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Airline Based En Route Sequencing and Spacing Field Test Results

Observations and Lessons Learned for Extended Metering

Peter M. Moertl
Center for Advanced Aviation System Development
The MITRE Corporation
McLean, Virginia, USA
pmoertl@mitre.org

***Abstract*— Airline Based En Route Sequencing and Spacing (ABESS) is a concept of operations that allows airlines to precondition flights during their en route phase of flight for spacing prior to entry into the terminal domain. This preconditioning process is intended to prepare flights for advanced descent procedures including Optimized Profile Descents (OPDs) and Flight-deck based Interval Management (IM). This paper describes the ABESS concept and a series of four field-tests with the United Parcel Service (UPS) Airline Operations Center (AOC) where an ABESS software prototype had been fielded and tested between 2006 and 2010 during regular UPS operations. The results of the field tests indicate improvements over the four year test period, and demonstrated flight trajectory predictions of up to 100 minutes (min) that allowed the detection of up to 90 percent of spacing conflicts and lead to additional work areas to make long distance spacing preparations operationally feasible for airlines. This paper discusses the contributors to, and limits of stability for long-term trajectory predictions in the context of the flight tests. These findings are expected to be useful for the Next Generation Air Transportation System (NextGen) and Single European Sky ATM Research (SESAR) projects that require longer-term predictions of flight trajectories and fix crossing times during the en route phase of flight.**

Keywords-extended metering, optimized profile descents, interval management, trajectory based operations

I. INTRODUCTION

The number of flights in civil airspace is projected to continually increase over the next years and planning efforts are underway to establish the needed changes to accommodate these increases (i.e., the Next Generation Air Transportation System [NextGen] and the Single European Sky ATM Research [SESAR]). Because runways and airspace are already highly-valued assets now and will be even more so in the future, it is projected that congestion will occur at an increasing number of airports. Also, pressure is growing to reduce fuel burn, emissions, and noise levels during airport arrivals.

Some of these problems may be addressed by new and efficient descent paths. Specifically, Optimized Profile Descents (OPDs), including variants such as Energy Managed Arrivals and Continuous Descent Arrivals, are intended to reduce the environmental impact of arrivals while also reducing costs. Because efficient OPDs require minimal intervention by controllers during the descent phase of flight, arrival flows must be preconditioned (adequately spaced) prior to the descent phase to minimize the need for controller intervention to establish safe separation. It is assumed that OPDs would primarily benefit commercial carrier aircraft that have flight systems capable of flying such approaches.

The merging of traffic streams establishes the arrival sequence of aircraft to the runways in use. In order for the merge to be successful, aircraft on the routes to be joined must be appropriately spaced. The spacing between successive arriving aircraft needs to be sufficient to allow for other aircraft downstream to merge into the overall flow while maintaining the minimum required separation between aircraft. Air Traffic Control (ATC) establishes the spacing by issuing speed and vector instructions to flight crews.

The methods used to achieve the arrival sequence and spacing can significantly impact both air traffic efficiency and airline costs. In the case of express package operations (e.g., United Parcel Service [UPS], Federal Express [FedEx]), flights operating at high speeds to minimize flight time between departure and destination may arrive closely spaced in the en route and arrival sectors, requiring controllers to utilize speed and vector clearances to achieve the necessary spacing and sequence. If spacing is not properly achieved early in the arrival flow, additional speed and vector clearances may be needed in the final en route sectors or at low altitudes in the Terminal Radar Approach Control (TRACON) airspace. These additional instructions may increase flight crew and ATC workload as well as fuel consumption and flight time. Additionally, for passenger carriers, aircraft that arrive too early or too late, can unnecessarily increase operating costs, increase passenger delays and affect planned connections.

Interval Management (IM) describes a set of applications to improve sequencing and spacing of converging flights and facilitate OPD operations. IM is one of several new concepts that are in line with NextGen that includes a strong focus on time based operations. Fig. 1 shows the set of different applications that are part of the IM application developments.

