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DYNAMIC TRAFFIC FLOW PLANNING FOR ATC AND AIRSPACE USER REQUIREMENTS

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ABSTRACT

Airline deregulation and associated cost factors have increased the operational need for airspace users and providers of the Air Traffic Control (ATC) service to define new methods of providing airspace operational improvements. Some of these improvements will result from the use of integrated Traffic Flow Planning and Management systems that dynamically adapt to the changing operational environment.

This paper describes the development and application of new technology and concepts that meet the challenges of providing improved airspace utilization that is integrated with users' operational needs and ATC System capabilities.

1 INTRODUCTION

In a recent edition of the Journal of Air Traffic Control, published by the Air Traffic Control Association, Inc.(ATCA), a letter to the FEEDBACK column ended with the statement "Technology must stay in step with system demand, or the system will fail." This phrase emphasizes a growing concern among users and providers of the Air Traffic Control System concerning a mismatch between flight deck, communications, and ground technical capabilities.

The speed with which this mismatch is evolving adds a further dimension to the concern. Three additional factors are safety, efficiency, and users operational needs. This does not imply that either user or provider will tolerate an unsafe operating environment; but, rather that efficiency and operational needs must be maximized without an effect on flight safety. We suggest that required levels of efficiency can be accomplished by providing a flight deck-to controller and user flight dispatch integrated capability that has matched technical functionality.

2 USER PERSPECTIVE

From the airspace user perspective, the three key events that have fueled this mismatch are deregulation effects, advancements in flight deck technology and the availability of powerful and inexpensive microcomputer workstation based ground systems. A characteristic of those users that have charted a successful economic course through the challenges of deregulation is the ability to plan, manage and control their schedules and daily flight operations. Most major aircarriers now routinely use airspace and ground simulations which account for all airspace traffic to predict the effects of new schedules on connecting hub complexes. Dispatch planning and control has become more dynamic because of the workstation automation that has been implemented. These dispatch systems in many cases have the capability to dynamically predict in real time (ie., fast time simulation) the effects of daily conditions on schedule and cost performance. Flight deck advancements have increased the integration of the crew into planning and control by allowing access to the ground system's larger and expanded view of the airspace. The airspace management is also integrated into airline landing slots and scheduling or occupancy gate utilization functions. Thus, there has emerged sophisticated flight deck to user dispatch and airport operations automation that provides dynamic planning and management aimed at balancing resources and demand. This balancing strives to maximize customer service and user economic performance.

3 FLIGHT PLANNING AND MANAGEMENT

This section defines a typical technical approach that can be used in the development of a Flight Planning and Management System (FPMS).

The FPMS has two primary operational functionalities. These are the generation of flight plans and the management or control of flights by the dispatcher or flight controller interfacing with the system. An operational scenario will be suggested as a means of presenting the proposed system from the person machine interface.

Each dispatch controller would be provided with a workstation high resolution graphics display. The normal or default mode of this display is to provide a worldwide tracking display of all flights based on position data. In addition to this data, the system will also contains world wide map data. The base longitude and latitude that determines the projection is automatically selected to minimize distortion of the selected area. All ATC Flight Information Regions (FIRS), special use airspace and political boundaries are shown. All routes and airports that are serviced and alternate airports are shown. Reporting points, routes and Navigation Aids (NAVAIDS) are also shown. After the NAVAID/world map data has been read into the system, the operator can select specific NAVAIDS or airports to modify characteristics in response to Notice To Airman (NOTAM) information. As an example the outage of a NAVAID or an ILS, etc.. The NOTAM can be entered or displayed. Standard Instrument Departure (SID) and Standard Arrival Route (STAR) data is also stored for the selected airports. Thus the system contains the airways superimposed over a grid structure. The grid structure is used for the weather data base and will discussed in a later section.

4 OPERATOR INTERFACE

The operator must initially generate a network that defines all possible routes between two cities. This is only done once, and then retained within the system until erased at the specific request of the operator. A network can be dynamically modified by a dispatch controller. The dispatch operator enters a city pair and any intermediate airports and the algorithm searches all possible paths from the departure to the intermediate cities to the destination. ATC preferred routings are entered as part of the NAVAID data base. An algorithm determines the maximum trip distance.

