IMPACTS OF ATC RELATED MANEUVERS ON MEETING A REQUIRED TIME OF ARRIVAL

Paul Ostwald, The MITRE Corporation, Egg Harbor Township, NJ

Abstract

The Next Generation Air Transportation System (NGATS) as defined by the Joint Planning and Development Office includes Trajectory-Based Operations (TBO) as part of its concept of operation. TBO are envisioned to form the basis for both more strategic planning in the NGATS and for more tactical operations including separation management. The cornerstone of this concept is the establishment of a four-dimensional trajectory. The concept also calls for the use of a Controlled Time of Arrival (CTA) to help manage the use of a specific system resource.

A Flight Management System (FMS) onboard the aircraft has capabilities that may prove useful when operating under TBO. Such capabilities include Required Time of Arrival (RTA) – the capability to "self-deliver" to a specified waypoint at a specified time. The RTA capability may be employed to implement a CTA. This paper presents an investigation into the FMS capabilities to meet an RTA and looks at the impact of using a lateral offset maneuver to address a tactical situation has on a flight's ability to meet an RTA. Several PC-based models of a Smiths Aerospace FMS/Boeing 737 aircraft were used during this investigation. This study focused on an RTA at a waypoint during the cruise phase of a flight.

Introduction

Aircraft operations worldwide present a number of challenges for both airspace users and Air Navigation Service Providers (ANSPs). User desires include flexibility and efficient operations of their individual flights. ANSPs, managing the overall operation, strive for efficient utilization of system resources such as airports and airspace. This management is particularly important during heavy traffic situations when demand approaches or exceeds the available capacity of the system resources. Although impacts on users are virtually unavoidable during such situations, ANSPs work to maintain overall system efficiency while minimizing the number and magnitude of "actions" users must conduct.

Within the Unites States National Airspace System (NAS), the Next Generation Air Transportation System (NGATS), as being developed by the Joint Planning and Development Office (JPDO), is looking to address these challenges in the future. Forecasts for increased demand on the NAS mean that heavy traffic situations are likely to increase. JPDO includes aircraft Trajectory-Based Operations (TBO) as part of its concept of operations for the NGATS [1]. Trajectory-based operations are envisioned to form the basis for both more strategic planning in the NGATS and for more tactical operations including separation management.

The cornerstone of TBO is the establishment of a four-dimensional trajectory (4DT) that will lead to improved predictability. Part of this improvement could be achieved by replacing "open-ended" flight maneuvers (such as vectoring) that reduce predictability, with "closed" trajectory-based maneuvers (such as a lateral offset) that preserve predictability. The concept also calls for the use of a Controlled Time of Arrival (CTA) assigned for use of a specific system resource [1]. A CTA may be generated for some resources by a Time-Based Metering (TBM) system.

Under the TBO concept, 4DTs, comprised of the Estimated Time of Arrival (ETA) at each waypoint along the trajectory, are shared between the aircraft and the ground system. A Flight Management System (FMS) onboard the aircraft, such as one built by Smiths Aerospace, would generate accurate ETAs that would be downlinked from the aircraft. As discussed in the *Fuel Action Plan* [2] by the International Air Transport Association, users can employ the FMS to efficiently operate a flight at a user selected Cost Index (CI) and to perform other efficient operations such as a Continuous Descent Approach (CDA). Use of such procedures will be reflected in the 4DT as predicted by the FMS.

Required Time of Arrival (RTA) [3] is the capability of an FMS to "self-deliver" to a specified waypoint at a specified time. Use of the RTA capability is one way to implement a CTA. Use of this RTA capability in the future system may help reduce the level of ANSP interaction and service required in certain situations – the FMS monitors and actively manages meeting of the RTA. Evolution of FMS's continues [4], improving their ability to meet an RTA with a specified time tolerance.

Operational Context & Research Question

Many issues surround RTAs that must be addressed before new 4D related concepts can be developed, gain acceptance, and be employed commonly in the NAS. This paper presents an initial look into one such issue.

The RTA capability provides a powerful time-based control mechanism for use with the trajectory-based operations concept. In particular, RTAs have the potential for common use during certain situations such as management of arrival traffic to an airport. Time-based metering is a key scheduling technique for use in managing arrivals and employment of the RTA capability at an arrival-oriented waypoint (such waypoints could include top-of-descent, an arrival fix during the descent, and the runway threshold) can provide a mechanism to implement the scheduled times. Use of RTAs is attractive in that they take advantage of existing aircraft capabilities that are expected to become more widespread throughout the fleet. The FMS computes a cost-effective change to the original trajectory to meet the RTA. In addition, since the FMS can "self-deliver" to the RTA, subsequent coordination between the user and the service provider is expected to be significantly reduced. Finally, since the FMS actively and directly "controls" the aircraft to meet the RTA, very accurate arrival is possible with minimal human intervention.

Of course separation between aircraft needs to be maintained, even when an aircraft has been assigned an RTA. RTA related flight trials conducted in Sweden in 2001 [5], showed reduced RTA accuracy during "flawed" cases, where these "flawed" cases included intervention for other traffic. This raises a fundamental question: "Can maneuvers be employed to address tactical situations (such as maintaining separation) without impacting a flight's ability to meet an RTA?" Under the TBO concept, it would be desirable to be able to employ such maneuvers to resolve such tactical situations without "breaking" the RTA (causing the RTA to be met with decreased accuracy or even becoming "unachievable" and requiring a new RTA to be established).

How many flights might get an RTA?

