Speed if Fault	Pilot Logic Query Fault Annunciation	None
Slat Handle Position Control Display	Adjust Slat Setting Adjust Flight Parameters	Pilot Logic Query Fault Annuncation	None
Landing Gear Position lights Landing gear handle position	Chg. Gear Position Manual Drop Visual Verification Gear up ldg/Gear Down Flt	Pilot Logic Query Fault Annunciation	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous	Auto if Fault Pilot Cmd.
	Continuous	Auto if Fault Pilot Cmd.
	Continuous	Auto if Fault Pilot Cmd.
	Continuous	Auto if Fault Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.1	Acft Sys Status	Airframe Component	Speed Brake	Speed Brake Lever Position Aircraft Handling Characteristics	Digital Interface Manual Pilot Input
1.2	Traffic Status	None	Traffic Oper. Area	ATC Clearances/Directives Direct Observation Pilot (other)/ATC Voice Comm TCAS	ATC (Datalink) Manual Pilot Input Digital TCAS Interface
1.2	Traffic Status	None	Dest. Appch. Traffic	ATC Clearances/Directives ATC Amended Clearances ATC Delay Clearances	ATC Amended Clearances ATC Delay Clearances Manual Pilot Input

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Speed Brake Lever Position	Deploy/Retract Red. V Inc. V if Stall Immin.	Pilot Logic Query Fault Annunciation	None
Voice ATC Diverter Display	See and Avoid ATC Vector Around Resp to TCAS Cmd.	Pilot Logic Display ATC Datalink Display TCAS Alert Display Diversion Plan. Display	Heading/Route Selection
ATC Voice (Radio)	Course or Route Change Execute Holding Procedure	Datalink communications Flight Planning Info	Navigation Evaluation Navigation Update

Interface Display	Pilot Display Avail.	Divertor Display Avail.
	Continuous	Auto if Fault Pilot Cmd.
	Available at Conflict Available Cont (sit. Aware)	Traffic Conflict ATC Dat. Comm. (Cue/All) TCAS Alert Div. Flight Planning
	Available when clearance given	Pilot Cmd. Cue information pending Flight Planning

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.2	Traffic Status	None	Dest. Traffic Await Depart.	Amended Clearance Delay Clearance Procedures	ATC Amended Clearances ATC Delay Clearances Manual Pilot Input
1.3	Weather Status	Ceiling	Current/ Forcast WX (Route / Dest.)	Preflight FSS WX Briefing	Preflight Database Upload
1.3	Weather Status	Ceiling	Current/ Forcast WX (Route / Dest.)	Preflight Co. WX Briefing	Preflight Database Upload
1.3	Weather Status	Ceiling	Current/ Forcast WX (Route / Dest.)	Enroute FSS Update	Enroute Datalink Update

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
ATC Voice (radio)	Course or Route Change Execute Holding Procedure	Datalink communications Flight Planning Info	Navigation Evaluation Navigation Update
Txt. Disp. (Print Preflt. WX)	None	Txt. Disp.	Info. Display
Txt. Disp. (Print Preflt. WX)	None	Txt. Disp.	Info Display
Audio w/FSS (Radio)	None	Txt. Disp. Audio Disp.	Disp. Presentation

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Available when Clearance given	Pilot Cmd. Cue information pending Flight Planning
	Continuous During Preflight Pilot Cmd.	Pilot Cmd. Auto in Div. Flt. Planning Auto Pil. Chg. causes Conflict
	Continuous During Preflight Pilot Cmd.	Pilot Cmd. Auto in Div. Flt. Planning Auto Pil. chg. causes Conflict
	Pilot Cmd.	Pilot Cmd. Auto Msg. Cue Pilot Logic Query Auto if Conflict

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.3	Weather Status	Ceiling	Current/ Forcast WX (Route / Dest.)	Enroute ATC Advisories	Enroute Datalink Update
1.3	Weather Status	Ceiling	Current/ Forcast WX (Route / Dest.)	Terminal ATC Advisories	Enroute Datalink Update
1.3	Weather Status	Ceiling	Current/ Forcast WX (Route / Dest.)	Pilot-Pilot Communications	Man. Pilot Input Voice Recog. (Doubtful)

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Audio w/ATC (Radio)	None	Txt. Disp. Audio Disp.	Disp. Presentation
Audio w/ATC (Radio)	None	Txt. Disp. Audio Disp.	Disp. Presentation
Audio (Monitoring)	None	Pilot Logic Query	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Advisory Transmission Pilot Cmd.	Pilot Cmd. Auto Msg. Cue Pilot Logic Query Auto if Conflict
	Advisory Transmission Pilot Cmd.	Pilot Cmd. Auto Msg. Cue Pilot Logic Query Auto if Conflict
	Continuous Limited to Freq. Used	Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.3	Weather Status	Ceiling	Current/ Forcast WX (Route / Dest.)	Pilot-ATC Communications	Man. Pilot Input Voice Recog. (Doubtful)
1.3	Weather Status	Visibility	Current/ Forcast WX (Route / Dest.)	Preflight FSS WX Briefing	Preflight Database Upload
1.3	Weather Status	Visibility	Current/ Forcast WX (Route / Dest.)	Preflight Co. WX Briefing	Preflight Database Upload
1.3	Weather Status	Visibility	Current/ Forcast WX (Route / Dest.)	Enroute FSS Update	Enroute Datalink Update

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Audio (Monitoring)	None	Pilot Logic Query	None
Txt. Disp. (Print Preflt. WX)	None	Txt. Disp.	Info. Display
Txt. Disp. (Print Preflt. WX)	None	Txt. Disp.	Info. Display
Audio w/FSS (Radio)	None	Txt. Disp. Audio Disp.	Disp. Presentation

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous Limited to Freq. Used	Pilot Cmd.
	Continuous During Preflight Pilot Cmd.	Pilot Cmd. Auto in Div. Flt. Planning Auto Pil. Chg. causes Conflict.
	Continuous During Preflight Pilot Cmd.	Pilot Cmd. Auto in Div. Flt. Planning Auto Pil. Chg. causes Conflict
	Pilot Cmd.	Pilot Cmd. Auto Msg. Cue Pilot Logic Query Auto if Conflict

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.3	Weather Status	Visibility	Current/ Forcast WX (Route / Dest.)	Enroute ATC Advisories	Enroute Datalink Update
1.3	Weather Status	Visibility	Current/ Forcast WX (Route / Dest.)	Terminal ATC Advisories	Enroute Datalink Update
1.3	Weather Status	Visibility	Current/ Forcast WX (Route / Dest.)	Pilot-Pilot Communications	Man. Pilot Input Voice Recog. (Doubtful)

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Audio w/ATC (Radio)	None	Txt. Disp. Audio Disp.	Disp. Presentation
Audio w/ATC (Radio)	None	Txt. Disp. Audio Disp.	Disp. Presentation
Audio (Monitoring)	None	Pilot Logic Query	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Advisory Transmission Pilot Cmd.	Pilot Cmd. Auto Msg. Cue Pilot Logic Query Auto if Conflict
	Advisory Transmission Pilot Cmd.	Pilot Cmd. Auto Msg. Cue Pilot Logic Query Auto if Conflict
	Continuous Limited to Freq. Used	Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.3	Weather Status	Visibility	Current/ Forcast WX (Route / Dest.)	Pilot-ATC Communications	Man. Pilot Input Voice Recog. (Doubtful)
1.3	Weather Status	Thunder-storms	Current/ Forcast WX (Route / Dest.)	Preflight FSS WX Briefing	Preflight Database Upload
1.3	Weather Status	Thunder-storms	Current/ Forcast WX (Route / Dest.)	Preflight Co. WX Briefing	Preflight Database Upload
1.3	Weather Status	Thunder-storms	Current/ Forcast WX (Route / Dest.)	Enroute FSS Update	Enroute Datalink Update

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Audio (Monitoring)	None	Pilot Logic Query	None
Txt. Disp. (Print Preflt. WX)	None	Txt. Disp.	Info. Display
Txt. Disp. (Print Preflt. WX)	None	Txt. Disp.	Info. Display
Audio w/FSS (Radio)	None	Txt. Disp. Audio Disp.	Disp. Presentation