When an absence of airways or routes is encountered, the algorithm generates waypoints in accordance with ATC requirements and at FIR crossings or other reporting points. The direct routings that can be requested and received during certain hours of operation is not considered at this point since this network is for generalized flight planning. After generation, the route is stored and becomes part of the system generalized data base.

The operator selects a network and the network is displayed with intermediate stops. The destination weather is displayed and the crew capabilities and aircraft equipment used to determine the alternate list. The operator confirms the choices or specifies other choices. The system presents choices or alternatives and the operator approves or asks for other data. Any Significant Metrological Systems (SIGMETS) are indicated on the graphic display and the operator is requested to make the decision for flight plans through the effected area. The operator then selects flight plan generation and the system performs a four degree of freedom dynamic programming determination. The plans are graphically presented to the controller. The tail-number aircraft is selected from the equipment list versus the user predefined schedule list. The aircraft performance constants are selected for the specific tail number aircraft. Thus, the flight plan is specifically tailored to a network conditions, a specific aircraft, aviation weather and any ATC constraints. The crew documents and intermediate stop fuel loading requirements are generated. During self briefing at a departure city the controller can observe the same data as the crew if the need exists to review a plan with a crew member. The complete flight plan is stored to be used for comparisons. The dynamic flight plan generation starts at 35 feet above runway surface and the data base includes flap/gear retraction schedules. The complete climb and descent profile is generated for each aircraft. Allowances for ground taxi and ATC vectoring is included from the statistical data base.

5 FLIGHT TRACKING AND CONTROL

After departure, the aircraft projection and tracking begins. Immediately after departure the updated weather data base is used in conjunction with the data base to determine an arrival time. It is recognized that this time is subject to errors because of the outside impacts beyond the crew's control. However, arrival time is continually updated with each position report. Also, the data will assist the dispatch controller in evaluating reroutes and effects of aircraft unable to achieve altitude profiles. The objective of the flight monitor is to provide the cockpit with an overview of their situation. The remaining part of the trip is projected at each position report. Additionally, each Pilot Report (PIREP) of encountered weather is used to update the forecast. The ground weather data base has more data available about the remaining route and can assess the impact of an aircraft not receiving a step climb or of a forecast "wind bust" or error in forecasted wind conditions. In long over the water flights the cost advantage of reroutes can be determined, if desired. When requested by the crew or at the controller's initiative, various alternatives can be evaluated quickly and accurately with the overall objective of best safety in combination with minimum costs. The system further has the functionality of being able to communicate with both the ATC computers and the flight deck via data link. This includes both the receiving and sending of data.

The Flight Plan Performance analysis continually compares actual to planned performance both in terms of time and fuel burn. An aircraft which exhibits a significant change in fuel burn performance is detected and the controller notified as part of the flight plan performance report.

6 THE COST FUNCTION

This Operational Overview has presented details relating to the interaction of some data bases. These interactions will be covered in the following review. The elements of technology that have been used in the overall flight planning process are Aircraft Performance Modeling, continuously updated Dynamic Weather Data Base and a Four Degrees of Freedom Dynamic Programming Optimization that will minimize a Cost Function.