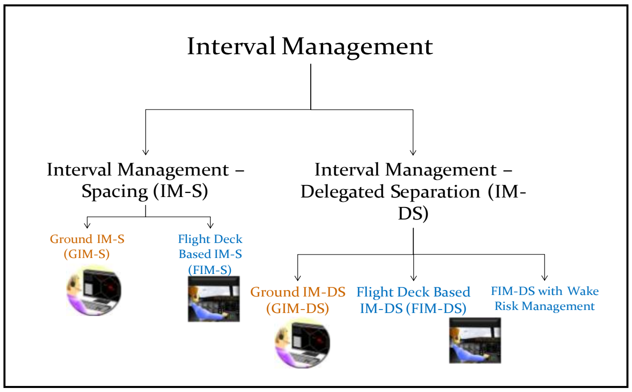

Figure 1. Overview of types of IM applications

IM contains two flavors that reflect considerably different roles and responsibilities of pilots and air traffic controllers. IM for Spacing (IM-S) reflects concepts that move some spacing tasks to the flight crew but air traffic controllers stay responsible for separation. IM for delegated separation (IM-DS) goes one step further and moves some separation responsibility from controllers to the flight deck. Ground-based IM for Spacing (GIM-S) contains the ground-based infrastructure for IM-S and can either be conducted by ATC or the Airline Operations Center (AOC). In either case, GIM-S consists of flights making minor speed changes further upstream from the airport's merge points to prepare the arrival flow and specifically, reduce the need for more significant trajectory modifications such as ad-hoc lateral maneuvers closer to the airport merge fixes. GIM-S can be implemented by controllers or by airlines. This document describes one possible implementation of an AOC GIM-S application that is called Airline Based En Route Sequencing and Spacing (ABESS) [4,5].

A. ABESS Concept Description

Under ABESS, the AOC sends speed advisories to flight crews to precondition flights spacing over an en route metering point. Speed advisories are sent via an electronic data link: the Aircraft Communications Addressing and Reporting System (ACARS). Speed advisories are sent between approximately 90 to 30 minutes (min) prior to crossing the meter point. Flight crews acknowledge and then follow those speed advisories to establish the desired arrival spacing. Under current operations without ABESS, flight crews may also receive speed requests from the AOC, and flight crews currently have the ability to fly speeds at their discretion within 5 percent or 10 knots of their filed speed, provided ATC has not given a specific speed instruction. With ABESS, the frequency of speed requests from the AOC may increase for some flights, but other operations remain the same.

ABESS consists of three phases: Setup, Conduct, and Termination (see Fig. 2). During setup, the ABESS operator coordinates with the flight dispatcher and operations supervisors to select the aircraft that should be merged over a selected merge fix. During the conduct phase, the flights are in what is called the Speed Adjustability Period (SAP). Here, the ABESS operator uses the ABESS tool to monitor for speed advisories and uplink them to flight crews. The operator then receives their responses and also monitors flight progress and weather information. Operator tasks during the termination phase consist of uplinking a final advisory to the flight crew and monitoring for completion when flights exit the SAP.

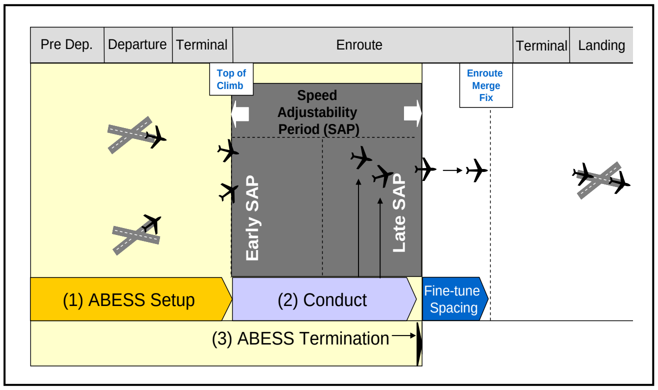

Figure 2. Overview of ABESS operations

When ABESS operations are being conducted, ATC monitors the traffic flow and intervenes as necessary if the flown speeds do not meet their overall traffic management goals. The responsibility for maintaining aircraft separation remains with ATC, and the ABESS target spacing between successive aircraft will always be greater than minimum ATC separation requirements. The distribution of responsibilities between the AOC and ATC does not change compared to current operations. If at any time ATC or the flight crew decides ABESS should be discontinued, or ATC issues a speed command, conventional operations are resumed.