A simple analysis was conducted to obtain a rough estimate of how many flights in today's NAS would potentially receive an RTA under the following assumptions:

- Time-based metering is in use at all major airports and is the source of CTAs
- One CTA is issued per flight (could be at top-of-descent, an arrival fix during descent, or at the runway threshold) during periods time-based metering is in use – an RTA is the control mechanism employed to achieve the CTA scheduled by the time-based metering capability
- All aircraft are RTA-capable

Aviation System Performance Metrics (ASPM) data [6] for May 4, 2006 was used for this analysis. ASPM data show airport arrival and demand for quarter-hour periods across the day. In particular, the ASPM fields "AAR" (the airport supplied arrival rate) and "EffArr" (a count of arrivals for efficiency computation) were used. For each quarter-hour period, the percentage of airport capacity utilized was calculated by dividing the number of arrivals by the arrival capacity (EffArr/ARR). The results were grouped into five categories:

- Category 1: greater than or equal to 100%,
- Category 2: 90% to 100%,
- Category 3: 75% to 90%,
- Category 4: 50% to 75%,
- Category 5: less than 50%.

In the NGATS timeframe, it is quite likely that time-based metering would be employed to generate RTAs when the percentage fell in one of the first two categories (demand >= 90% of capacity). RTAs are unlikely to be used when demand is less than 50% of capacity – the fifth category. RTAs might be used when operations fall within the third and fourth categories. The likely situation during these periods is some level of bunching of arrivals (two or more flights arriving at approximately at the same time) that could be addressed with the use of RTAs.

All 75 airports at which ASPM data is collected were examined. Table 1 shows the number of arrival flights individually for the top 15 ASPM airports, based on the count of arrival operations for the selected day. Also listed is the cumulative percentage of these arrivals flights that occurred in periods where the capacity/demand was greater than or equal to the percentage listed for the column. For example, 82% of Atlanta Hartsfield Jackson International Airport (ATL) arrivals occurred in periods where demand/capacity was ≥75% (Categories 1-3).

The table also contains information for the other 60 ASPM airports and a summary (in both percentage and count) for all 75 ASPM airports.

The total number of arrivals for all the ASPM airports was 29,536. Of these 4980 (17%) fell in category 1 and 6995 (24%) fell in categories 1 or 2. Thus, about 7000 RTAs is the lower bound that would be issued based on the stated assumptions. Possible upper bounds of about 11,000 and 19,000 RTAs may be issued if time-based metering is used to address bunching of flights that occurs at these lower levels of demand (demand/capacity of ≥75% and ≥ 50%, respectively).

In the future, as demand grows, it may outpace the growth in airport capacity, leading to a shift upward in the population of the categories defined here – more flights would likely be subject to time-based metering and would employ RTAs. RTAs could also be used for other situations such as airspace congestion and those involving convective weather. Thus, RTAs have the potential to be a commonly employed control mechanism in the future NAS – with the number employed in the future exceeding the estimates given here.

Table 1: Top 15 Airports Studied

		Cumulative % (demand/capacity)			
Airport	**Arrivals**	**≥100**	**≥90**	**≥75**	**≥50**
ATL	1392	49%	69%	82%	92%
ORD	1377	26%	51%	81%	90%
DFW	1030	0%	0%	5%	62%
IAH	907	14%	27%	48%	76%
LAX	863	8%	17%	47%	88%
DEN	823	0%	0%	10%	46%
PHL	789	48%	56%	75%	84%
LAS	773	45%	54%	77%	93%
PHX	752	16%	24%	38%	73%
CLT	739	33%	48%	61%	85%
MSP	697	18%	37%	56%	79%
DTW	695	31%	40%	63%	79%
EWR	681	25%	51%	69%	91%
MEM	654	17%	23%	32%	69%
LGA	624	49%	75%	80%	97%
Other ASPM	16740	10%	12%	24%	53%
All ASPM	**29536**	**17%**	**24%**	**38%**	**65%**
Total counts	**29536**	**4980**	**6995**	**11116**	**19146**

Methodology & Approach

A user's preferred 4D trajectory may be altered when an RTA is issued by the ANSP – the replanned 4D trajectory will incorporate the actions needed by the FMS to achieve the RTA. Additionally, the 4D trajectory may be altered by the ANSP to address a number of other situations, such as the need to resolve predicted conflicts, merge flights from different arrival streams, or maintain a desired spacing between successive flights. These situations are common during the arrival phase of flight, particularly during periods of heavy traffic. Resolving these situations may require actions that were not considered when a 4D trajectory was initially formulated to meet the assigned RTA.

A number of actions, such as a lateral offset, an altitude change, or a small reroute (as opposed to a vector that is "open-ended" and not compatible with trajectory-based operations) could be employed in these situations and have potential to be “compatible” with an RTA. A “compatible” action is one that can be implemented while allowing the RTA to still be met. A number of factors influence this compatibility including the magnitude of the action and the location of the application relative to the RTA waypoint. The RTA may include a specified tolerance or time window around the specified time within which the flight should cross the waypoint. In addition, the trajectory being followed to meet the RTA itself plays a major role – if the flight is operating near the edge of its performance envelope less controllability may be available to respond to these other actions. During this study one particular action, a lateral offset, was investigated for its compatibility with an RTA. Investigation of other potentially “compatible” actions is a rich area for further research.

A PC-based model (PCSim) of a Smiths Aerospace FMS/Boeing 737 aircraft [7] and the Smiths Aerospace PC-based Procedure Design Tool (PDT) [8] were used during this investigation. The PCSim had the full capabilities of the FMS including lateral offsets and RTAs. The PDT had a more limited set of capabilities but did record estimated fuel use. Each tool was initially used to gain insight into flight operations using an FMS by focusing on the cruise portion of a flight. A baseline flight was established with a cruise portion of about one hour. Sensitivity to changes in aircraft weight, cruise altitude and CI were examined.