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous Limited to Freq. Used	Pilot Cmd.
	Continuous During Preflight Pilot Cmd.	Pilot Cmd. Auto in Div. Flt. Planning Auto Pil. Chg. causes Conflict
	Continuous During Preflight Pilot Cmd.	Pilot Cmd. Auto in Div. Flt. Planning Auto Pil. Chg. causes Conflict
	Pilot Cmd.	Pilot Cmd. Auto Msg. Cue Pilot Logic Query Auto if Conflict

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.3	Weather Status	Thunder-storms	Current/ Forcast WX (Route / Dest.)	Enroute ATC Advisories	Enroute Datalink Update
1.3	Weather Status	Thunder-storms	Current/ Forcast WX (Route / Dest.)	Terminal ATC Advisories	Enroute Datalink Update
1.3	Weather Status	Thunder-storms	Current/ Forcast WX (Route / Dest.)	Onboard WX Radar	Digital Interface w/ Radar Man. Pilot Input

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Audio w/ATC (Radio)	None	Txt. Disp. Audio Disp.	Disp. Presentation
Audio w/ATC (Radio)	None	Txt. Disp. Audio Disp.	Disp. Presentation
Radar Disp. Cell Locations Return Density	Range Select Tilt	Pilot Logic Query	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Advisory Transmission Pilot Cmd.	Pilot Cmd. Auto Msg. Cue Pilot Logic Query Auto if Conflict
	Advisory Transmission Pilot Cmd.	Pilot Cmd. Auto Msg. Cue Pilot Logic Query Auto if Conflict
	Continuous Pilot Cmd.	Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.3	Weather Status	Thunder-storms	Current/ Forcast WX (Route / Dest.)	Pilot-Pilot Communications	Man. Pilot Input Voice Recog. (Doubtful)
1.3	Weather Status	Thunder-storms	Current/ Forcast WX (Route / Dest.)	Pilot-ATC Communications	Man. Pilot Input Voice Recog. (Doubtful)
1.3	Weather Status	Turbulence	Current/ Forcast WX (Route / Dest.)	Preflight FSS WX Briefing	Preflight Database Upload
1.3	Weather Status	Turbulence	Current/ Forcast WX (Route / Dest.)	Preflight Co. WX Briefing	Preflight Database Upload

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Audio (Monitoring)	None	Pilot Logic Query	None
Audio (Monitoring)	None	Pilot Logic Query	None
Txt. Disp. (Print Preflt. WX)	None	Txt. Disp.	Info. Display
Txt. Disp. (Print Preflt. WX)	None	Txt. Disp.	

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous Limited to Freq. Used	Pilot Cmd.
	Continuous Limited to Freq. Used	Pilot Cmd.
	Continuous During Preflight Pilot Cmd.	Pilot Cmd. Auto in Div. Flt. Planning Auto Pil. Chg. causes Conflict
	Continuous During Preflight Pilot Cmd.	

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.3	Weather Status	Turbulence	Current/ Forcast WX (Route / Dest.)	Enroute FSS Update	Enroute Datalink Update
1.3	Weather Status	Turbulence	Current/ Forcast WX (Route / Dest.)	Enroute ATC Advisories	Enroute Datalink Update
1.3	Weather Status	Turbúlence	Current/ Forcast WX (Route / Dest.)	Terminal ATC Advisories	Enroute Datalink Update

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Audio w/FSS (Radio)	None	Txt. Disp. Audio Disp.	Disp. Presentation
Audio w/ATC (Radio)	None	Txt. Disp. Audio Disp.	Disp. Presentation
Audio w/ATC (Radio)	None	Txt. Disp. Audio Disp.	Disp. Presentation

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Pilot Cmd.	Pilot Cmd. Auto Msg. Cue Pilot Logic Query Auto if Conflict
	Advisory Transmission Pilot Cmd.	Pilot Cmd. Auto Msg. Cue Pilot Logic Query Auto if Conflict
	Advisory Transmission Pilot Cmd.	Pilot Cmd. Auto Msg. Cue Pilot Logic Query Auto if Conflict

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.3	Weather Status	Turbulence	Current/ Forcast WX (Route / Dest.)	Onboard WX Radar Indirect (Thunderstorm areas)	Digital Interface w/ Radar Man. Pilot Input
1.3	Weather Status	Turbulence	Current/ Forcast WX (Route / Dest.)	Pilot-Pilot Communications	Man. Pilot Input Voice Recog. (Doubtful)
1.3	Weather Status	Turbulence	Current/ Forcast WX (Route / Dest.)	Pilot-ATC Communications	Man. Pilot Input Voice Recog. (Doubtful)
1.3	Weather Status	Winds(Aloft Surface)	Current/ Forcast WX (Route / Dest.)	Preflight FSS WX Briefing	Preflight Database Upload

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Radar Disp.	Range Select	Pilot Logic Query	None
Audio (Monitoring)	None	Pilot Logic Query	None
Audio (Monitoring)	None	Pilot Logic Query	None
Txt. Disp. (Print Preflt. WX)	None	Txt. Disp.	Info. Display

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous Pilot Cmd.	Pilot Cmd.
	Continuous Limited to Freq. Used	Pilot Cmd.
	Continuous Limited to Freq. Used	Pilot Cmd.
	Continuous During Preflight Pilot Cmd.	Pilot Cmd. Auto in Div. Flt. Planning Auto Pil. Chg. causes Conflict

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.3	Weather Status	Winds(Aloft Surface)	Current/ Forcast WX (Route / Dest.)	Preflight Co. WX Briefing	Preflight Database Upload
1.3	Weather Status	Winds(Aloft Surface)	Current/ Forcast WX (Route / Dest.)	Enroute FSS Update	Enroute Datalink Update
1.3	Weather Status	Winds(Aloft Surface)	Current/ Forcast WX (Route / Dest.)	Enroute ATC Advisories	Enroute Datalink Update

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Txt. Disp. (Print Preflt. WX)	None	Txt. Disp.	Info. Display
Audio w/FSS (Radio)	None	Txt. Disp. Audio Disp.	Disp. Presentation
Audio w/ATC (Radio)	None	Txt. Disp. Audio Disp.	Disp. Presentation

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous During Preflight Pilot Cmd.	Pilot Cmd. Auto in Div. Flt. Planning Auto Pil. Chg. causes Conflict
	Pilot Cmd.	Pilot Cmd. Auto Msg. Cue Pilot Logic Query Auto if Conflict
	Advisory Transmission Pilot Cmd.	Pilot Cmd. Auto Msg. Cue Pilot Logic Query Auto if Conflict

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.3	Weather Status	Winds(Aloft Surface)	Current/ Forcast WX (Route / Dest.)	Terminal ATC Advisories	Enroute Datalink Update
1.3	Weather Status	Winds(Aloft Surface)	Current/ Forcast WX (Route / Dest.)	Pilot-Pilot Communications	Man. Pilot Input Voice Recog. (Doubtful)
1.3	Weather Status	Winds(Aloft Surface)	Current/ Forcast WX (Route / Dest.)	Pilot-ATC Communications	Man. Pilot Input Voice Recog. (Doubtful)
1.4	Acft Route Progress	None	Aircraft Attitude	Altimeter	Altimeter (dig. interface)

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Audio w/ATC (Radio)	None	Txt. Disp. Audio Disp.	Disp. Presentation
Audio (Monitoring)	None	Pilot Logic Query Disp.	None
Audio (Monitoring)	None	Pilot Logic Query Disp.	None
Altimeter	Pitch/Power Changes	Pilot Logic Query Disp.	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Advisory Transmission Pilot Cmd.	Pilot Cmd. Auto Msg. Cue Pilot Logic Query Auto if Conflict
	Continuous Limited to Freq. Used	Pilot Cmd.
	Continuous Limited to Freq. Used	Pilot Cmd.
	Continuous	Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.4	Acft Route Progress	None	Aircraft Attitude	Vert. Speed Indic.	Vert. Speed (dig. Interface)
1.4	Acft Route Progress	None	Aircraft Attitude	Directional Gyro	Dir. Gyro (Dig. Interface)
1.4	Acft Route Progress	None	Aircraft Attitude	Attitude Indicator	AI (Dig. Interface)