After ABESS terminates, the spacing of flights is either managed by ATC as under current operations or, when appropriate flight deck equipment exists, the flights may transition to Flight Deck Based Interval Management FIM. In that second case, the flight crew uses onboard equipment to maintain and achieve the desired spacing.

Additionally, the conduct of OPDs imposes unique and sometimes larger spacing requirements on aircraft as compared to non-OPD operations. ABESS may be used to prepare flights spacing for OPDs in that ABESS speed advisories can help achieve these larger spacing's. After the AOC has used ABESS to prepare flights for their OPD's and ABESS has been completed, ATC is expected to transition flights to OPD's.

Information that is needed for the conduct of ABESS is shown in Fig. 3. The minimal requirements for the conduct of ABESS over all the test runs are underlined and italicized in

Fig. 3.[1] Flight plan and flight position report information is required along with accurate wind prediction forecasts for appropriate flight trajectories and updates as flights progress on their flight path. The flight's indicated airspeed is used to determine speed advisories that are feasible within a flights' speed envelope. Finally, the flight's confirmation about speed advisory acceptance or rejection is used by the ABESS tool to determine if alternative speed advisories should be developed and to determine if a detected spacing conflict can be expected to be resolved within the immediate future.

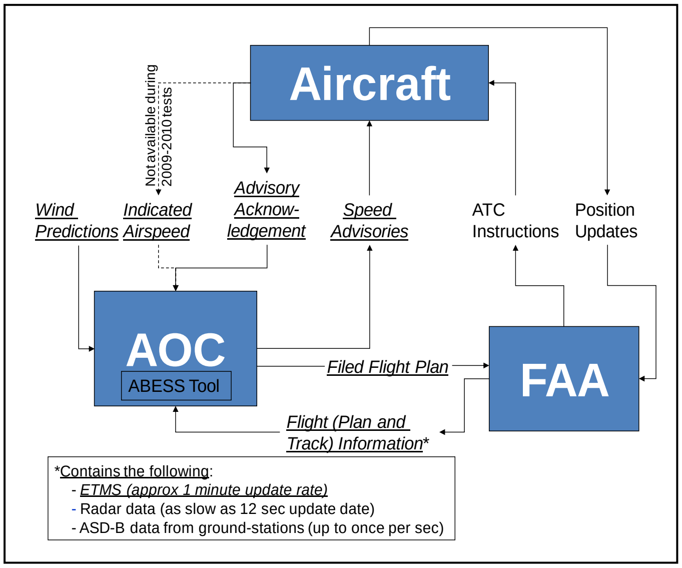

Figure 3. Information requirements for ABESS

Upon receiving a speed advisory from the ABESS tool, the ABESS operator first decides if a speed advisory is needed and if it is reasonable for a given spacing situation. The operator then selects the appropriate set of speed advisories if more than one is available. If the ABESS operator also functions as the flight's dispatcher, ABESS speed advisories can be directly uplinked to the flight crew. If the ABESS operator is not the flight's dispatcher, ABESS speed advisories are forwarded to the flight dispatcher who then decides if the speed advisory should be uplinked to the flight. The decision is based on the dispatcher's knowledge of a flights situation and plans. This process introduces sometimes delays in the speed advisory uplink that may degrade the efficiency of the ABESS operation. After the uplink, the flight crew responds back with information about their planned speed advisory compliance or non-compliance. The ABESS operator then inputs this information back into the ABESS tool.

II. ABESS SYSTEMS ARCHITECTURE

The ABESS software consists of three components: a trajectory modeler, a speed advisory algorithm, and a user interface. Each of these elements is described in the following subsections.

A. Trajector Modeler

The trajectory modeler was designed to produce a four-dimensional (4-D) trajectory for a given aircraft based on flight plan data, the aircraft's current location, adaptation data, and environmental data [1]. Adaptation data include Adaptation Controlled Environment System (ACES) data, National Flight Data Center (NFDC) data, and aircraft performance characteristics. The environmental data include wind, temperature, and pressure data at different altitudes. The trajectory is the best estimated behavior of an aircraft based on filed flight plan, and airspace characteristics that are known to the computer. Based on the trajectory, presumed fix crossing times can be calculated to allow the prediction of spacing conflicts between flights.