Subsequently, employment of an RTA and of a lateral offset during cruise was investigated via use of the PCSim. Insight was also gained on the amount of time control available relative to aircraft speed, and phase of flight. Lastly, employment of an RTA with subsequent use of a lateral offset was examined.

Metrics

The 4D trajectory of the flight was recorded under the various test conditions. For the PCSim, this was done by recording data logged to the “intent bus.”[9] The FMS calculation of intent, for the entire trajectory while on the ground and for the waypoints not yet crossed while in the air, is placed on the intent bus about once each minute or when an event occurs (such as a manual entry into the FMS) that triggers a recomputation of the trajectory. The information for each waypoint includes the latitude, longitude, altitude and ETA. An indicator of the type of waypoint, such as top-of-descent and top-of-climb, is also included. Note that no information on fuel use is included in this intent information.

For the PDT, a file containing the 4D trajectory was examined. This file was produced each time the PDT was executed. This file contained all of the information in the intent bus plus additional items such as the estimated fuel use.

The primary metrics examined were flying times and fuel used. To ensure consistency over the many runs made a cruise portion of the flight between two waypoints was examined. This portion was a subset of the cruise for all flights examined and did not contain any portions of the climb or descent profiles. The flight was flown on the same base route between these waypoints for all tests.

The total time to fly between the selected waypoints was calculated as the difference in the ETA for the waypoints as determined by the FMS logic in the PCSim or the PDT.

The estimated fuel usage was determined from the PDT. Several measures of fuel were examined: total fuel consumed between the selected waypoints and the average rate of fuel consumed – calculated as the total fuel consumed divided by the total time to fly the portion of the flight examined.

Baseline Flight

A baseline flight plan was defined for use during the analysis to provide a reference for comparison when changes to the parameters of the flight (i.e., cost index, cruise altitude, or weight) or control actions (i.e., lateral offset and/or RTA) were made. Specifically, a medium haul flight of about 90 minutes was used. The flight was based on an actual city-pair currently flown by a Boeing 737 Next Generation (NG) aircraft. Enhanced Traffic Management System (ETMS) [10] data was examined to define this flight. A flight operated by Delta Airlines from Houston Hobby Airport (HOU) into ATL was selected.

This medium-haul flight length allows use of the preferred cruise altitude for the weight of the aircraft (including total payload of both passengers and cargo). This cruise segment was about one hour in duration, just less than 500 nautical miles in length, and was flown at one flight level during cruise. Flights with these characteristics are quite common in the NAS.

The PCSim was configured for a 737-600 aircraft. This was the initial series of the NG configuration and a limited number were made, primarily for Scandinavian Airlines. In the United States, most NG 737's in use today are -700 or -800 series. These aircraft are similar in performance to the -600 series, but are longer and heavier. The inputs to the models were made as if the flight was flown using a -600 aircraft. The information obtained from the ETMS data included the flight path and filed cruise altitude. The PCSim requires other information including aircraft weight, CI setting, and runways used. Similar information is required to run the PDT. The same baseline flight was run with both the PCSim and the PDT. Modeling for the cruise portion of the flight examined was quite similar in the two tools: flying times differed by one second between the PCSim and the PDT.

Airport diagrams were obtained and runways selected at the airports for both departure and arrival. Since the focus was on the cruise portion of the flight, the actual runway used was not critical to this study. Several days of filed flight plans were examined for the city pair. A commonly used route was selected (HOU..VUH1..BTR.GCV..HONIE2..ATL). Again, the actual flight path is not critical to the study, but a route commonly flown ensured compatibility with the navigation database loaded into the PCSim and used by the PDT. The flight's path includes the VUH1 Standard Instrument Departure (SID) and the HONIE2 Standard Arrival Route (STAR), found in many of the actual flight plans.

The cruise altitude was selected based on examination of the Flight Level (FL) in ETMS data for flights operating between this city pair. FL390 was selected for the HOU-ATL flight. It was desirable to have the aircraft operate at or near the most efficient FL given the weight for the baseline flight.

A Cost Index setting is also required when operating the FMS. The CI, according to IATA's *Fuel Action Plan* [3], includes the cost of time (crews, time-based maintenance, etc.) and the cost of fuel. A CI of 0 is defined to optimize the flight for minimum fuel burn. In most situations the cost of time is a factor and a cost index of greater than zero results in the lowest total cost of operation[1]. Each airline may establish a CI using proprietary information such as company specific crew and operating cost factors. The range of CI that can be entered on the 737-NGs using the Smiths FMS is from 0 to 200. A nominal CI of 25 was assumed for the baseline flight. A CI of 30 was used in the Sweden trials in 2001 [2]. A slightly lower CI was assumed here due to increasing fuel costs since 2001.

The 737-600 has a basic operating weight of 80,200 pounds [11]. A passengers and cargo payload of 23,800 pounds was assumed, thus generating a zero fuel weight (ZFW) of 104,000 pounds. This corresponds to a passenger load factor of roughly 70%.

The fuel required for the baseline flight was estimated using a Boeing document for the 737 aircraft [12]. The calculation used assumed a 200 nautical mile alternate, typical mission reserves, ZFW of 104,000 pounds, range of 700 nautical miles, and operation at long range cruise. Based on these assumptions, the required fuel was estimated to be 13,000 pounds. The gross takeoff weight of the aircraft was the sum of the ZFW and the required fuel.