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Vert. Speed Indicator	Pitch/Power Changes	Pilot Logic Query Disp.	None
Directional Gyro or HSI	Roll and Yaw Changes Emerg - Power setting Poss.	Pilot Logic Query Disp.	None
Attitude Indicator/HUD/ETC	Roll, Pitch, Yaw Changes	None Pilot Logic Query Disp. Divert. Flt. Planning disp.	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous	Pilot Cmd.
	Continuous	Pilot Cmd.
	Continuous	Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.4	Acft Route Progress	None	Map Pos.	Lat/Long. Information	Inertial Navigation Sys. RNAV Sys. Loran Sys.
1.4	Acft Route Progress	None	Map Pos.	Pos. Ref Multiple VOR's Pos. Ref Single VOR w/DME	VOR (dig. interface) DME (dig. interface) Flight Director
1.4	Acft Route Progress	None	Map Pos.	Pos. Ref ADF	ADF (dig. Interface)
1.4	Acft Route Progress	None	Map Pos.	Pos. Ref Ground	Man. Pilot Input

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Cockpit Nav. Display	Select display	Txt. Symbolic Pilot Logic Query Disp. Divert. Flt. Planning Disp.	Poss. Station/Source Selection
VOR Course Deviation Indicator VOR Azimuth DME (Station Distance) Mult. VOR Point Intercept	Select VOR/DME	Symbolic Pilot Logic Query Disp. Divert. Flt. Planning Disp.	Display Selection Poss. Station/Source Selection
ADF Multiple ADF's	Select ADF Stations	Symbolic Pilot Logic Query Disp. Divert. Flt. Planning Disp.	Display Selection Poss. Station Selection
Ground Landmarks	None	Symbolic	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Pilot Cmd.	Pilot Cmd. Div. Flt. Planning
	Continuous	Pilot Cmd. Divert. Flt. Plan Present.
	Continuous	Pilot Cmd. Div. Flt. Planning Pilot Logic Query
	Cont. if VFR Day Intermitant/None dep on IMC	Pilot Cmd. Div. Flt. Planning

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.4	Acft Route Progress	None	Map Pos.	ATC Advisory (Radio)	ATC Advisory (datalink)
1.4	Acft Route Progress	None	Map Pos.	Moving Map Display	Moving Map - Dig. Interface Digital Database Route Attr.
1.4	Acft Route Progress	None	IFR Route Pos.	VOR Radial/Dme Location Flight Director Location Info RNAV Location Info Printed Charts Map Display	Navigational Digital Interface Digital Database Appch. Attr.

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Audio ATC advisory	None	Txt. on CDU	None
Moving Map Display	Pilot Sys. Selection	Symbolic	n/a
VOR/DME Printed Charts Flight Director Displays RNAV Displays	Display/System Selection	Symbolic	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Pilot Request At ATC Advisory	Pilot Cmd. Auto Msg. Cuing Pilot Logic Query Divert. Flt. Planning
	Pilot Cmd. Selection Continuous	n/a
	Continuous	n/a

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
1.4	Acft Route Progress	None	Aprch. Route Position	VOR/DME/ILS Nav Sys's Flight Director Approach Plates Approach Map Display	Navigation Digital Interface Digital Database Appch. Attr.
1.4	Acft Route Progress	None	Traffic Proximity Position	Visual References ATC Information Changes in ATC Clearance TCAS	Poss. ATC Datalink Manual Pilot Input TCAS Digital Interface
1.4	Acft Route Progress	None	Terrain Proximity Position	Acft Att. (prev. Function) Ground Proximity Warning Radar Altitude Printed Material Map Display	Acft Att. Indic. dig. intface. GPW Dig. Interface Radar Alt. Digital Interface Digital Database - Route Attr.
2.0	Impact Assess.	None			

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
VOR/DME CDI/OBS/Dist Disp. Flight Director Displays Approach Plates/Elect. Displays	Display/System Selection	Symbolic	None
Visual Monitoring Audio ATC directives	None	Symbolic Text - of traffic positions	None
Primary Flt. Displays GPW Display Radar Alt Display Printed Map Material Electronic Map Display	None	Symbolic Text	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous	Pilot Cmd. - Logic Query
	Continuous	Pilot Cmd. Auto Traffic Conflict
	Continuous Pilot Cmd.	Pilot Cmd. Auto Terrain Proximity Alert

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
2.1	Reliab. Assess.	Info. Quality	Regularity of Dissem.	Source Knowledge Prior Source Experience Source Regularity Info Perceived Source Update Info	Source Info Database Source Update Rate (inst)
2.1	Reliab. Assess.	Info. Quality	Reasp. for Dissem.	Source Knowledge Prior Source Experience Source Regularity Info	Source Info Database
2.1	Reliab. Assess.	Info. Quality	Info. Quality Standards	Source Knowledge Prior Source Experience Source Regularity Info	Source Info Database

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Text Date/Time Info Perception	None	Txt.	None
None	None	Txt	None
None	None	Txt	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous	Pilot Cmd (logic Query)
	Continuous	Pilot Cmd. (logic Query)
	Continuous	Pilot Cmd. (logic Query)

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
2.1	Reliab. Assess.	Info. Quality	Info. Redundancy	System Operational Knowledge Same info. on Mult. Displays Same info from Mult. Systems	Sys Arch. Info-Rules/Database Compar. Red. Inst. Info.
2.1	Reliab. Assess.	Info. Consist.	Congruence of Mult. Sources	Info. from Mult. NonRed. Sys's	Sys Arch. Info-Rules/Database Compar. NonRed. Inst. Info.
2.1	Reliab. Assess.	Info. Consist.	Congruence w/ Mental Models	Info. from Mult. NonRed. Sys's Pilot Knowledge (training) Pilot Mental Model	Sys Arch. Info-Rules/Database Compare System Information
2.1	Reliab. Assess.	Info. Consist.	Acceptable Level of Inaccuracy	Knowledge of Source Know. Source Accuracy Stand. Acc. Attrib. Contrl. Limit.	Database Weighting of Sources Poss. Comparison of Acc. lev.

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Flt/Nav/Systems Displays	None	Txt	None
Flt/Nav/Systems Displays	None	Txt	None
Flt/Nav/Systems Displays	None	Txt	None
none	none	Txt	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous	Pilot Cmd. (logic Query)
	Continuous	Pilot Cmd. (logic Query)
	Continuous	Pilot Cmd. (logic Query)
	n/a	Pilot Cmd. (Logic Query)

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
2.1	Reliab. Assess.	Info. Consist.	Previous Experience with Inaccuracy	Pilot Experience	Database Weighting of Sources Poss. Comparison of Acc. lev.
2.2	Signif. Assess.	None			
2.2.1	Affects Perf.	None	Calc. (expect) Perf. Current Perf.	Flt. Mgmt. Comp. Perf. Calc. Sys's Info.	Avionics Dig. Inter. FMC Dig. Inter.

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
none	none	Txt	None
FMC Output Written Calculations Sys's Indic (airspeed,climb)	Adj. Flt. Param. Adj. Flt. Plan	Txt Symbolic	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	n/a	Pilot Cmd. (Logic Query)
	Pilot Cmd. Continuous	Pilot Cmd. (info query) Pilot Cmd. (logic query)

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
2.2.2	Dest/Route Chg.	None	Calc. Current/Forcast Perf. Flight Plan Info. Destination Info.	Flight Managment Computer Comparison to Flt. Plan Calc. Flight Director	Flight Management Computer Dig. Flt. Info Database Flt. Dir. Dig. Interface
2.2.3	Passenger Safety	None	Safety Threat Info. Sys's/Flt Att/Conflict Info.	Pilot Experience Pilot Knowledge Acft. Sys's Info. Conflict Info (sit. Awareness)	Flt. Database Dig. Interface Flt. Sys's Dig. Interface
2.2.4	Perf. Capab.	None	Acft. Sys's Knowledge Acft. Sys's Status Info Current / Expected Perf.	Training Acft. Sys's Displays FMC Flt. Plan	Acft. Flt. Attr. Database Flt. Sys's Dig. Interface FMC Dig. Interface Flt. info. Dig. Int.
2.2.5	Assess Impact	None	Info From 2.2.2	Flight Managment Computer Comparison to Flt. Plan Calc. Flight Director	Flight Management Computer Dig. Flt. Info Database Flt. Dir. Dig. Interface