The Cost Function that would be used represents the combination of fixed and variable costs that would be minimized for each flight. The simplest form of this function would be to minimize fuel burn with an aircraft operating at a fixed or company policy Mach number. However, the impact of variable fuel costs at different airports could not be considered. In order for the system to provide cost effective solutions to tankerage decisions, the cost of fuel must be considered. An additional cost consideration involves the system generating a flight plan that makes use of a variable Mach that operates the aircraft such that an early or late arrival is allowed in certain markets to effect an overall reduction in costs. This flight planning capability requires that a cost be assigned to a late arrival at an airport. As an example, the schedule is derived based on a seasonal statistical winds and temperatures data base between a city pair with the aircraft being operated at a fixed or variable Mach number. On a particular day when the winds are such that the schedule can only be achieved by the aircraft being operated at a higher speed. the flight planning system should be able to make this determination. This involves assigning a relative dollar cost to the late arrival time increment. As an example the cost would be high for a highly competing connecting hub where a large proportion of arriving passengers are connecting with another flight that is the last flight of the day. A lost connection involves lost revenue to another carrier or an overnight expense and poor customer service. This arrival situation contrasts to a non-connecting arrival at a city where all passengers are terminating or have an extended wait time. In this latter case the additional cost that would be spent for an on time arrival becomes an issue. A cost function can be developed that provides a flight plan that has the sensitivity to minimize overall costs by providing the crews with the needed planning that reflects the required operating policy. The first generation of this type of planning capability is already in use in the form of the marriage between simulation and flight planning. Also, the cost function, if fully developed, can provide a what-if capability for defining the cost impacts of an over-flight of an intermediate point. It is recognized that the exact assignment of dollar costs to late arrivals cannot be precisely defined; however, relative marketing penalty cost factors can be assigned. This expansion of the flight planning functionality to include dynamic cost control represents a major advance in flight planning capability.

7 DYNAMIC PROGRAMMING OPTIMIZATION

The use of four degrees of freedom dynamic programming optimization requires a computer efficient mathematically continuous representation of aircraft performance. Also, the engine performance limits must be modeled. The performance modeling equations make use of airframe and engine constant sets that represent a particular aircraft type. Specific tail number performance indexes are then used to adapt the modeling to a specific fleet aircraft. The initial constant set and specific aircraft constant sets would be derived for a generic aircraft type. Soft ware that accepts and generates constant sets for individual aircraft based on operational engineering input data would then be used to adapt to a specific aircraft.

8 SOLUTION SPACE DEFINITION

A system of latitude and longitude points (nodes) and the connecting links that satisfy ATC route requirements and defines all possible paths that can be followed to go from a departure point to an arrival point is used to define a solution space. A node can be an airport, navigational fix, NAVAID or a point in the oceanic or CONUS airspace environment. A nodal data base also contains all forecasted and updated aviation winds and temperatures for the previous forecast and 36 hours into the future. The range of altitudes is from 5,000 feet to 45,000 feet. The Schedule flight time including intermediate stops and ground time is used. The wind component for each step is considered. The aircraft is located at each arrival STAR node at an altitude and velocity that reflects the arrival gross weight and wind/temperature conditions. At each node the cost and path to the arrival point is known. Since the Top of Descent (TOD) can occur between nodes, it is detected and recorder at the closest node for later inclusion into the crew documents. All nodes in the network are examined for all possible cruise altitudes and Mach numbers and the minimum cost path recorded. This process continues until the exit nodes or node from the departure SID is reached. The Top of Climb (TOC) is reached when the rate of climb is reduced to 500 feet per minute, pressurization limits or the correct altitude for the route direction is reached. The TOC is a variable point that may occur between nodes. ATC altitude increments and values are incorporated into the dynamic programming technique.

9 FUEL TANKERAGE CONSIDERED

The variable altitude, Mach and path through the network is a true minimum cost function This backward/forward optimization is able to determine the least cost flight plan in the presence of an intermediate stop with respect to the fuel tankerage decision. Since the total time is a matrix variable, an added dimension is added to the optimization problem. The total time also must be adjusted to reflect ground time at the intermediate point. Also the backward optimization defines the Mach number that should be flown to achieve the schedule time.

10 AVIATION WEATHER FORECASTS

The aviation weather forecasts are received in the Marsdan square grid format. An aviation data base contains a grid with all NAVAIDs, route reporting points, gateways and airports. A Bessel interpolation is used to compute the winds and temperatures at alternate altitude levels from 5,000 to 45,000 feet. Also, 36 hours of forecasts are retained in the data base. The receipt and processing of the forecasts every twelve hours is automatic. In addition to the winds and temperatures, surface observations at all airports in the data base are used. As PIREPS are received as part of the aircraft position reports, they are automatically inserted into the weather data base. The report value is interpolated in time and altitude to update the past and future forecast. PIREPs influences the surrounding node points. In the proposed system the updated weather is available for aircraft projection and to assist the flight controllers in evaluating in flight changes. The ground system has a better picture of winds at other altitudes and on the route ahead than the cockpit crews and can provide a valuable input to climb and reroute decisions. Also, this information is valuable for diversions and redispatch decisions. All updates and weather is transparent to the operator. A graphics weather display allows the operator to superimpose weather features over the traffic display.

