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Integrating the Cockpit With Air Traffic Management: The Concept of Path Objects

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ABSTRACT

A ‘path object’ is a set of instructions that would be used by an aircraft’s Flight Management System (FMS), or area navigation (RNAV) computer, to construct a three dimensional flight trajectory, based on the values of parameters provided by the pilot or Air Traffic Control (ATC) system. The Path Object concept can be viewed as a high level “path language” with which aircraft and ATC systems communicate RNAV-based flight path intentions. Once a particular path object is established as part of an aircraft’s route, it can be altered by changing any one of the parameters. One example of a path object would be an “S-turn” specified by the notation [ST1, P1, c, d, a], describing an S-shaped maneuver beginning at point, P1 along course “c”, having an amplitude of deviation of “a,” and returning to course at a distance d” from P1. Path Objects allow the *dynamic* alteration of RNAV routes in lieu of radar vectoring, with minimal communication requirements. Because of the compact expressions for the path objects, these procedures could be used in a voice communications environment as well as a data link environment. The concept of avionics-based Path Objects is a change in thinking about the role of avionics technology. It offers a means to include the precision of modern RNAV technology into the ATC system during the transition from today’s system to the future’s fully automated control system. It has the potential to *enhance* future ATM/CNS concepts and increase the utility and maintainability of the FMS/RNAV computer.

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Introduction

The current Air Traffic Control (ATC) system is not making full use of the capabilities of advanced Flight Management Systems (FMSs) and Area Navigation (RNAV) systems. This is due in part to the difficulty for the pilot in altering the flight path—it is very cumbersome to key in waypoints while flying an aircraft.

The current plan is to increase the number of pre-stored RNAV routes. However, this has the drawback of increasing the size of the FMS/RNAV database, which is updated every 28 days. There is a very large labor cost associated with maintaining the large database and there are increasing concerns about the integrity of the data. Moreover, even a large number of pre-stored routes does not provide complete flexibility. In addition, the demand for RNAV routes has led to a growing navigation database which is too large for most aircraft. Early B767 aircraft, for example, had only 200K of memory. Operators of these aircraft must carefully select which subset of the navigation database they wish to carry on transoceanic flights.

Figure 1a: FMS interface for Holding Pattern

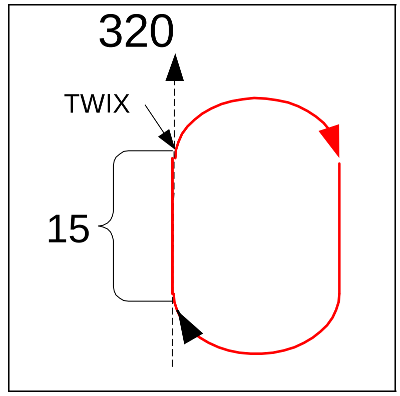

Figure 1b: FMS Can Construct Holding Pattern

At present, a pilot can use the FMS to fly holding patterns shown in Figures 1a and 1b, by entering only a few key parameters that are then used to construct a flight path. The pilot enters the holding fix, course, and length of each leg. The FMS or RNAV computer then computes the pattern and executes the instructions.

The Concept of Path Objects (POs) can be thought of as a generalization of this idea. It offers a simple *path language* for expressing RNAV/FMS routes, designed to simplify the pilot-FMS interface. Path Objects offer a means to have dynamically generated random three-dimensional (3D) RNAV capability (primarily) for terminal area operations. The ability to dynamically generate routes could reduce the size of the pre-stored database and increase the flexibility of RNAV routings.

The intention of the PO concept is to store several useful patterns in the aircraft that are defined by only a minimal number of parameters. The parameters are chosen to be useful and meaningful to pilots and controllers. With a properly designed interface for the controller and pilot the aircraft can be kept on an RNAV route while easily varying the dimensions of the route segment. This provides increased flexibility while maintaining the integrity of the aircraft's intentions.

Definition of Path Objects

A path object is the set of instructions for creating a three-dimensional shape whose location is determined by specifying only a few key parameters. The parameters are chosen so that they have operational meaning to the pilot and controller. All fixes that are part of the definition are in three dimensions using GPS-based latitude and longitude as well as barometric altitude.

Path objects provide a higher level 'path language' that makes it much easier to define aircraft intentions along an RNAV route and to change the intentions in complex ways. The compact notation minimizes the data storage and transmission requirements.

The notion of a path-stretching PO is shown in Figures 2a and 2b. The idea is that an aircraft traveling from **TANGO** to **MIKE** must insert an *S-turn* maneuver 12 miles off course between the two fixes. By specifying the endpoints and the magnitude of the deviation, the maneuver is completely defined.