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
FMC Output Display Txt. Flight Plan Info	None	Txt Symbolic	None
sys's info (sym/txt) Conflict info (aud/Sym/Txt)	Acft. Route Chg. Acft. Att. Chg.	Symbolic Txt	None
Acft. Flt. Info. Disp. FMC Display Txt. Flt. Plan	None	Txt	None
Symbolic and Textual Display	Adj. Flight Plan / Perf. Param	Txt Symbolic	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Pilot Cmd. Continuous	Pilot Cmd. (Info. Query) Pilot Cmd. (Logic Query)
	Cont. Flt. Disp. Cont. Traffic/Conflict Disp.	Pilot Cmd. (Info Query) Pilot Cmd. (logic Query)
	Continuous Pilot Cmd.	Pilot Cmd. (logic query) Pilot Cmd. (info. query)
	Continuous	Pilot Cmd. (logic Query) Pilot Cmd. (info. Query) Auto - Conflict (traf./Route)

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
2.2.6	Safety Effect	None	Info From 2.2.3	Pilot Experience Pilot Knowledge Acft. Sys's Info. Conflict Info (sit. Awareness)	Flt. Database Dig. Interface Flt. Sys's Dig. Interface
2.2.7	Evaluate Signif.	None			
3.0	Assess Response Options	None			

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
sys's info (sym/txt) Conflict info (aud/Sym/Txt)	Acft. Route Chg. Acft. Att. Chg.	Symbolic Txt	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Cont. Flt. Disp.	Pilot Cmd. (Info Query)
	Cont. Traffic/Conflict Disp.	Pilot Cmd. (logic Query)

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
3.1	Req. Emerg. Action	None	Safety/accept. continued flt. w/ normal procedures	Performance Calc. Diff b/t Expected/Minim. Perf. Nav. Status for Env./traffic Onboard Emergencies	Dig. Flt. Inst. Interface FMC Digital Interface Database of Perf. Levls Nav. Conflict Status Pilot Input
3.2	Need for Diversion		Current System's Status Current Nav. Position Current Flt. Attitude Enroute Terrain Conflicts Enroute/Dest. WX/Traffic Obst. Onboard Emerg. Info Acft. Performance	Nav/Flt/Eng. Sys's Print/Elect. Map Enr/Dest WX/Traffic Advisories Crew Member Info Disp/Calc Perform. Measures	Digital Sys's Interface Dig Nav Sys Interface WX/ATC Database & Datalink Pilot Onboard Emerg. Input Data/Rulebase Acft Perform.
3.2.1	Emer. Req. Flt. Plan Chg.	None	Forcast Performance Minimum Req. Performance Deter. Flt. Cont. w/Perform.	Flt./Nav./Eng. Sys FMC/Flt. Dir. Perf. From FMC/Charts	Flt./Nav./Eng. Dig. Int. FMC/Flt. Dir. Dig. Interface Perf. Database
3.2.2	Acft. Cap. Req. Flt Chg.	None	Forcast Performance Minimum Req. Performance Deter. Flt. Cont. w/Perform.	Flt./Nav./Eng. Sys FMC/Flt. Dir. Perf. From FMC/Charts	Flt./Nav./Eng. Dig. Int. FMC/Flt. Dir. Dig. Interface Perf. Database

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Eng./Nav./Flight Displays FMC Displays Txt. Perf. Calc.	Flt. Att./Nav. Changes Engine Power Changes	Txt.	None
Flt./Nav./Eng. Disp. FMC/Flt Dir. Prnt/Verbal WX/ATC Advis./Clnc Audio(verbal) onbrd. Emerg. Perf. Graphs/Tbls/Knowledge	Info Source Select. Perf. Disp Read/Calc.	Txt Symbolic	None
Flt./Nav./Eng. Displays FMC Displays Perf. from Computer/Tables	Display Selection Flt./Eng./Nav. Perf. Chgs.	Txt. Symbolic	None
Flt./Nav./Eng. Displays FMC Displays Perf. from Computer/Tables	Display Selection Flt./Eng./Nav. Perf. Chgs.	Txt. Symbolic	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous Pilot Cmd.	Auto. in Emerg. Cond. Pilot Cmd. (logic/info Query)
	Continuous Pilot Cmd. As Req.	Auto in Emerg. Cond. Pilot Cmd. (logic/Info Query)
	Continuous Pilot Cmd.	Emerg. Annun. Pilot Cmd. (Logic/Info Query)
	Continuous Pilot Cmd.	Emerg. Annun. Pilot Cmd. (Logic/Info Query)

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
3.2.3	WX Req. Flt	None	WX Data	Pre/InFlt WX Advisories	
	Plan Chg.		Forcast Perf.	Flt./Nav./Eng. Sys	Flt./Nav./Eng. Dig. Int.
			Min. Req. Perf.	FMC/Flt. Dir.	FMC/Flt. Dir. Dig. Interface
			Deter. Flt. Cont. w/ Perform.	Perf. From FMC/Charts	Perf. Database
3.2.4	Exist. Route	None	Forcast Performance	Flt./Nav./Eng. Sys	Flt./Nav./Eng. Dig. Int.
	Viable		Terrain Conflicts	FMC/Flt. Dir.	FMC/Flt. Dir. Dig. Interface
			Traffic Conflicts	Perf. From FMC/Charts	Perf. Database
			Airspace Conflicts	Terrain info : charts	Terrain Info : Datab+se
			WX Conflicts	Traffic Info : ATC Comm.	Traffic Info : ATC Datalink
			Minimum Req. Performance	Airspace Confl: ATC/Charts	Airspace Confl : ATC Datlink
			Deter. Flt. Cont. w/Perform.	WX Conflicts:ATC/Radar/Brief	WX:Dig Int Radar/ATC Datlink
				WX Conflicts:ATC/Radar/Brief	Close Traffic : TCAS Dig. Int.
3.3	No Action	None	Forcast Performance	Flt./Nav./Eng. Sys	Flt./Nav./Eng. Dig. Int.
	Req.		Minimum Req. Performance	FMC/Flt. Dir.	FMC/Flt. Dir. Dig. Interface
			Deter. Flt. Cont. w/Perform.	Perf. From FMC/Charts	Perf. Database

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Audio/Txt. WX Reports Flt./Nav./Eng. Displays FMC Displays Perf. from Computer/Tables	Display Selection Flt./Eng./Nav. Perf. Chgs.	Txt. Symbolic	None
Flt./Nav./Eng. Displays FMC Displays Perf. from Computer/Tables Terrain:Charts / ATC Advise. Traffic:Audio ATC Airspace:Charts/ATC WX:PreFlt Txt;ATC Audio WX: Radar symbolic	Display Selection Flt./Eng./Nav. Perf. Chgs.	Txt. Symbolic	None
Flt./Nav./Eng. Displays FMC Displays Perf. from Computer/Tables	Display Selection Flt./Eng./Nav. Perf. Chgs.	Txt. Symbolic	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	As Available Continuous Pilot Cmd.	Emerg. Annun. Pilot Cmd. (Logic/Info Query)
	Continuous Pilot Cmd.	Emerg. Annun. Pilot Cmd. (Logic/Info Query)
	Continuous Pilot Cmd.	Emerg. Annun. Pilot Cmd. (Logic/Info Query)

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
4.0	Exec. Emerg. Action	None			
5.0	Assess Diversion Requirements	Subsect			
5.1	Landing Point Assessment	Subsect			
5.1.1	WX Cond. at Landing Pt.	Subsect			

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Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
5.1.1.1	Set Time Windows		Current Location Route to Destination Distance to Destination ETA to Destination Current Time Possible Holds/Clearance Chg. Segment Performance Traffic Conflicts Maximum Endurance	Radio Nav. Equip. Flt. Director/Loran/INS/GNS Enroute Charts/App Plates ATC Radar Advisories Flight Plan Perf from FMC ATC/Traffic Delays from ATC ATC/Traffic Delays from ATC ATC Radar Advisories Flight Management Computer	Radio Nav. Dig. Int. Dig. Int. w/ Flt Nav Equip. Database Chart/App. Plate Info ATC Datalink Radar Advisories Database Flight Plan Info Database Perf. Info Dig. Int. FMC for Perf Info Traf/ATC Delays ATC datalink Radar Adv. from ATC Datalink FMC dig. Int.
5.1.1.2	Assess Field @ Arr. Wind.		Field WX at ETA Status of Field at ETA Facility Avail. at ETA	WX : Preflt. WX brief WX : Enroute ATC/FSS updates WX : ATIS updates Field : Enroute ATC/FSS update Facilites:ATC/FSS/Company Facilites:ATIS/Notams	WX Prflt:WX database WX Update:FSS Datalink WX update:ATC Datalink (atis) Field:FSS/ATC Datalink Facil:FSS/ATC/Company Datalink
5.1.1.3	Field Closed		Info that Field is Closed	Notams FSS WX Preflt Brief. FSS Enroute Advisories ATC Advisories ATIS info	Notams Database WX Briefing Database FSS/ATC Datalink Advisories