Sensitivity Analysis

Three key parameters that influence flight performance were examined by conducting a sensitivity analysis. While the entire range of possible flight operations was not examined, this analysis intended to examine the most typical ranges of operation during cruise based on the baseline flight used here.

The ZFW was modeled at weights of 94,000 and 114,000 pounds, 10,000 pounds above and below the weight selected for the baseline flight profile. These correspond to roughly a 40% and 100% passenger load factor respectively. This

---

[1] Note that in a delay situation, time is constrained and is not a factor. In this case a CI=0 or even a negative CI would be appropriate.

variation in weight is typical, as variation in passenger load factor commonly occurs.

Changes to the assumed cruise flight level were also modeled. An optimum flight level (as calculated by the FMS) depends primarily on the weight of the aircraft. For this scenario, the optimum altitude for the flight when fully loaded (114,000 pounds zero fuel weight) was FL390. For the lighter weights of 104,000 pounds and 94,000 pounds the optimum altitude was the aircraft's performance ceiling of FL410. For the sensitivity analysis, flight levels from FL370 to FL410 were examined. Aircraft are not always operated at their optimum cruise flight level as evidenced by the range of filed flight levels in the ETMS data examined. Users are limited by the rules specifying flight level by direction of flight, although this is much less restrictive since the introduction of Reduced Vertical Separation Minima (RVSM). Users may also choose a flight level other than the optimum for reasons such as avoiding clean air turbulence.

The third key parameter examined was the Cost Index. The CI was varied between 0 and 50, both above and below the baseline value of 25.

For the baseline case (ZFW=104,000 pounds, FL390, CI=25) the time to fly the selected cruise portion of the flight (from waypoint DRAGS on the VUH1 SID to waypoint IVLUH on the HONIE2 STAR) was predicted at 45.04 minutes and the fuel consumed was predicted at 3,185 pounds.

Figures 1 through 3 show the results of the sensitivity analysis for the cruise portion flying time (figure 1), total fuel consumed (figure 2) and rate of fuel consumption (figure 3) for various flight levels, weights, and cost indices. Each curve plotted is for the runs made at a specific combination of flight level and zero fuel weight as shown in the legend (e.g, "FL370-94" are the runs made at flight level 370 and with a ZFW of 94,000 pounds).

Note that the baseline flight averaged fuel burn of 71 pounds per minute. So, if the flight was vectored (adding extra miles to the flight path which burn fuel at the average rate) each minute of vectoring would consume about 71 pounds of fuel. A one minute vector has a larger fuel impact than flying 2,000 feet below the optimum FL (the baseline flight at FL390 consumes less than 50 pounds more fuel than its optimum at FL410) for about 45 minutes over the portion of cruise examined.

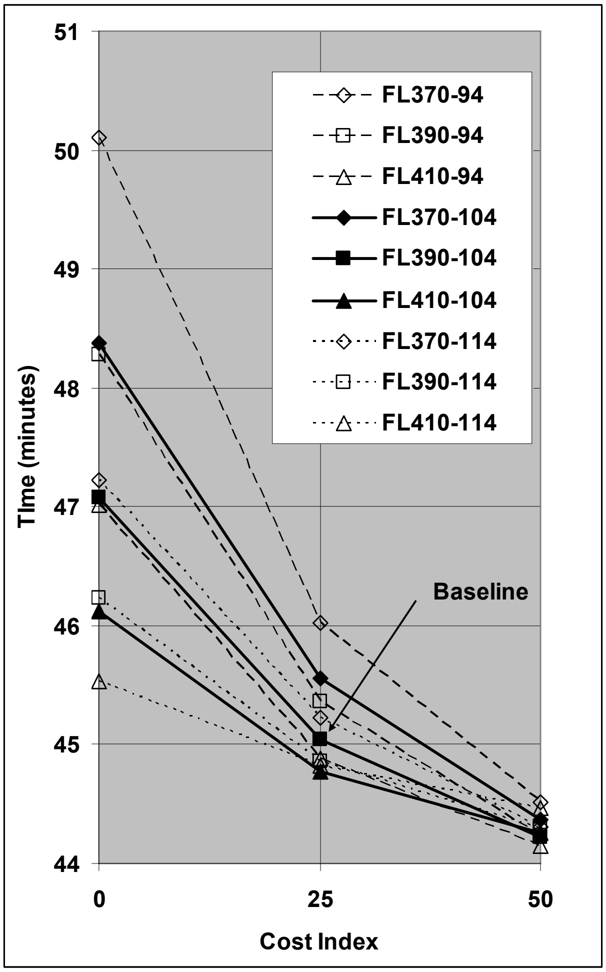

Figure 1: Time for Sensitivity Runs

The following example, using information from the tables, illustrates the sensitivity to changes in weight. For the baseline CI (25) and FL (390) the lighter ZFW of 94,000 pounds resulted in flights taking slightly longer (about 20 seconds more) but burning less fuel (about 140 pounds less). For the heavier ZFW of 114,000 pounds the time to fly was slightly faster (about 10 seconds) but more fuel was consumed (about 190 pounds). This is over a 336 nautical mile portion of the cruise. Note that while not zero, these time differences are not large. They illustrate the magnitude of typical errors in ETA predictions over this portion of cruise if accurate weight is not known.

A second example illustrates sensitivity to changes in flight level. For the baseline CI (25) and

ZFW (104,000 pounds) flying at a lower FL (370) resulted in flights taking slightly longer (about 30 seconds more) but burning more fuel (about 83 pounds more). Flying at FL410 (the optimum for this weight) resulted in slightly faster flight (about 20 seconds less) and slightly less fuel (about 37 pounds less). These time variations are a little larger than those due to just changes in ZFW, while the fuel differences are less.