Figure 2a: Hypothetical Pilot Interface

In addition, once the path is defined, the extra distance flown as well as the added time required to fly it can be calculated. Alternatively, an ATC application may know how much time or distance it wants to add, and then construct the deviation required to achieve it.

The concept of having a compact way of expressing patterns is not new to ATC. Shapes such as traffic patterns, holding patterns, and instrument procedures such as 'procedure turns' are in current use. Both pilots and controllers are familiar with the concept of patterns.

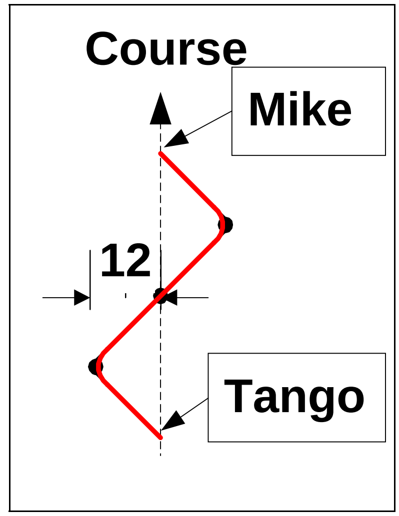

Figure 2b. Path Stretching S-turn

The set of basic POs will include lines, turns, and arcs. For example, if a line's path is called "L1," then it only needs two points to implement it, and the simple notation, [L1, **P1**, **P2**], where **P1** = (x1,y1,z1) and **P2** = (x2,y2,z2) completely defines the path. The fixes—**P1** and **P2**—are 3D fixes using latitude, longitude, and barometric altitude. This is illustrated in Figure 3. The PO in this case consists of the instructions (stored in the computer under the label 'L1') and the two parameters (**P1** and **P2)**. Another aspect of Path Objects is that there will be multiple ways of representing the same shape. In addition to L1, there will be an L2 notation that represents a line segment as a fix, heading, distance, and ending altitude [L2, **P1**, c, d, a]. The same line can be represented as L1 or L2, at the convenience of the user. The choice will be determined by which parameters the users are going to be varying for the control process of interest.

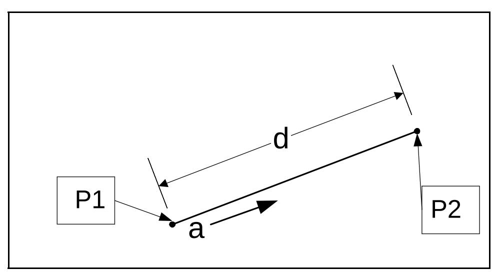

Figure 3: Line segment

Arcs may be segments of a circle, parabolic, or other curves. The turn radius object shown in figure 4 could also be useful in a *free flight* setting if an aircraft wanted to convey to the ground that it was going to deviate around a thunderstorm. The altitude and radius parameters can be used to create continuous descent curved approaches.

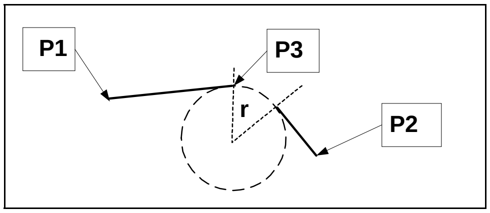

Figure 4: Turn Radius PO

The traffic pattern shown in Figure 5 can be defined by, a fix, a course, and three adjustable dimensions (the initial downwind (IDW), the downwind (DW), and 'base,' which is the width of the pattern). The sign of the parameter 'base' is used to control the direction of the turn; right or left.

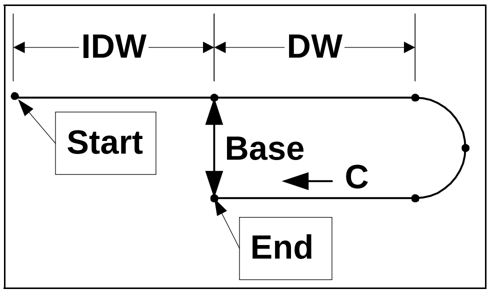

Figure 5: Traffic Pattern

Problems Addressed By Path Objects

Path Objects increase the flexibility of the RNAV system. As discussed below under Operational Concepts, an aircraft's route of flight will become a series of path object segments, rather than a sequence of straight lines from waypoint-to-waypoint. The most important aspect of POs is that, once an aircraft's planned route is established as a sequence of POs, any PO in the sequence can be modified by simply changing one or more of the parameters that define it. This PO feature offers increased flexibility through dynamic alteration of RNAV routes with minimal increase in workload. In contrast, using waypoints, the entire set of waypoints would have to change when a parameter such as 'base' is changed. It also offers a tremendous increase in flexibility over the current pre-defined RNAV routes that must be loaded into the FMS prior to take-off, or transmitted via data link for those aircraft that have data link integrated with their RNAV computers.