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Radio Nav. Displays Flt. Nav. Displays Txt/Elect. Map/Plate Displays Audio ATC Radar Adv. Txt/Elect Sym Flt. Plan FMC Txt/Elect. Displays ATC Audio Traffic/Radar Adv.	Selection of Source Navigation Changes Performance Changes	Txt. Symbolic	Display Location
Txt WX Brief Audio FSS/ATC/ATIS Updates Txt Facil Info Audio Facil (ATC/FSS/ATIS)	Source Selection Nav./Flt. chgs.	Txt Symbolic	Display Selection Info Prioritizing
Txt : Preflt WX Brief Txt : Notams Audio : Enroute WX update Audio : ATC/ATIS Advisories	Source Selection	Txt : Messages/Cueing Txt : Pilot Info/Logic Query Discrep. Info Advisories	Display Selection Diverter Planning

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	As Info Available Pilot Cmd. Continuous	Pilot Cmd. Diversion Planning Process
	Pilot Cmd. As Info. Avail.	Info Cueing Info Annunciation Auto if Emerg.
	As Information Available Pilot Cmd.	Auto Msg Cueing Pilot Cmd. Auto Discrep/incomplete info Cueing

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
5.1.1.4	Field Poss. Closed		Current/Forcast WX Cond. Equipment/Facility Status Deter. WX Chg in Time Window	Notams FSS PreFlt WX Brief (forcast) FSS Enrte WX Advis. (Forcast) FSS Enrte Advisories ATC Advisories ATIS info Comp. Current/Forcast WX w/ Comp. Current/Forcast WX w/ Time Window	Notams Database WX Briefing Database FSS/ATC Datalink Advisories
5.1.1.5	Assess Delay Options		Current/Fórcast WX Cond. Equipment/Facility Status Deter. WX Chg in Time Window Endurance/Delay Opts./Effect.	Notams FSS PreFlt WX Brief (forcast) FSS Enrte WX Advis. (Forcast) FSS Enrte Advisories ATC Advisories ATIS info Comp. Current/Forcast WX w/ Comp. Current/Forcast WX w/ Time Window FMC for Perf.	Notams Database WX Briefing Database FSS/ATC Datalink Advisories
5.1.2	Landing Pt. Facil.	Subsect			
5.1.2.1	Assess Rwy. Avail.		Current Rwy in Use Status of Rwy Apchs. Traffic Conflicts	ATC Audio Communications ATC Audio Clearance ATC Audio ATIS Info WX info (Wind dir) Notam (closed Runway) Notam (inop. equip)	ATC Datalink ATC Enroute Datalink Updates FSS WX info Notam Database FSS Notam Datalink Updates

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Txt : Preflt WX Brief Txt : Notams Audio : Enroute WX update Audio : ATC/ATIS Advisories	Source Selection	Txt : Messages/Cueing Txt : Pilot Info/Logic Query Discrep. Info Advisories	Display Selection Diverter Planning
Txt : Preflt WX Brief Txt : Notams Audio : Enroute WX update Audio : ATC/ATIS Advisories	Source Selection	Txt : Messages/Cueing Txt : Pilot Info/Logic Query Discrep. Info Advisories	Display Selection Diverter Planning
Audio Clearance/Info Comm. Preflt. Txt WX Briefing Audio Enroute WX Briefing Txt Notams	None	Txt	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	As Information Available Pilot Cmd.	Auto Msg Cueing Pilot Cmd. Auto Discrep/incomplete info Cueing
	As Information Available Pilot Cmd.	Auto Msg Cueing Pilot Cmd. Auto Discrep/incomplete info Cueing
	As Info Available Pilot Cmd.	Auto Info Cueing Pilot Cmd. Pilot Logic/Info Query

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
				ATC Traffic Info ATC Traffic Info Apch Contrl Traffic Info	
5.1.2.2	Assess Airport Facil.		Passenger Facilities Terminal Facilities Emergency Facilities	Gov. Facil. Dir. Company Facil. Dir. Company Facil. Radio Comm.	Passenger Facilities Database Terminal Facilities Database Emergency Facilities Database Company Facil. Datalink Term. (via ATC) Datalink
5.1.2.3	Assess Airport Flt. Act.		ATC Traffic Info Monitor. Pilot/ATC Comm.	ATC Audio Voice Comm. Pilot/ATC Audio Comm.	ATC Datalink Pilot Input
5.1.3	WX Cond. at Alt.		Forecast WX Actual WX FSS enroute Updates ATC WX Info Pilot/ATC Comm Pilot/Pilot Comm Company Radio Info.	FSS Preflight Briefing FSS Enroute WX Briefing ATC WX Advisories (ATIS) Pilot/ATC Audio Comm Pilot/Pilot Audio Comm Company Radio Audio Comm	WX Database Enroute FSS WX Datalink (database U ATC Datalink Manual Pilot Input Company Datalink

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Txt. Printed Sources Audio Comp. Radio Comm.	None	Txt	None
Audio Clearances Audio Radio Traffic	None	Txt.	None
Txt. WX Briefing Audio Radio WX Updates Audio ATC WX Advisories Audio Pilot-/Pilot /ATC Comm Audio Company Radio Comm	None	Txt	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	As Info. Avail. Pilot Cmd.	Pilot Cmd.
	As Info Available	Pilot Cmd. Pilot Logic/Info Query
	Continuous Pilot Cmd. As Info Available	Auto Info Cueing Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
5.2	Acft Capabil. Assessment	Subsect			
5.2.1	Assess Acft. Perf.		Current Acft. Status Flt. Mode Env. Cond.	Primary Flt. Inst. Flt. Mgmt. Computer (FMC) Env. Cond. from FMC, Flt. Inst. Pilot Knowl. of Perform. Pilot Experience	Flt. Inst. Dig. Interface FMC Dig. Interface Perf. Database
5.2.2	Assess Expend.		Amt. Fuel Avail. Amt. Oil Avail. Amt. Oxygen Avail. Fuel Usage Rate Oil Usage Rate Oxygen Usage Rate Forcast Perf on Fuel,Oil,O2 Minimum Expend. Levels	Exp. Quantity Displays FMC (Usage Rates) Know. Min. Lev. Allow.	FMC Dig. Int. Source Lev. Dig. Interface Perf. Database Acft. Info Database
5.2.3	Est. Max. Range Endurance		Expendables Assessment Fuel Consumption Rate Forcast Expend. Usage Rate Current Acft. Pos.	Expend. Quantity Displays FMC (Usage Rates) Know. Min. Lev. Allow. FMC (Forcast Usage Rates) Nav. Equip (Position) FMC Maximum Endurance Distance	FMC Digital Interface

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Sym flt. Inst. Txt. FMC	Select/Query Data Sources	Txt Sym	Display Selection Flt. Plan Info Comm.
Fuel Quantity Gauge Oil Quantity Gauge Oxygen Quantity Gauge Expend. Usage Rate Gauges FMC Perf. Disp. Acft. Handbook/Placards	Adj. Perf. Levels	Txt. Symbolic	None
Expend. Quantity Displays FMC Displays Nav Displays FMC Endurance Indication	None	Txt Symbolic	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous Pilot Cmd.	Pilot Cmd. Pilot Logic/Info Query Diversion Planning
	Continuous Pilot Cmd.	Pilot Cmd. Auto if Perf. at Critical Lev.
	Pilot Cmd. Continuous	Pilot Cmd. Diverter Flt. Planning