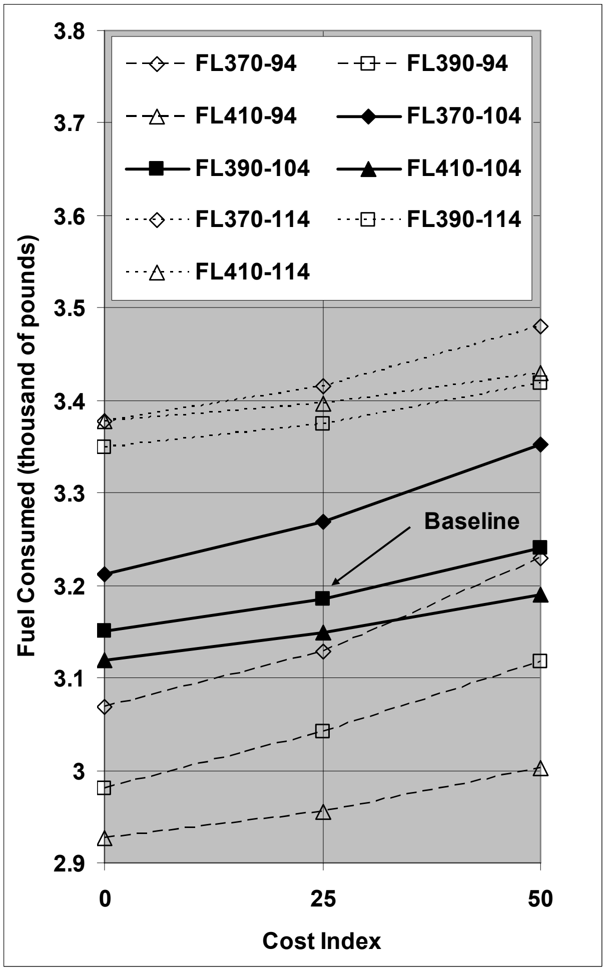

Figure 2: Fuel Consumed for Sensitivity Runs

The last example shows the sensitivity to changes in the cost index. For the baseline FL (390) and ZFW (104,000 pounds), flying at a lower CI (0) resulted in flights taking longer (about 124 seconds more) but burning less fuel (about 34 pounds less). An increase in the CI to 50 resulted in faster times (by about 80 seconds) and increased fuel use (by 55 pounds). Note that this case produces the largest time differences – from at least 50 to over 110 seconds larger than the differences due to changes in weight or flight level. This illustrates the importance of knowing the CI (or getting the ETAs from the FMS), particularly as adjustments to CI are use to manage achieving the RTA.

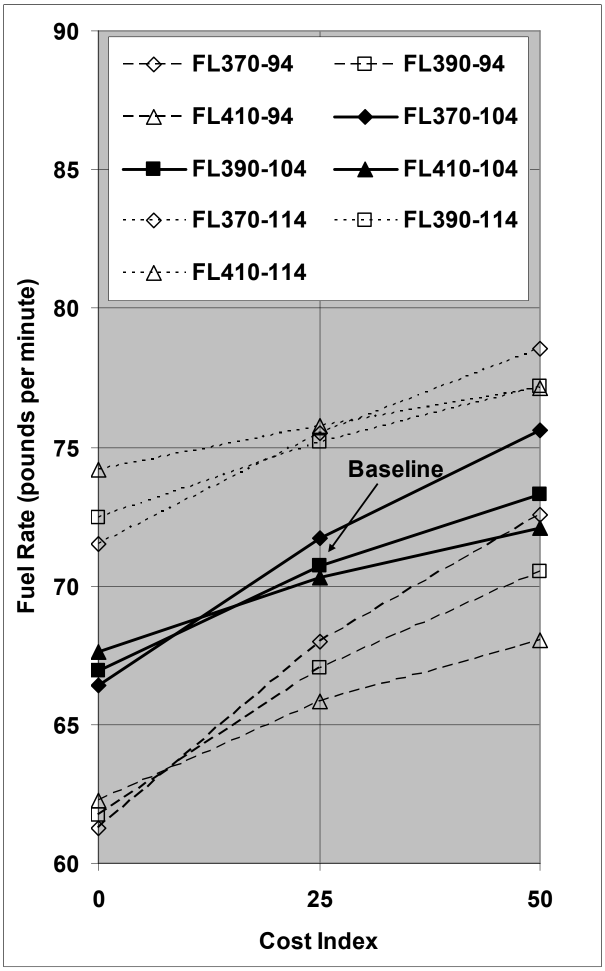

Figure 3: Fuel Rate for Sensitivity Runs

Investigation of Required Time of Arrival

For this investigation, an RTA was entered at OBXAY, the last waypoint prior to top-of-descent for the baseline trajectory. The RTA was entered when the flight was airborne and had completed its climb – so the entire event (location of flight when RTA was entered and the crossing of the waypoint) occurred during the cruise portion of the flight. When the FMS was in a mode to accept an RTA (a waypoint had been selected), it displays the earliest and latest times that an RTA can be achieved.

The speed during cruise for the baseline case (ZFW=104,000 pounds, CI=25) was 0.78 Mach. At a distance of about 400 nautical miles prior to the waypoint, the earliest achievable RTA was just under two minutes earlier and the latest achievable RTA was about eleven minutes later. Each of these times was entered as an RTA. To achieve the earliest RTA a speed of 0.806 Mach was planned. Note that without an RTA this speed would be flown at a CI of about 100. At the baseline altitude, the full range of CI was not available – the flight was limited in speed – and was only able to meet an RTA of at most about two minutes earlier that the ETA (when flying at CI=25 prior to entry of the RTA).