The trajectory modeler receives information from multiple sources. Aircraft position information was received from five ADS-B ground stations and fused with radar position information from five long range radar sites. The frequency and accuracy of position update information has some impact on how quickly the trajectory modeler can detect deviations from the flight path. Therefore, higher update rates and accuracy that is available via ADS-B position reports are preferred over lower update rate and accuracy data. Flight plan as well as flight plan update information was received via ETMS. Wind information was received from the National Oceanographic and Atmospheric Administration (NOAA) on hourly update rates (Rapid Update Cycle [RUC]).

During the first test in 2006, the MITRE CAASD tool comprised a trajectory modeler that had been designed for a traffic flow management tool. This trajectory modeler included simplified assumptions and parameters about airspace characteristics as it was optimized for the prediction of large sets of traffic. During the remaining tests starting in 2008, the MITRE CAASD tool comprised a trajectory modeler that had been designed for an ATC tool (User Request Evaluation Tool [URET]). This second trajectory modeler included more detailed airspace characteristics and parameters than the first tool.

B. Speed Advisory Algorithm and Graphical User Interface

The ABESS tool provides speed advisories to the ABESS operator if fix crossing times of two or more flights indicate that these flights would be arriving within the minimal spacing target (e.g., 150 seconds [sec]) over the merge fix. The speed advisories consist of the speeds that flights need to fly to stay at or above their desired spacing minimum. The speed advisory algorithm does not advise speeds that reduce the spacing between flights and speed-ups are only provided to the leading aircraft in a sequence of aircraft to increase spacing. Slow-downs are provided to flights that are following other aircraft. If multiple solutions to a given spacing problem are possible, the tool provides the operator with a set of solution alternatives to select the one that optimally meets the operational goals.

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[1] This figure summarizes information as it emerged from the combination of all test events. Therefore, in the tests that are described later on within this document, not all information depicted in Fig. 3 was always available in every test event. For example, during the 2006 ABESS test, only Enhanced Traffic Management System (ETMS) flight plan and track information were made available to ABESS. Automatic Dependent Surveillance-Broadcast (ADS-B) data and radar data were available to ABESS in the 2008–2010 ABESS tests. Also, indicated airspeed was available to ABESS in the 2006 event, but not in the 2008–2010 events.

Once the appropriate speed advisory was selected, the ABESS operator will then uplink speed advisories to flights or let the flight's dispatcher know about the speed advisories. After the uplink, the flight crew responds either with the intent to comply or not. The ABESS operator then enters the flights crews' response into the ABESS tool so that the ABESS tool stops providing new speed advisories for flights that had just previously received and accepted speed advisories.

Speed advisories are presented to the ABESS operator using a Graphical User Interface (GUI) that also provides additional essential flight information for the purposes of spacing flights. The operator can select different solutions and for each solution view the proposed speed advisories for all flights.

The ABESS GUI provides also additional information beside speed advisories. First, the tool presents essential flight information for flights that are filed over the merge fix including flight identification, type of aircraft, departure airport, predicted spacing, and predicted fix crossing times. Second, the tool presents a timeline that displays spacing information graphically. Third, status information (i.e., flight plan information, update rates of position and indicated airspeeds, and previous speed advisories) are shown on the bottom of the display. Once the ABESS tool detects a spacing conflict between two or more flights, the tool displays a yellow border around those flights. This yellow highlighting indicates that a speed advisory should be given to resolve the spacing conflict. There are no auditory cues associated with new speed advisories.

III. ABESS TESTING

The ABESS concept was tested in a series of test events in which different software systems and input data were used during regular, but modified UPS operations. During the tests, no special test flights were scheduled. Tests were conducted at the UPS AOC in Louisville, KY with a set of UPS flights that arrive late at night from the Western United States into Louisville. Speed advisories were uplinked to the flights during the SAP which overlapped roughly with the airspace of Kansas City En Route Air Traffic Control Center (ZKC). At the time when flights were traveling through that center, there was relatively little other, non-UPS traffic. This environment allows for a good test environment of the ABESS concept because traffic can fly on trajectories that are undisturbed from other traffic due to their late night arrival times. All participating flights were routed over the same en route metering point. This filing was slightly different from the filings that flights would receive on normal, non-ABESS test days, when flights typically merge at the terminal boundary.

Though ABESS is intended to prepare the spacing of flights for OPD's, no OPD's were actually flown during the tests. Instead, it was observed if ABESS would help achieve the spacing that would be needed for OPD entry.