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
5.3	Plan. Route Viability	Subsect			
5.3.1	Determ. Current Location		Flt. Nav. Info Lat/Lon Info Route Info	Flt. Director Radio Nav. Aids Charts/Appr. Plates Flt. Plan Flt. Nav. Computer	Flt Dir. Dig. Interface Radio Nav. Dig. Interface Database appr plates/charts Database Flt. Plan Flt Nav. Comp Dig. Interface
5.3.2	Assess Current Flt. Path		Current Location Planned Flt. Path Current Flt. Path Traffic Conflicts Terrain Conflicts Performance Limitations Weather Conflicts	Flt. Director Radio Nav. Equip Flt. Plan Route Info Charts / Maps (route info) Computerized Route Info ATC Traffic Confl. Advisor. Terrain info:Chart/Moving Map Terrain info:Chart/Moving Map Perf.:FMC/Perf. Charts WX:Preflt./ATC/FSS/ATIS/Pilot	Flt Dir. Dig. Int. Radio Nav. Dig. Int. Database Chart/Map/Route Info ATC Datalink Route/Traf. Info Terrain Info Database Perf. Info Database WX Preflt. Database Uploads Enroute WX FSS Datalink Enroute WX ATC Datalink Manual Pilot Input

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Flt. Dir. Nav. Info Radio Nav. Disp. Appr. Plates/Charts Elect. appr. plates/charts Flt. Plan (paper/elect) Flt. Nav. Comp Disp.	None	Txt Symbolic	None
Flt Dir. Graphic/Txt Disp. Radio Nav HSI/VOR Txt/Graph Disp Flt Plan Txt/Symb Disp. Moving Map/Txt Charts Traffic ATC Radio Terrain Chart Info Perf. Eng/Flt Disp/POH WX Txt Flt Plan/Voice Comm	Source Selection	Txt/Symbolic	Flt Info Comm. Flt. Info Disp

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous Pilot Cmd.	Pilot Cmd. Flt. Planning Flt. Progression
	Pilot Cmd. Continuous	Flt. Planning Nav. Asst/Display Pilot Cmd (logic/Info Query)

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
5.3.3	Assess Obst/ Traff Conf.		Performance Systems Status WX Max Perf Capabilities	Prev. Flt. Path Assessment Prev. Assessment of Route Performance Assessment	
5.4	Determine Req.	Subsect			
5.4.1	Planned ldg. Pt. Closed		Landing Point Status Info	ATC Landing Point Status Info FSS Landing Point Status Info WX at Landing Point Facil. Avail. at Landing Point Notams for Landing Point	ATC Datalink ATC Database Preflt. Update FSS Datalink FSS Database Preflt. Update Notams Database Datalink Notams Enroute Update
5.4.2	Plan. ldg. pt close/pred. open		Cause/Circumstance of Closure Predicted/Current WX Facilities Status	WX : Preflt. FSS/Company Brief WX:Forcast/Current Conditions ATC WX Enroute Info Notam Facilities/Status Info Enroute Notams Updates Enroute ATC Field Advisor.	WX PreFlt. Database Current/Forcast WX Datalink ATC Preflt. Database Update ATC Enroute Datalink Enroute Notams Datalink Update Enroute FSS Datalink Updates

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
ATC/FSS Radio Comm.	Info Source Selection	Txt	None
FSS Preflt. Txt. Briefing		Symbolic	
FSS Symbolic WX info (maps)			
Published Notams			
Radio Comm Notams (ATIS)			
Txt WX Briefing-CO/FSS	None	Txt.	None
Audio FSS WX Updates			
Audio ATC WX Updates			
Txt Preflt Notams			
Audio Notam Updates (ATIS)			
Audio Enroute FSS/CO Updates			

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous As Info Avail. Pilot Cmd.	Diversion Planning Pilot Info/Logic Query Pilot Cmd.
	Pilot Cmd. As Info Avail.	Pilot Cmd. Pilot Logic/Info Query

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
				Enroute FSS Advisories Enroute FSS Advisories Enroute Company Advisories	Enrt Comp. Datalink Updates
5.4.3	Plan. ldg. pt open/rt. no		Enroute WX Status Route WX Viability Assess. Route Traffic Viability Assess. Route Terrain Viability Assess. Enroute Nav. Aids Avail/Status Enroute Forcast Perf. Min. Enroute Perf. Req.	Txt Enroute Facil Dir. Audio Notams FSS Preflt. Notams PreFlt/Enroute WX (FSS Audio) ATC Enroute Traffic Directives Terrain Attr. from Charts Nav. Aids. Status (Notam txt) Nav. Aids. Status (Notam txt) Nav. Aids Status (Notam Audio) Enroute Perf:Perf. Calculation Enroute Perf:FMC Min. Enr. Perf.:Enroute Confl.	Facility/Route Database. Datalink FSS Notam Update WX Database Enroute WX FSS Datalink Update Traffic : ATC Datalink Terrain Attr. : Route Database Enroute Perf : FMC Dig. Int. Min. Enrt Perf:Route Database
6.0	Plan Diversion	Subsect			
6.1	Landing Pt. Diversion	Subsect			

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Facilities : Txt Notams : Audio/Txt Preflt WX : Txt Enroute WX : Audio ATC Traffic : Audio Terrain : Symbolic Perf : Txt (Paper/Electronic)	None	Txt Sybolic	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Pilot Cmd. As Info Avail.	Pilot Cmd. Diversion Flt. Planning

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
6.1.1	Det. Alt. ldg. Pt.	Subsect			
6.1.1.1	Det. Viabl ldg pt		Max. Range Land. Pts. in Max. Range Land. Point Attrib. Landing Point WX ATC Directives Destination Facilities Company Directives	FMC Charts Dest. Attr:Charts/AFD/Co Info Dest. WX : FSS Preflt (alt) Dest. WX : FSS Enroute Update ATC Dir. : Enroute ATC Comm Dest. Facil : AFD/Co Info Dest. Facil : AFD/Co Info Company Radio Comm Notams FSS Info Onboard Sys's Status Apch Limit.	FMC Dig. Int. Nav. Database Dest. Database Preflt WX Database Enroute WX Datalink Updates ATC Datalink Dest. Facil. Database Company Datalink FSS Datalink Onboard Sys Dig. Int.
6.1.1.2	Deter. Prob. Route	Subsect			
6.1.1.2.1	Assume Dir. Crs		none		

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
FMC : Txt Charts : Txt/Symbolic Dest. Attr:Txt/Symbolic Dest WX : Txt/Symbolic ATC Dir. : Audio Dest Facil : Txt Co Comm : Audio FSS : Audio	None	Txt/Symbolic	None

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Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Pilot Cmd. As Info Avail.	Pilot Cmd. Diversion Flt. Planning Pilot Logic/Info Query

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
6.1.1.2.2	Deter. Prob Descent		Acft. Sys Assess. WX Assess. Terrain Assess. Passenger Difficulties Emerg. Letdown Perf. Emerg. Letdown Traffic Confl.	Systems Displays Preflt WX Brief. Enroute FSS WX Brief Enroute ATC WX Directives ATIS Company WX Directives Chart Terrain Info Chart Terrain Info Terrain:Charts/App. Plates/ Radar Alt./GPR Passenger Info : Crew Perf : Perf. Tables Perf : FMC Traffic : ATC/Crew Obs/TCAS ATC Directives	Sys. dig. Int. Preflt WX Database Enroute FSS Datalink Enroute ATC Directives Enroute ATIS (FSS Datalink) Company Datalink Terrain/Route Database Pilot Input : Pass. Pblms Perf : FMC/Perf. database TCAS dig. Int.
6.1.1.2.3	Assess Rte Viability	Subsect			
6.1.1.2.3.1	Assess Poss. Traff. Conf.		Traff. Confl. on Routes	ATC Directives TCAS (short Range Only) See and Avoid (short Range)	ATC Datalink TCAS Dig. Int. Manual Pilot Input

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Txt. Symbolic Audio	None	Txt Symbolic	None
Audio ATC Comm. Symbolic/Txt TCAS Info Visual See and Avoid	Change Flt. Path	Txt Symbolic	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Pilot Cmd. Continuous As Info Avail.	Pilot Cmd. Pilot Logic/Info Query Diversion Planning
	As Info Avail. Pilot Cmd.	Pilot Cmd. Diversion Planning Pilot Logic/Info Query