To achieve the later RTA a speed of 0.678 Mach was planned. However, a much larger range of control was available for later RTAs – fully ten minutes of delay could be taken over the 400 nautical miles available prior to the waypoint. The flight had a lower speed available when in RTA mode (Mach = 0.68) than at CI=0 (Mach = 0.75). Achieving many of these later RTAs would result in a savings in fuel over the baseline flight.

The range of controllability was also observed as the flight progressed towards the waypoint OBXAY. Figure 4 shows the earliest and latest RTAs that the FMS showed as “achievable” for the baseline flight at FL390 and a test flown at FL370. The controllability is shown as the time relative to the ETA at OXBAY – note that an RTA was not entered during this test (only the range of achievable RTAs was recorded).

Note in Figure 4 the slightly wider range of controllability at the lower flight level, illustrating that the aircraft’s performance envelope widens at lower altitudes.

Several observations of RTA controllability were also made at different CIs. At slightly greater than 400 nautical miles from the waypoint OBXAY, operating with CI=0 caused the ETA at OBXAY to be later by just under two minutes – reducing the range for achieving a later RTA by that amount but increasing the ability to meet an earlier RTA. The opposite effect occurred when a higher CI was being flown (e.g., CI=50).

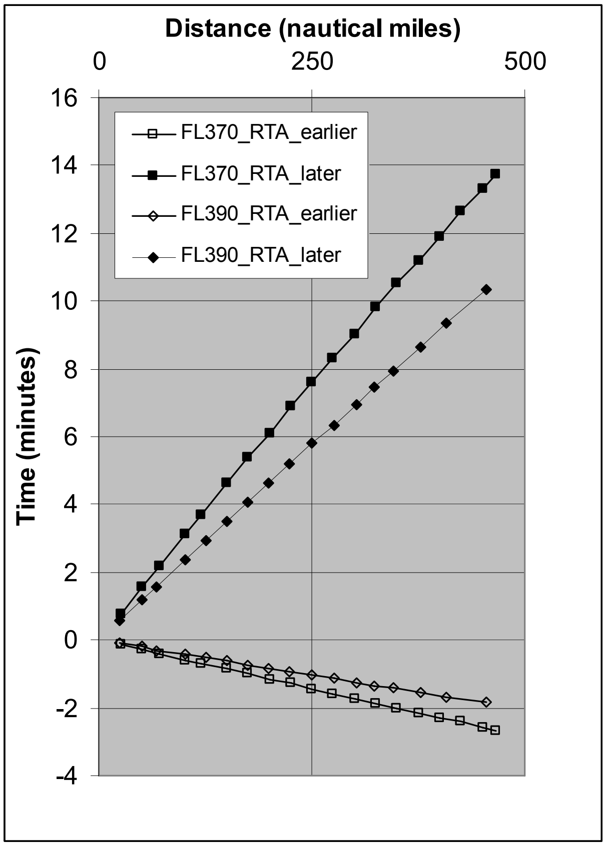

Figure 4: RTA Controllability

Investigation of Lateral Offsets

A lateral offset maneuver is one in which an aircraft operates along a path parallel to the original route for some portion, offset from the original path by a specified distance. Most FMS’s can perform offset maneuvers. The Smiths FMS supports the offset via entry of the following information [4]: the offset distance, the offset direction (left or right of the original path), the beginning waypoint (present position is assumed if no waypoint is entered), and the ending waypoint. Upon entry, the FMS recomputes the ETAs for the trajectory, making the lateral offset a maneuver compatible with TBO.

The PCSim tool was used to examine lateral offsets of varying size where the offset was initiated at BTR and ended at GCV during the cruise portion of the flight. The length of flight during the offset was about 150 nautical miles. Offsets of 3 to 9 nautical miles were examined, in increments of 1 nautical mile. They were implemented via the FMS. Figure 5 shows the beginning of a 5 nautical mile offset to the right; the straight baseline path is also shown.

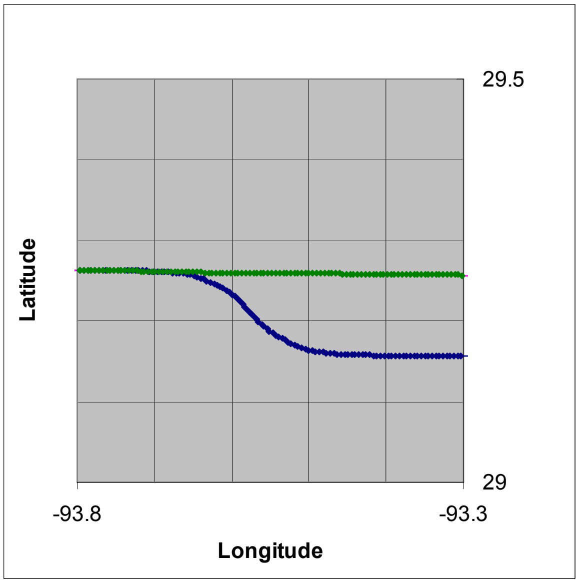

Figure 5: The Beginning of a Lateral Offset

The FMS executes a turn at the point where the offset is specified to begin and flies until a turn is executed to intercept the offset path. The same procedure is conducted when rejoining the original flight path, except that the maneuver begins such that the flight rejoins the original path by the specified ending waypoint. The time added is that required to fly the additional distance of these two legs over the original distance of the flight's path. Table 2 shows this extra time over the baseline flight as measured from the PCSim runs for the various offsets. The table also lists the estimated increased fuel consumption, assuming an average fuel consumption rate of 71 pounds per minute during cruise for the baseline flight.