The use of POs has the potential to permit the dynamic alteration of RNAV routes, increasing flexibility while maintaining the integrity of the intent information, without the proliferation of fixed, predefined RNAV routes. The phrase that is being used in the USA to describe this capability is "dynamically calculated random 3D RNAV routes."

While it is possible to publish many pre-calculated routes and store those in the aircraft's navigation database, this only provides a limited amount of flexibility while increasing the size of the database. The use of POs would reduce the size of the database necessary to represent the fixed routes of the world. There would be a simple data table to link named routes to the POs that define them.

The operational concept for using datalink for Air Traffic Management (ATM)-linked path control, is to transmit strings of waypoints to the aircraft. While this is certainly technically possible if all aircraft are properly equipped, it is by no means clear how the different ATM functions will work in an environment of only partial equipage. ATM functions require datalink (or some other means) to keep the FMS/RNAV computer in the control loop. This provides the necessary precision in path control and the integrity of aircraft intent information.

"How do we gain the advantage of ATM when there is only partial or intermittent datalink equipage?"

The Path Object Concept offers an alternative (and compatible) way to perform simple path control functions. Simple path objects such as S-turns and downwind extensions can be performed in a voice environment because only a single parameter needs to be communicated and changed. Path Objects can therefore provide basic flexibility to support ATM, while keeping the FMS/RNAV in control of the flight path, without increasing workload or size of navigation database, in an environment of partial data link equipage.

This offers a *transition strategy* to full data link equipage. Initial Path objects will be simple. These can be used in a voice communications environment as an alternative to radar vectoring. With these commands, the controllers and pilots could begin using the FMS/RNAV for terminal area maneuvering while transitioning to a fully-automated ATM system.

As traffic volumes build the controller is increasingly forced to revert to radar vectoring as a means to provide flexibility. From the controller's perspective it is anticipated that maneuvering by POs, rather than radar vectors, will reduce the communications workload and surveillance workload. By keeping the aircraft's RNAV system in control of the flight path definition it should result in an increased compliance with instructions. In an automated world the controller can maintain situational awareness by assigning aircraft to POs rather than strings of waypoints. This should also provide a simple interface for modifying RNAV routes.

Operational Concepts

Path objects offer additional operational concepts that do not exist if the controller (control system) is restricted to fixed RNAV routes, radar vectoring, and waypoints.

Replacement for Radar Vectoring

The most important change would be that controllers could use POs rather than radar vectoring to alter RNAV flight paths. The use of POs could maintain precision in path definition, while reducing workload. A single PO can replace several vectors and could be issued prior to an aircraft reaching the point where the PO segment begins. Simulation studies at MITRE have shown significant reduction in workload as a consequence of using path objects to replace radar vectoring.

The earliest implementation of Path Objects would include the S-turn, traffic pattern, and arc turn described above as well as a simple on-off course maneuver called a 'dog-leg' which is a single command to leave the route and return to it according to precise instructions.

With these commands, the controllers and pilots could begin using the RNAV computer for terminal area maneuvering while transitioning to a fully-automated ATM system.

Path Object Based Routing

Another operational concept being considered for Path Objects is the use of POs to define RNAV routes through terminal and transition airspace. Rather than defining a route as a string of waypoints, the routes would be a series of flexible path objects. This would provide a familiar environment for the controller and pilot, increase situational awareness, and simplify the task of altering an arrival route. Interface tools would be provided to the controller and pilot for inserting, deleting ,and altering these path objects.

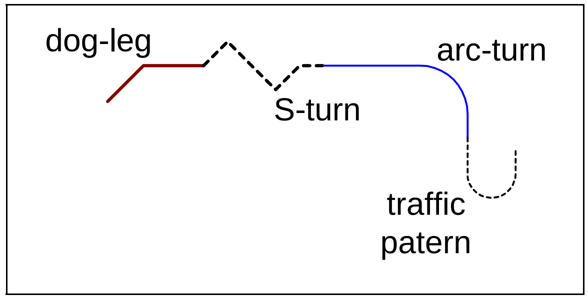

Figure 6: Flight Plans Become Sequences of POs

Unlike waypoint-based routes, PO shapes are defined independently of their location. POs are based entirely on RNAV. Consequently, an aircraft with RNAV capability, such as the Global Positioning System (GPS), need only carry these shapes with it to be able to construct any RNAV route anywhere in the world. The control system can dynamically change RNAV routes by changing only the relevant parameters rather than an entire string of waypoints. This means that the update cycle of the RNAV database could be lengthened as interim changes could be issued dynamically.