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
6.1.1.2.3.2	Assess Poss WX Conf.		Enroute WX Information Enroute WX Conflicts	Preflt. WX Briefing Enroute ATC WX Updates Enroute FSS WX Updates ATIS Weather Info FSS Pireps Pilot Observation Onboard WX Radar Onboard WX Radar	Preflt. WX database Enroute ATC WX Datalink Enroute FSS WX Datalink Manual Pilot Input Onboard WX Radar Dig. Int.
6.1.1.2.3.3	Assess Terr/Air-Space Conf		Terrain Conflict/Perf. Locations Airspace Conflict/Perf. Locations	Perf. Assess : FMC Aircraft Systems Status Acft. Attr. (affect perform.) Prnt. Mat. (Charts,App. Plates,AFD) ATC App. Control on Par Onboard Displays (Alt/Radar Alt.)	FMC Dig. Int. Sys. Dig. Int. Acft. Database Route Info Database ATC Datalink
6.1.1.2.3.4	Assess Route		Navigation Assessment Airspace Conflict Assessment Weather Conflict Assessment Traffic Conflict Assessment Performance Limit. Assessment	Nav. Equip. Avail/Status Airspace Conflt (Prnt Charts) Airspace Conflt (ATC Clear. Chg.) WX : FSS Preflt. Briefing WX : FSS Radio Comm. WX : ATC Radio Comm (incl. ATIS) Traffic : ATC Radio Comm. Traffic : ATC Radio Comm. Traffic : TCAS (close Range) Perf : FMC Perf : Printed Perf Charts WX : Onboard WX Radar	Nav. Equip. Dig. Int. Airspace/Route Database Airspace : ATC Datalink WX : FSS Preflt. Database WX : FSS Enroute Datalink WX : ATC Enroute Datalink Advisor. Traffic : ATC Datalink Traffic : TCAS Dig. Int. Perf : FMC Dig. Int. Perf : Acft. Perf. Database Onbrd WX Radar Dig. Int. Manual Pilot Input
6.1.1.2.4	Revise Route	Subsect			

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Preflt : Txt/Symbolic Enroute ATC : Audio Enroute FSS : Audio ATIS : Audio Pireps : Audio/Txt Pilot Obs : Visual Onboard Radar:Symbolic/Visual	None	Txt Symbolic	None
FMC : Txt Acft. Sys : Txt/Symbolic Acft Attr:Txt Prnt Mat : Txt/Symbolic ATC : Audio Onboard Dis : Txt/Symbolic	Perf. Changes	Txt. Symbolic	None
Nav : Txt/Symbolic Displays Airspace : Txt/Symbolic/Audible WX (Pre) : Txt/Symbolic WX (enrt) : Audible Traffic : Audible/Txt/Symbolic Perf : Txt/Symbolic Onboard Radar : Symbolic	None	Txt/Symbolic	Download Info to Acft. Sys

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	As Info Avail Pilot Cmd. Continuous	Pilot Cmd. Diversion Planning Pilot Logic/Info Query
	Continuous Pilot Cmd. As Info Avail.	Pilot Cmd. As Info Avail Diversion Planning
	Pilot Cmd. As Info Avail. Continuous	Pilot Cmd. Pilot Logic/Info Query Diversion Planning/Activation

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
6.1.1.2.4.1	Min. Rt. Chg.		Distance of Route Change	Charts Flight Director	Route Database Flight Director Dig. Int. Nav. Sys. Dig. Int.
6.1.1.2.4.2	Assess Revised Route		Navigation Assessment Airspace Conflict Assessment Weather Conflict Assessment Traffic Conflict Assessment Performance Limit. Assessment	Nav. Equip. Avail/Status Airspace Conflt (Prnt Charts) Airspace Conflt (ATC Clear. Chg.) WX : FSS Preflt. Briefing WX : FSS Radio Comm. WX : ATC Radio Comm (incl. ATIS) Traffic : ATC Radio Comm. Traffic : ATC Radio Comm. Traffic : TCAS (close Range) Perf : FMC Perf : Printed Perf Charts WX : Onboard WX Radar	Nav. Equip. Dig. Int. Airspace/Route Database Airspace : ATC Datalink WX : FSS Preflt. Database WX : FSS Enroute Datalink WX : ATC Enroute Datalink Advisor. Traffic : ATC Datalink Traffic : TCAS Dig. Int. Perf : FMC Dig. Int. Perf : Acft. Perf. Database Onbrd WX Radar Dig. Int. Manual Pilot Input
6.1.1.2.4.3	Iterate until Accept.		Route Assessment	Info Prev. Route Assess.	Info Prev. Route Assess.

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Charts : Txt/Symbolic (elect/Paper) Flt. Dir. : Txt/Symbolic	None	Txt/Symbolic (map/Graphic)	None
Nav : Txt/Symbolic Displays Airspace : Txt/Symbolic/Audible WX (Pre) : Txt/Symbolic WX (enrt) : Audible Traffic : Audible/Txt/Symbolic Perf : Txt/Symbolic Onboard Radar : Symbolic	None	Txt/Symbolic	Download Info to Acft. Sys
None	none	None	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Pilot Cmd.	Pilot Cmd. Pilot Logic/Info Query Diversion Planning
	Pilot Cmd. As Info Avail. Continuous	Pilot Cmd. Pilot Logic/Info Query Diversion Planning/Activation
	n/a	n/a

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
6.1.1.2.4.4	Accept Route For Alt.		Info About Route Acceptability	Info From Prev. Eval. Functions	Info From Prev. Eval. Functions
6.1.1.2.4.5	Abandon Alt.		Comp. b/t alt. and Div. alt.	Info From Prev. Eval. Functions	Info From Prev. Eval. Functions
6.1.1.3	Assess Fuel Req.		Distance of Route Perf. per Segment Fuel Avail. Fuel Usage Forecast	Dist. : Charts/Flt. Dir. Perf : FMC, Perf. Charts Fuel : FMC,Fuel Quant. Displ. Fuel Use. : FMC,Usage Rate	Route Database Flt. Dir. Dig. Int. Nav. Sys Dig. Int. FMC Dig. Int. Acft. Perf. Database Acft. Sys. Dig. Int.
6.1.1.4	Deter. Sec. Alt. Avail.	Subsect			

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
None	Pilot Selection of Route	Route Attr. (txt/Symbolic) Lnd Point Attr. (txt/symbolic)	Download Info to Acft. Sys.
None	Pilot Selection of Route	Route Attr. (txt/Symbolic) Lnd Point Attr. (txt/symbolic) Prev. & Div. Route Comp. (symb)	Download Info to Acft. Sys.
Dist : Txt/Symbolic Perf : Txt/Symbolic Fuel : Txt/Symbolic	None	Txt/Symbolic	Download info to Acft. Sys.

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	n/a	Pilot Cmd. Pilot logic/info Query Diversion Planning
	n/a	Pilot Cmd. Pilot logic/info Query Diversion Planning
	Continuous Pilot Cmd.	Diversion Planning Pilot Info/Logic Query Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
6.1.1.4.1	Deter. Rng. Given Fuel		Qty. Fuel remain at Dest. Performance (segment to Secondary incl. Winds, Airspeed, Fuel Usage, Fuel Avail.)	WX : FSS Preflt. WX Briefing WX : FSS Enroute WX updates WX : ATC WX advisories WX : onboard WX Radar Perf. : FMC Fuel : Sys Displays Fuel : FMC Perf. Calc Fuel : FMC Perf. Calc	WX : FSS database WX : FSS datalink WX : ATC Datalink WX : Onboard Radar Dig. Int. Perf. : FMC Dig. Int. Fuel : Sys. Dig. Int. Fuel : FMC Dig. Int.
6.1.1.4.2	Deter. Viable Sec. ldg pt.		Endurance Distance	FMC : Perf. Measures Charts : Dest. Options/Attrib. AFD : Dest. Attributes	FMC Dig. Int. Airspace/Route/Airfield Database Airfield Attr. Database
6.1.1.5	Iterate all ldg. pts.		None		

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
FSS : Txt FSS : Audio (enrt) ATC : Audio Radar : Txt/Symbolic Perf : Txt Fuel : Txt/Symbolic	None	Txt/Symbolic	Download of info to Acft. Sys.
Charts :txt/Symbolic AFD : Txt/Symbolic FMC : Txt	None	Txt/Symbolic	Download of info to Acft. Sys.