Based on these results, lateral offsets have the potential for use in certain tactical situations while not severely impacting the aircraft's 4D trajectory[2]. For example, they might be useful for resolving conflicts with another flight along the same path (i.e., overtakes with zero closing angles) or on paths with small closing angles. These situations occur frequently in the NAS today and could increase in the future if RTAs are in common use (and are being met by adjustment to the CI which is largely a speed adjustment). Lateral offsets could also be employed where a flight is climbing and needs to merge into an overhead stream. The offset could be employed if no gap or hole is present to allow the flight to merge into the stream.

Table 2: Impact of Lateral Offsets

Offset amount	Extra time	Extra fuel
Nautical miles	**Seconds**	**Pounds**
3	16	19
4	29	34
5	36	43
6	44	52
7	54	64
8	61	72
9	68	80

The Concept of Operations for NGATS [1] includes reduced and performance-based separation standards. If reduced separations are available in the future, smaller offsets may be available for use at cruise altitudes. These smaller offsets would allow separation assurance with reduced impact on the flight.

The offset maneuver has several other potential impacts. A lateral offset may allow a flight to "pass" without significant penalty; relative to reducing speed and remaining behind a slower aircraft. The impact on other flights may also be reduced, as the need to create spaces in an overhead stream might be lessened. The offset can also be efficiently coordinated since the maneuver includes the rejoining of the original trajectory without requiring a second coordination.

Lateral Offsets and RTAs

Under the operational context described earlier, if an RTA is in place but the aircraft must maneuver to address a tactical situation, it would be desirable to select a maneuver that is "compatible" with the RTA. That is, one that allows the situation to be resolved while still achieving the RTA. Due to the characteristics discussed previously, a lateral

---

[2] This paper only has examined lateral offsets in the limited context of extra time and fuel use and their utility in conjunction with use of RTAs. Additional investigation needs to be done to address issues such as those related to their operational acceptability before increased use of lateral offsets can occur.

offset is one such maneuver that may be useful for some situations.

In general, if the RTA was for a later time than the original ETA (such that the flight has "slowed down" to meet the RTA) and the lateral offset can be initiated with sufficient lead time before the RTA, the FMS can replan in most cases to still meet the RTA. In the case where a flight is given a later RTA, a higher CI can be selected that will allow an aircraft to reach a waypoint by an earlier time equal to the extra time induced by the lateral offset – thus still having a plan to cross the waypoint at the assigned RTA.

Several experiments were conducted using the PCSim. Given the wide range in controllability when the flight is far from the waypoint being considered (ranging between the earliest and latest RTAs achievable of over ten minutes when at about 400 nautical miles), any RTA in this range except within about one minute of the "earliest end" would still be "achievable" if an offset of the sizes discussed here was implemented. Such cases were entered into the FMS and the RTA remained "achievable."

Indeed, if small offsets were operationally acceptable in the future, the smaller time impact would mean that some RTAs could still be met if the offset was begun relatively close (e.g., 50 nautical miles) to the RTA waypoint.

Summary

This study focused on the cruise phase of flight. Options for several maneuvers available to resource management and to management of tactical situations (including separation assurance) during this phase of flight were examined. These maneuvers were evaluated in terms of time control provided and in most cases fuel use was also estimated.

CTAs generated by automation, such as time-based metering, are envisioned as a primary means of resource management in the future system.

For a CTA earlier than the ETA at a waypoint during cruise, the flight has to "make up time" to meet the CTA. One way to accomplish this is to fly a shorter path than planned prior to the waypoint – often referred to as a "direct" for some portion of the route. For our baseline case, this would consume less fuel – at the savings of about 71 pounds for each minute of time save – making this a desirable maneuver. However, this option may not always be available – as users get routes closer to their preferred routing, less opportunities will likely be available for flying an even shorter path during cruise. The other alternative to "make up time" is to increase the speed. The amount of speed increase available depends on the CI being flown and other factors such as the cruise flight level. For our baseline case, less than 2 minutes of time could be gained over a 400 nautical mile cruise segment. Slightly more time could be gained if the flight descended to a lower flight level. Increases in speed result in increased fuel consumption.

For a CTA later than the ETA, the flight has to "loose time" to meet the CTA. One way to accomplish this is to fly a longer path – vectoring, rerouting and flying a lateral offset all do that. These maneuvers result in increased fuel consumption – an additional 71 pounds for each minute of additional fling time for our baseline flight. Based on the options explored during this study, reducing speed appears to be a more attractive option for "loosing time." For our baseline flight, slowing to a CI of 0 over a 336 nautical mile segment increased flying time just over two minutes (124 seconds) while actually saving 34 pounds of fuel. Achieving the same time increase (124 seconds) via lengthening the flight path costs 147 pounds of fuel, a net increase of 181 pounds over the reduced CI case. Again, the magnitude of controllability depends on the CI being flown and on other factors such as the cruise flight level. For the baseline flight, use of the RTA capability resulted in about 8 minutes of controllability to loose time (over a 336 nautical mile segment) – the increase due to the FMS's ability to use a negative CI.