The UPS AOC coordinated all ABESS operations with the respective en route air traffic control centers through which the flights passed through. Flights spent the most amount of time during their SAP in ZKC airspace. The UPS AOC requested that the centers not send flights on routes other than those for which flights had been planned except if needed for separation purposes. Specifically, controllers were requested not to clear flights to fly direct to their terminal fix, which, on other nights, would have represented a standard controller procedure.

During all tests, UPS dispatchers uplinked speed advisories from the AOC via ACARS to the flight deck.

All tests were coordinated with the ATC facilities through which the UPS flights generally fly. ABESS flights travelled most extensively through ZKC airspace. Late at night, when traffic levels are low, sectors in ZKC centers were combined and staffed at reduced staffing levels.

The remainder of this section describes the ABESS test environments, and then summarizes results for each of the test activities.

A. 2006 October ABESS Test

The first ABESS test was conducted during two weeks in October 2006 (October 3–6 and October 9–11). Two ABESS tools were tested during this event. One tool had been developed by MITRE CAASD and was tested during week one. The second tool had been developed by the National Aeronautics and Space Administration (NASA) Ames and was tested during week two. The two systems were different in that the MITRE CAASD tool calculated speed advisories based on an internal trajectory modeler, whereas the NASA tool calculated speed advisories without trajectory modeler, based on the straight line distances between aircraft and the metering point. The NASA tool did not utilize wind information or other flight plan information.

The methodology and results of this ABESS test are described in detail in [2], and are here only summarized. Air traffic controllers appeared to find ABESS operations acceptable and were generally cooperative during the test. During the first night of operations, controllers issued direct routings to flights. After an intervention by the UPS test director, no direct routings were observed during subsequent nights. This matched the overall requirements for ABESS. Controllers remarked that they wanted earlier, "more aggressive" speed advisories for flights to more effectively adjust the spacing. Controllers seemed to welcome the help of the AOC for their spacing tasks, and no interference of ABESS operations on other operations (i.e., traffic that was crossing the stream of aircraft that were performing ABESS) was observed.

Flight crews followed the speed commands, and accepted all of the 46 uplinked speed advisories. Flight crews were interviewed after the ABESS test and found operations acceptable.

The ABESS operators at the UPS AOC generally found ABESS operations acceptable and were able to coordinate the uplink of speed advisories to the flights. However, ABESS operations required two operators who made decisions about which speed advisory to uplink. ABESS operators remarked that the accuracy and reliability of speed advisories was low with both tested ABESS tools. Accordingly, operators generally delayed the uplink of speed advisories until they had processed corroborating evidence about the correctness of the speed advisories. That was contributed by the fact that the

ABESS tool provided too many speed advisories compared to the number of advisories that were actually uplinked. MITRE CAASD's ABESS tool predicted crossing times on average within 60 sec of their actual crossing time for the last 100 min prior to flights reaching the fix crossing time.

Overall, the results of the first test promised operational feasibility of ABESS while also pointing to the need for improving ABESS tool performance; both in terms of predictive fix crossing time accuracy and reducing the number of speed advisories by improving speed advisories' reliability and stability.

B. May/November 2008 ABESS Test

ABESS was then operated at the UPS AOC on three nights between May 20–23, 2008 and again in November the same year. Two tools were tested this time. One had been developed by Mosaic ATM, Inc. (Mosaic ATM) and was part of the Surface Management System (SMS), a suite of software capabilities that is being used by UPS for planning and management of surface movements at Louisville. This tool received input from a data feed with trajectory information from a Traffic Management Advisor (TMA) research prototype at NASA AMES. The second tool was developed by MITRE CAASD and consisted of an updated version of the tool that had been tested two years earlier. This updated version that was also used in the following flight tests utilized a prototype trajectory modeling algorithm that MITRE CAASD had developed for the URET.