Improved ATM Functions

Another important change in operations would be that additional types of functionality could be added to the system. For example, the RNAV computer could have a function that inserts a delay of exactly so many seconds by calculating an s-turn that achieves that objective. The pilot could simply enter a "50-second delay" command and the s-turn would be calculated and transmitted according to the definition of this PO. Consequently, it would be possible for the controller to request that the aircraft "insert 50 seconds of delay along its route prior to reaching its next fix." A properly designed interface would allow the pilot to "INSERT – 20s – BEFORE REACHING – NEXT FIX." The computer would easily calculate the resulting S-turn and its 3 parameters which would be sent back to the controller by voice or data link. If, when the aircraft approaches the point where the delay is to begin, the system no longer requires so much delay, the controller could simply tell the aircraft to reduce the delay to, say, 20 seconds.

In this way, the concept of Path Objects opens the door to new opportunities to improve the efficiency of the system through improved ATM techniques. In addition, the existence of a common 'Path Language' de-couples 'functions/applications' development from FMS development. An ATM developer can develop flow management algorithms for using path control in the terminal area without having to worry about modifications to the FMS. The instructions from the ATM algorithm can be communicated to any aircraft using path objects.

Pilot Initiated Route Changes

The concept also enhances air-to-ground communications. In the case that an aircraft must deviate from its flight plan, for example to avoid turbulence, it can communicate an arc or dog-leg deviation very precisely and succinctly using path objects. This maintains the RNAV computer in the loop and allows the ground's conflict detection system to know precisely where the aircraft will be.

The concept for implementation is that aircraft could equip their RNAV computers with path object processors gradually over time. The benefits to the aircraft operator are the savings from the reduced size of the navigation database and the increased utility of the FMS/RNAV system. The benefits of path objects increase as equipage increases. Initial applications will be simple, and replace existing functions. Arrival and departure information, currently provided by ATIS, can be made more flexible by referring to path objects. Controllers can gradually replace radar vectoring with PO commands.

This would also lead to easier route designs with less reliance on paper-based products. In addition, the certification efforts could be directed to an aircraft's ability to fly path objects, rather than certifying the aircraft to fly each new traffic flow management pattern. It will only be necessary to certify PO algorithms once, resulting in faster development cycles.

Application to ADS-B

In addition, the concept could be used as an augmentation to the Automatic dependent surveillance – broadcast (ADS-B) concept. ADS-B may possibly be enhanced by using a bit-encoding for common POs. For example, the code 01010 might express the fact that the aircraft was going to remain on its current course for more than 100 miles, and 011 might mean that it will turn right at the next waypoint by more than 30 degrees.

Conclusions

The Path Object concept has the potential to solve many problems facing the world's future ATM systems. It does this by *incorporating the aircraft's FMS/RNAV system into the architecture of ATM systems*, making the FMS/RNAV more useful to the airlines, the pilot, the controller, and the ATM system. It offers a common 'language' that can reliably express complex information about the aircraft's intended path as well as a simple paradigm for altering RNAV routes.

It solves practical problems related to the maintenance of navigation databases, commonality of procedures, situational awareness, charting and cockpit display of information, and the efficiency of transmission whether by voice or datalink.

It presents new opportunities for ATM developers by simplifying the solution set (flight paths), and it offers a way to use ATM functions with partial data link equipage.

<u>An international standard for Path Objects is needed</u>

- END-

Author

John N. Barrer is a member of the technical staff at the MITRE Corporation where he specializes in computer modeling and analysis of airport capacity and delay. He has a BA in Mathematics and both an M.S. and Ph.D. in Operations Research. Dr. Barrer has written papers on topics in airport capacity and mathematical programming. In addition to his 18 years at MITRE, he has been a Professor at Georgetown University and SUNY, Buffalo where he taught courses in Operations Research. As a consultant to The International Air Transport Association (IATA) in London England, he was actively involved with several governments in Europe, helping to address airport capacity problems. He is a Certified Flight Instructor and active general aviation pilot. Dr. Barrer has worked as a consultant to several organizations including Aéroport de Paris, NASA, Rockwell International, Standard Oil (Ohio).