The operator has the capability to display SIGMETS and other areas of turbulence or severe weather. The controller can also designate these airspace areas as being excluded from being available for flight planning. All plans will be planned around these areas.

In addition to the updated data base a seasonal statistical weather data base is generated on line for use in scheduling analysis and future schedule generation.

11 CITY PAIR NETWORK DEFINITION

The network is a worldwide grid with all route fixes, NAVAID, reporting points and airport locations superimposed on the basic grid structure. Any unconstrained or direct routing makes use of the free grid structure in the generation of networks. The weather data base is referenced to the grid structure. As an example a network for a flight from Dallas to Narita, Japan goes to the Soviet border on the north to Honolulu FIR on the south.

The generalized network for a city pair is produced by initially specifying a departure airport, arrival airport and intermediate stops. A search area is defined that stretches from the departure to the arrival point . The ATC Route and NAVAID Data Base had been used previously to load all data into the grid data base. Therefore the search routes, airports and all nodes in the search area are extracted from the grid data base. A network algorithm that reflects ATC and ICAO reporting requirements selects the appropriate network points and provides the links. The completed network is displayed. The network is superimposed over a map so that the controller can observe the relationship between map features. The display may be zoomed to observe an enlarged small area. The completed network is stored for later use.

12 FLIGHT PLANNING INTERACTION

At controller specified times, for instance every half hour, the Schedule Data Base is checked for departures during the next six hours. These trips are loaded into the system and at a parameter time increment before departure the display is notified that the flight planning process should begin. At this time the Crew Availability and Capability Data Base is accessed for crew/flight assignment to the trip. The crew data is entered into the system data base. A data base is checked for the aircraft maintenance status, including systems required for dispatch. Problem areas are highlighted. Based on the surface forecasts, the alternate airport is selected. The controller also calls up the airport data base and confirms that the system has accepted the airport restrictions and impact of arriving/departing aircraft. The SIGMET data base is accessed and areas displayed on the network along with pertinent information. The controller makes the decision whether to allow a flight to enter a SIGMET area and the data is written to the crew briefing file and the impact on the network displayed. The controller selects a flight plan generation time and the dynamically modified network is copied into the active network file. At the selected generation time the flight plan generation will occur and the controller notified for plan review. The system accesses the Airport and Airspace Delay Data Base and statistical data is extracted for these airports and airspace. This data and weather surface forecasts is checked periodically to confirm that everything is satisfactory.

The addition of flight deck to dispatch data link and onboard integration of flight management computers presents the possibility of dynamic reroutes that is coordinated with ATC. This has the potential of providing improved economic and operational benefits to both the airspace users and ATC providers. These capabilities are available in aircraft that are currently being delivered by major aircraft manufactures.

13 ATC PROVIDERS PERSPECTIVE

The challenges presented to the Air Traffic Control (ATC) providers are even more complex. Airline deregulation has produced dramatic increased traffic demand in those geographic areas of the ATC system that service the most profitable route structures. The proliferation of connecting hubs has placed additional demands on the system. The added demand translates to increased pressure on the controllers to provide separation assurance while maximizing airspace utilization. Airspace throughput is directly tied to the number of aircraft that an individual controller can safely manage and control. This translates to controller workload. Workload is a very complex issue in that the physical actions performed by a controller. The abstract mental activity associated with absorbing data, formulating plans and performing "what if's" are the keys to controller productivity. However, the traffic load presented to the controller must still be matched to the integrated capabilities of the flight deck to controller system. This includes the basic functions of communication, surveillance and control. The planning and management of demand translates into the matching of traffic flow to the available ATC and airspace resources.