After initially testing both tools in shadow mode on the first day, the tools were used by the AOC to provide speed advisories to flights on two days. For a randomly selected set of flights for which accuracy was analyzed, MITRE CAASD's ABESS tool provided predictions of crossing times for a given flight (i.e., less than 2 min of errors up to 100 min prior to reaching the en route fix), but predictions did not converge toward the true fix crossing times as flights approached the fix. This reflected integrity problems with the trajectory modeler as it was expected that fix crossing time predictions converged toward the true fix crossing times as flights approached that fix. These trajectory modeler integrity problems were likely caused by unexpected variability in data formats of flight plan and position update data that had not been encountered during the preceding tests. The Mosaic ATM tool's fix crossing time predictions were significantly inaccurate for this flight (around 20 min at 100 min prior to reaching the fix) but converged, as expected, to a zero error as the flights approached the metering point. Overall, the tests results indicated differences in tool integrity and accuracy between the two tested tools and suggested that both tools needed further development before tools could be used in daily operations.

In addition to the test in May, a second ABESS test was performed November 17–20, 2008. Again, trajectory information from NASA's TMA prototype was made available to the ABESS tool that was running at the UPS AOC in Louisville. Speed advisories were uplinked to flights. It was found that the TMA generated trajectories could be successfully linked to the ABESS tool at the UPS AOC. However, tool performance was similar to the May test event, and operators indicated being dissatisfied about the frequent unreliability of the presented information.

C. 2009 Spring ABESS Test

Based on the previous tests, the ABESS tool was modified and updated and then tested in a longer term shadow test event. In 2009, the ABESS tool was run approximately four days each week between April 1 and June 8 at UPS in Louisville, KY without the uplink of speed advisories. Fix crossing times for the set of ABESS flights were calculated and recorded. The software was run remotely at the UPS AOC and controlled from the MITRE facility in McLean, Virginia. After each run, fix crossing time predictions for the UPS flights were downloaded from the ABESS system, including wind predictions and flight planning information. These test data were then processed, analyzed, and summarized and are described in more detail in [3]. Because no speed advisories were uplinked to flights, only the trajectory modeling components were tested during this event.

Average fix crossing time prediction errors for a single day (April 14) are shown in Fig. 4 which was the day from the four week test period that showed the lowest trajectory prediction errors. The categorized signed prediction errors in Fig. 4 show the median, 25%, 75% error quartiles. As expected, errors decreased as aircraft approached the metering point. The results indicate that the trajectory modeler integrity problems that had been observed in the previous test had been resolved. In addition, the contributors to prediction errors were analyzed and are reported in [3] in more detail and are here only summarized. Contributors to prediction errors fell into the following groups. First, unpredicted step climbs of flights from intermediate to final altitudes caused uncertainty in the predictions due to differences in predicted wind fields at different flight levels. Second, ground speed reported from ADS-B, radar tracking systems, and indicated airspeed reported via ACARS appeared highly variable. This variability in speed reports was found to contribute to trajectory uncertainty and thereby results in the delayed detection of non-conformance of flight trajectories with observed flight behavior. Third, limitations of wind prediction accuracy were found to have a significant impact on the quality of longer look-ahead trajectories, resulting in significant prediction errors as close as 30 min prior to the merge fix. Reference [3] also identifies methods to improve trajectory quality based on the assessments and comparison of wind prediction accuracy with apparent aircraft movement and reported airspeeds. Finally, trajectories were found to be disturbed by the transmission of incorrect flight identifiers that caused failures in associating the correct flight plan and position information and therefore resulted in large prediction errors.