The ability to address a tactical situation while having a CTA at a future waypoint (this study used the RTA capability to meet the CTA) was also examined. The lateral offset maneuver was used. This maneuver is compatible with the TBO concept. The lateral offset was entered into the FMS – allowing the FMS to replan and evaluate its ability to still meet the RTA. The RTA will remain "achievable" if the remaining controllability prior to the waypoint is larger than the impact of the offset. For example, an offset of 6 nautical miles increased the flying time by 44 seconds. For the baseline flight that has slowed to meet an RTA, the RTA may still be achieved as close as about 100 nautical miles if an offset of this magnitude is employed.

Next Steps

This paper discusses an initial look into one maneuver compatible with trajectory-based operations, the lateral offset, which shows promise as being useful to resolve some number of tactical situations while allowing an RTA to still be achieved. Other maneuvers should be investigated to provide a wide range of alternatives to address as many tactical situations as possible. An obvious type of maneuver to investigate is an analogous one in the vertical dimension – a change in flight level or an “altitude offset”. Given the recent introduction of RVSM and proposed NGATS concepts such as trajectory-based airspace’s flow corridors [1], the altitude dimension holds promise in the future to also be an increasingly valuable dimension for resolution of tactical situations.

This paper also limited the investigation to the cruise portion of a flight. The ability to resolve a tactical situation and still meet an RTA needs to be examined over the entire flight trajectory. In particular, investigation needs to be done on the descent portion of a flight trajectory, a portion of the trajectory where RTAs may also be used frequently. Time-based metering concepts have traditionally placed a control point (often called a meter fix and a likely candidate for an RTA) at some point during the descent. Some current research efforts are looking at employing an RTA as late in the descent as the runway threshold.

Lastly, this initial investigation did not include the effect of winds. In general, upper wind prediction errors are a factor in determining how accurately an RTA can be achieved. The FMS will perform its calculations of the plan to meet an RTA based on entered winds and will attempt to compensate for any wind error encountered during the execution of the maneuver. Further investigation of the impacts of winds is warranted.

Conclusions

The use of an RTA holds promise as a control mechanism for resource and flow management in the future. However, some tactical situations are expected to arise and must be resolved. This paper reports on an initial investigation of the utility of the lateral offset maneuver to resolve some conflict situations, while still enabling an RTA to be achieved. The lateral offset may also be useful in addressing other tactical situations. A key to successful use of a lateral offset when an RTA is being employed is to detect and resolve the tactical situation with a lead time longer than that often used in the NAS today.

References

[1] Joint Planning and Development Office, 2006, Concept of Operations for the Next Generation Air Transportation System (DRAFT), Version 0.2, Washington, DC, Joint Planning and Development Office, www.jpdo.aero.

[2] IATA, 2004, Fuel Action Plan: Guidance Material and Best Practices for Fuel and Environmental Management, IATA, www.iata.org

[3] Smiths Aerospace, 2005, FMSC Guide, 4MCU FMC Update 10.6, Grand Rapids, MI, Smiths Aerospace, Chapter 1.

[4] Wichman, Keith D., Göran Carlsson, Lars G.V. Lindberg, 2002, Flight Trials: “Runway-to-Runway” Required Time of Arrival Evaluations for Time-Based ATM Environment – Final Results, Monterey, CA, AIAA GNC Conference.

[5] Wichman, Keith D., Göran Carlsson, Lars G.V. Lindberg, 2001, Flight Trials: “Runway-to-Runway” Required Time of Arrival Evaluations for Time-Based ATM Environment, 0-7803-7034-1,IEEE.

[6] FAA Office of Aviation Policy & Plans, 2006, FAA Operations & Performance Data, Washington, DC, FAA, www.apo.data.faa.gov.

[7] Smiths Aerospace, 2000, Users Manual for the Smiths Industries Flight Management Computer System Basic Flight Training Device, UM1211, Grand Rapids, MI, Smiths Aerospace.

[8] Smiths Aerospace, 2001, Procedure Design Tool Help, PDT 4.01, Grand Rapids, MI, Smiths Aerospace.

[9]Airlines Electronic Engineering Committee, 2000, Advanced Flight management Computer System, ARINC characteristic 702A-1, Annapolis, MD, Aeronautical Radio, Inc., pages 33-35.

[10] Volpe National Transportation Systems Center, 2005, enhanced Traffic Management System (ETMS), Functional Description, Version 8.0, VNTSC-DTS56-TMS-002, Cambridge, MA, Volpe National Transportation Systems Center.

[11] Boeing, 2005, 737 ebrochure, Seattle, WA, Boeing Commercial Airplanes, www.boeing.com/commercial/737family/e_brochure.

[12] Boeing, 2005, 737 Airplane Characteristics for Airport Planning, D6-58325-6, Seattle, WA, Boeing Commercial Airplanes, page 93.

Disclaimer

This work was produced for the U.S. Government under Contract DTFA01-01-C-00001 and is subject to Federal Aviation Administration Acquisition Management System Clause 3.5-13, Rights In Data-General, Alt. III and Alt. IV (Oct. 1996). The contents of this document reflect the views of the authors and/or the Director of the Center for Advanced Aviation System Development. Neither the Federal Aviation Administration nor the Department of Transportation makes any warranty or guarantee, expressed or implied, concerning the content or accuracy of these views expressed herein.

Email Address

postwald@mitre.org

Acknowledgments

The author thanks Mr. Greg Nelson, Mr. Edward Hahn, and Mr. Michael Cramer of MITRE CAASD for their valued support and review. Thanks also to Randy Ottobre of MITRE CAASD for support in making runs with the PCSim. The author also thanks Michael DeJonge of Smiths Aerospace for reviewing the paper.

25th Digital Avionics Systems Conference
October 15, 2006