14 FLOW PLANNING AND MANAGEMENT

The Traffic Flow Planning and Management functionality is presently performed by the integrated Traffic Management System. This system consists of an ATC System Command Center Facility (ASCCF) which provides coordination traffic planning and management for all enroute Air Route Traffic Control Centers (ARTCC). Each ARTCC has a Traffic Management Unit (TMU) that is responsible for traffic flow management and planning within the center airspace.

The ASCCF defines a daily plan for the overall system which integrates the flows for all ARTCC's. The ARTCC's then organize the individual aircraft movement to meet the flow requirements. As conditions change during the period, the ASCCF makes changes to the plan to reflect these new conditions. As an example, the impact of severe weather storms on a route may require the adjustment of flows to a new route.

It is apparent that one of the key elements in traffic flow planning and management is the ability to predict or forecast the flows. As an example, low ceilings and reduced visibility at an airport will reduce the hourly landing and departure flow rate. This reduced rate causes a reduced departure rate for a feeder airport. Aircraft that are given a gate delay at the feeder airport will affect inbound aircraft from other airports since gates may not be available. Thus conditions at one airport can affect other airports.

Delays have other impacts, in that aircraft are not available at the airports to be used in the makeup of new departing flights. An added complexity is the volume of active aircraft in the system which can exceed 3000. The build-up and movement of thunderstorms which can restrict traffic movement on routes are also an added complexity.

The ASCCF presently has established a Severe Weather Avoidance Program (SWAP) which selects alternate routes around severe weather cells. This procedure or program makes use of present weather cell location and a metrologist estimate of the position of severe weather at some time in the future. The traffic management specialists thens selects alternate routes and coordinate the selection of a best route with airspace users and the affected ARTCC's.

15 SIMULATION AND MODEL CHALLENGES

In the previous descriptions of the various functions performed by the users and ATC providers the common key element is the capability to predict what will occur at some future time and to define the best action based on this prediction. Thus, simulation and modeling provide a definition of the future state of the system and the mapping of the transition. If the future state of the system is unacceptable, ie. a controller/airspace capacity is exceeded, then a control or management system must be devised that has the capability to affect the simulation and modeling to provide the desired outcome. Throughout this process the operator must be integrated so that the process and the results understood and accepted. However, the process should not just mimic the controller's manual unaided methods, but should add a new dimension in functionality. The computer power of advanced RISC based workstations adds a new dimensionality to the functionality that can be devised. The following example will serve to illustrate the evolutionary path that an ATC traffic planning system development follows. The emphasis of the description is from a technical perspective rather than a procurement or program viewpoint.

The FAA is presently installing a fully documented production version of a Dynamic Ocean Track System (DOTS) that provides improved efficiency in the traffic flow planning and management of oceanic airspace. The first step in this development was to build a computer efficient performance model of the aircraft that operated in the oceanic airspace. Next, a dynamic aviation weather data base was developed. This data base makes use of forecasted winds and temperatures that are updated with actual aircraft reported data. This real time data is used to update both past and future forecasts. The next element was the capability to model the aircraft operating techniques used by the airspace users. These techniques do not take into account other aircraft operating in the airspace. This means that ATC separation and other operating requirements are not considered. Also, the efficient utilization of ATC resources are not taken into account. Next, the ATC automation capability that provides separation and efficient use of ATC resources was developed. It is the goal of the overall system to provide a planned operating environment that maximizes airspace user operating efficiency while meeting safety and ATC resource utilization requirements. All the elements that have been previously described exist in the DOTS.

The previous description has served to illustrate the elements that must exist in an ATC planning system design. The use of real time simulation and modeling has been illustrated. The final element in the DOTS is the interface of the DOTS to the user flight planning and dispatch control system. This integration insures that the capabilities of the ATC and user systems are matched and coordinated. Prior to flight plan filing with ATC, the user sends a tentative flight plan to the DOTS. The DOTS responds with projected altitude availability profiles on the requested route and any alternatives. The profiles take into account airspace competition and ATC flow requirements. The user selects the best route and files a flight plan. After departure, the user is informed of changes to the available alternatives as the aircraft proceeds toward the oceanic fir entry point. The user has the option of revising the plan if desired.