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous As Info Avail. Pilot Cmd.	Pilot Cmd. Pilot Logic/Info Query Diversion Planning
	Pilot Cmd.	Diversion Planning Pilot Cmd. Pilot Logic Query

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
6.1.2	Select Best alt ldg pt		Lnd Point Attr (prev. Sect) Route Attr. (prev. Sec.)	Prev. Sect. Lnd. Pt. Attr. Prev. Sect. Route Attr.	Prev. Sect. Lnd. Pt. Attr. Prev. Sect. Route Attr.
6.1.3	Confer w/ATC Company		Lnd. pt./Route Attr. Acft. Status	Company	Company Datalink
6.2	Route Diversion	Subsect			
6.2.1	Define Alt. Routes	Subsect			

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
None	Select Alternate	Txt/Symbolic Altern. Represent.	Download Info to Acft. Sys.
Audio	None	Txt Poss Symbolic (Co. Diversion Sugges	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	n/a	Pilot Cmd. Diversion Planning Pilot Logic/Info Query
	As Info Avail.	Diversion Planning Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
6.2.1.1	Deter. Min. Crs. Chg.		Course Angle Change	Charts Flight Director	Route Database Flight Director Dig. Int. Nav. Sys. Dig. Int.
6.2.1.2	Deter. Time/Dist. Chg.		Orig. Time/Dist. Diversion Time/Dist.	Prev. Flt. Plan Eval. Diver. Flt. Plan. Eval.	Prev. Flt. Plan Eval. Diver. Flt. Plan. Eval.
6.2.1.3	Define New Route	Subsect			

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Charts : Txt/Symbolic (elect/Paper) Flt. Dir. : Txt/Symbolic	None	Txt/Symbolic (map/Graphic)	None
Perf. Criteria Route Info.	none	Txt/Sym comp. Flt. Plans	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Pilot Cmd.	Pilot Cmd. Pilot Logic/Info Query Diversion Planning
	Pilot Cmd.	Diversion Planning Pilot Logic/Info Query Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
6.2.1.3.1	Deter. Crs. Near. Wpt.		Direct Course Assumption Enroute WX Conflicts Enroute Terrain Conflicts Enroute Airspace Conflicts Enroute Traffic Conflicts Enroute ATC Advisories Performance Limitations	Charts/ appr. plates Flight Director Preflt FSS WX Info Enroute FSS WX Info Enroute ATC WX Info ATC Airspace advisor. ATC Traffic Advisories ATC Traffic Advisories FMC Performance Calculations Engine/Acft Perf. Measures	Route Database Flt. Dir. Dig. Int. FSS Preflt WX Database FSS WX Datalink Update ATC WX Datalink Update ATC Datalink FMC Dig. Int. Acft. Perf. Database
6.2.1.3.2	Assess Crs. WX/ Traffic Conf.		Direct Course Assumption Enroute WX Conflicts Enroute Terrain Conflicts Enroute Airspace Conflicts Enroute Traffic Conflicts Enroute ATC Advisories Performance Limitations	Charts/ appr. plates Flight Director Preflt FSS WX Info Enroute FSS WX Info Enroute ATC WX Info ATC Airspace advisor. ATC Traffic Advisories ATC Traffic Advisories FMC Performance Calculations Engine/Acft Perf. Measures	Route Database Flt. Dir. Dig. Int. FSS Preflt WX Database FSS WX Datalink Update ATC WX Datalink Update ATC Datalink FMC Dig. Int. Acft. Perf. Database
6.2.1.3.3	Revise New Route		Location/Type of Conflict	Route Attributes (prev. Eval. Functions)	Prev. Eval. Funct.
6.2.1.4	Iterate to Nxt. Crs. Chg.		n/a	n/a	n/a

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Txt/Symbolic Charts/Plates Txt/Sym Flt. Dir. Txt/Sym Preflt. Wx Audio Enroute FSS WX Audio ATC Advisories Txt. : FMC	Select Desired Course	Txt/Symbolic	None
Txt/Symbolic Charts/Plates Txt/Sym Flt. Dir. Txt/Sym Preflt. Wx Audio Enroute FSS WX Audio ATC Advisories Txt. : FMC	Select Desired Course	Txt/Symbolic	None
None	Select New Route	Txt/Symbolic Route Desc.	Update FMC Update Flt/Nav/Eng/Acft Sys
n/a	n/a		

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous Pilot Cmd. As Info Avail.	Diversion Planning Pilot info/logic Query Pilot Cmd.
	Continuous Pilot Cmd. As Info Avail.	Diversion Planning Pilot info/logic Query Pilot Cmd.
	n/a	Diversion Planning Pilot Cmd.
	n/a	

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
6.2.2	Select Opt. Route		Comparison of Route Attributes	Route Attributes Route Conflicts Attribute Weightings	Route Attributes Route Conflicts Attribute Weightings
6.2.3	Confer w/ATC Company		Lnd. pt./Route Attr. Acft. Status	Company	Company Datalink
6.3	Delay Diversion				

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
None	Select Route	Symbolic/Txt Route comparison	Update FMC/Flt. Dir. Update Acft. Nav/Eng/Flt Sys
udio	None	Txt Poss Symbolic (Co. Diversion Sugges	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	n/a	Diversion Planning Pilot Cmd.
	As Info Avail.	Diversion Planning Pilot Cmd.

Function Number	Functional Req.	System	Info Used	Source (Pilot)	Source (Diverter)
7.0	Execute Diversion		Update Flt Displays Update Nav. Equip. Update FMC Update Flt. Plan Download Data to Company Download Data to ATC	Diverter Flt. Planning Funct.	Diverter Flt. Planning Funct.
7.1	Program FMC		Info From Prev. Route/ldg pt Eval.		
7.2	Locate/Prepare Charts,app plates		Location/Source of Needed Info	None	Flt/Nav/Route Databases
7.3	Comm/Consent from ATC/Company		Lnd. pt./Route Attr. Acft. Status	Company	Company Datalink

Current Pilot Display	Current Pilot Control	Suggested Diverter Display	Diverter Control
Txt/Symbolic (new Flt Plan) Txt/Symbolic (new Nav. Data) Txt (Flt Plan)	Selection/Confirmation	Txt Flt Plan Sybolic/Txt Flt/Nav Updates	Update Flt/nav Displays Download Info to ATC/FMC/Comp.
None	Locate/Organize Charts/appr info	Txt/symbolic (app/chart auto. disp. on Nav/CDU Disp).	None
Audio	None	Txt Poss Symbolic (Co. Diversion Sugges	None

Interface Display	Pilot Display Avail.	Diverter Display Avail.
	Continuous	Continuous (become new flt. Param)
	n/a	Continuous
	As Info Avail.	Diversion Planning Pilot Cmd.

NASA National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-182070		

4. Title and Subtitle
"Diverter" Decision Aiding For In-Flight Diversions

5. Report Date
August 1990

6. Performing Organization Code
LG90ER0040

7. Author(s)
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8. Performing Organization Report No.

10. Work Unit No.
505-66-41-06

9. Performing Organization Name and Address
Lockheed Aeronautical Systems Company-Georgia Division
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Marietta, Georgia 30063

11. Contract or Grant No.
NAS1-18029

13. Type of Report and Period Covered
Contractor Report

12. Sponsoring Agency Name and Address
National Aeronautics And Space Administration
Langley Research Center
Hampton, Va. 23665-5225

14. Sponsoring Agency Code

15. Supplementary Notes
Langley Technical Monitor: Michael T. Palmer
Technical Representative of the Contracting Officer: Cary R. Spitzer
Final Report - Task 4A

16. Abstract It was determined that artificial intelligence technology can provide pilots with the help they need in making the complex decisions concerning en route changes in a flight plan. A Diverter system should have the capability to take all of the available information and produce a recommendation to the pilot. Phase III illustrated that using Joshua to develop rules for an expert system and a Statice database provided additional flexibility by permitting the development of dynamic weighting of diversion relevant parameters. This increases the fidelity of the AI functions cited as useful in aiding the pilot to perform situational assessment, navigation rerouting, flight planning/replanning, and maneuver execution. Additionally, a prototype Pilot-Vehicle Interface was designed providing for the integration of both text and graphical based information. Advanced technologies were applied to PVI design, resulting in a hierarchical menu based architecture to the efficiency of information transfer while reducing expected workload. Additional efficiency was gained by integrating spatial and text displays into an integrated user interface.

17. Key Words (Suggested by Author(s))
Artificial Intelligence, Decision Aiding, In-Flight Diversion, Script-Based tool, Rule-Based Tool, In-Flight Planning/Replanning, Hierarchical Menus, Integrated Display of Predicted Weather.

18. Distribution Statement
Unclassified-Unlimited
Subject Category 06

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	298	

NASA FORM 1626 OCT 86