16 FLOW PLANNING AND MANAGEMENT

Two of the three levels or tiers of Traffic Flow Planning and Management have been presented and discussed. They are the ATC System Command Center and the Air Route Traffic Control Center Traffic Management Unit. The third tier deals with the design of the airspace. Airspace design includes routes, sectors and airports. Airports can be viewed as a subsystem that interfaces with the airspace. Airports have unique characteristics that must be analyzed and designed. Ground simulations and modeling has started to be used in both determines the design and how the runways, taxiways and gates can be utilized to maximize utilization. The challenges are much similar to the airspace in that the design of taxiways is a complex requirement. Of equal importance is the dynamic use of these ground resources in dynamic traffic situations. Safety considerations are of equal importance as increased traffic volumes have added new complexity to the controller functionality. We anticipate that new systems and technology will be needed to answer the need for improvements in safety and efficiency. The requirement for planning, management and control are just as critical as the airspace. The elements are the same in that surveillance, communications and planning must be performed in a dynamic environment.

Airspace design begins with simulation and modeling. However, these capabilities by themselves are not the most effective in providing solutions. The reason is that modeling and simulation can only measure the impact of "what if's" based on experience and judgement. The third element that must be added is the functionality to define the changes that simulations and models are used to evaluate. This entails developing a capability that dynamically generates airspace design changes that are derived from optimization. Thus, optimization can provide an airspace configuration that has the most efficient airspace utilization in the presence of defined traffic flows. From a system perspective, this is similar to the question of defining the optimum network in the presence of aircraft sources and sinks within a system. The degrees of freedom involved within this optimization offer some unique challenges. The cost function that will be used includes airspace utilization, airspace user operational needs, and safety requirements.

17 SUMMARY AND CONCLUSIONS

The foregoing discussion has presented examples of the use of simulation and modeling in the air transportation system that consists of the users and ATC providers. It was pointed out that the ATC providers have as the primary objective safety followed by the optimal use airspace resources. The users' systems seek to maximize operational efficiency which translates to economic performance. As was stressed, this does not mean that a user will tolerate unsafe operations, but rather that it is not a user system function. A users flight planning system only considers single aircraft in the planning. This points to the need for increased integration of the user and ATC systems from the system perspective. This translates to a total system objective of providing the best operational condition for an airspace user in the presence of competition between users for system resources. This applies in the cases of all resources from airport gates to enroute airspace.

The evolution of the flight deck to dispatch systems linkages provides new opportunities for the user to plan and manage flight operations. The integration of these linkages provide a dynamic capability that can be used to optimize operations. The addition of the flight deck to ATC planner/controller linkage serves to integrate the overall system. A similar linkage from ATC planner/controller to user dispatch is also necessary. These three linkages provide both an opportunity and a challenge to effectively integrate the capabilities that become available from an overall system perspective. Both ATC and user procedures and functionality concepts must be derived and integrated. As these capabilities evolve, they must be made to operate in concert for the overall system to be effective. Additionally, both the user and ATC systems must be technically capable of supporting the required functionality.

An additional challenge to achieving improvements to the integrated ATC provider and user systems is the transition from present to future systems. This challenge includes economic, political and technical factors. As an example, the level of functionality in bordering FIRs should be matched so that airspace users encounter a seamless operating environment. An example of this challenge potentially exists in the Automatic Dependant Surveillance (ADS) program. This program is a satellite based data link system that receives position data automatically from flight deck hardware. Also, the ADS System provides two way data link with ground based systems. This system has the potential for reducing separation in the oceanic environment by providing more frequent position reports that are automatically generated without flight crew action. However, the ability of the ATC system to handle aircraft that are not ADS equipped while allowing equipped aircraft to operate at reduced separation has not been resolved. Additionally, two adjacent FIRS should have the same capability to process ADS reports in order for the operating improvements to be achieved. This means that worldwide ATC system integration in combination with matched capability is required. Seamless ATC is being pursued by numerous international organizations, but the process is complex and requires dedicated effort by many different government and private organizations.

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