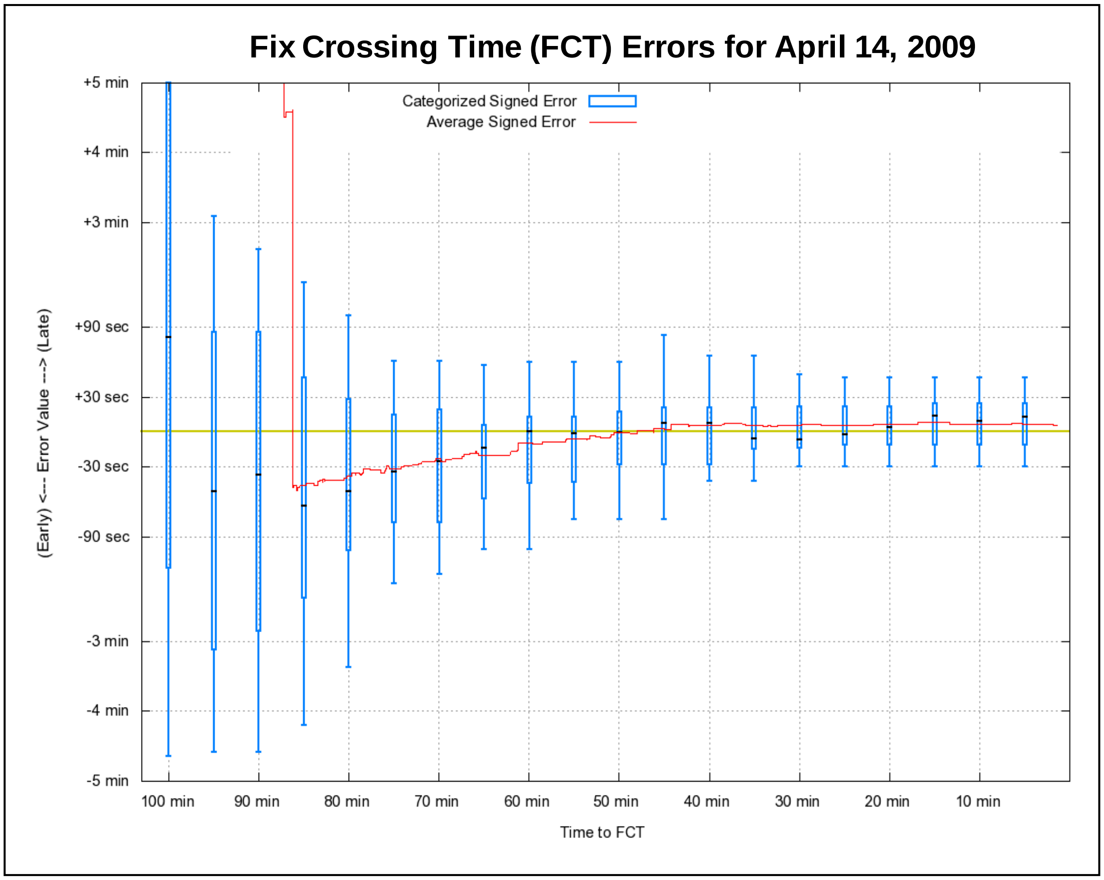

Figure 4. Average Fix Crossing Time Prediction Errors during the 2009 Test

D. 2010 June ABESS Test

The ABESS testing in 2010 had several objectives. First, the ABESS tool performance was intended to be measured in terms of its ability to predict fix crossing times and the spacing of flights up to 100 min prior to reaching an en route metering point. Secondly, it was intended to assess how accurately ABESS could resolve any spacing problems through the uplink of speed advisories as early as up to 80 min prior to reaching the fix. Finally, operational acceptability of ABESS for controllers, pilots, and AOC personal should be confirmed.

The ABESS tool was run on six nights in June 2010 (June 7–9 and 14–16). Observers were located in the UPS AOC and at the ZKC en route ATC facility and observed traffic conditions, controller setup and sector configurations, and controller interactions. If the opportunity arose after the operations, observers asked controllers about their impressions of ABESS operations.

As in previous test events, flights were filed over a common en route metering point (Centralia, ENL). The target spacing was set to 120 sec. For flights that are traveling at approximately 500 knots, 120 sec translates to a horizontal spacing of 16.7 nautical miles (NM), which is well above the separation minimum in en route airspace (5 NM) and above the informally agreed on spacing between flights transitioning from ZKC to Indianapolis Center (ZID). That spacing is generally 10 NM.[2]

In the first of the six test nights, baseline operations were conducted in shadow mode testing without uplink of ABESS speed advisories. After the first night, speed advisories were given in all following test nights. During the second night, severe weather required the change of flight plans toward a different fix, thereby restricting ABESS operations to only a set of four flights. During all remaining nights, ABESS operations were conducted as expected. Because of the described differences in the first two nights, the last four nights are referred to as “regular” ABESS test nights.

IV. RESULTS OF JUNE 2010 TEST

A. Metering Predictions

The quality of en route fix crossing time predictions was assessed by comparing predicted metering fix crossing times at the time the last of the ABESS aircraft entered the SAP (80 min prior to reaching the metering point). Fig. 5 shows the fix crossing time predictions for all flights at the time the last of the flight reached the SAP (80 min prior to the metering point). Only flights were included in this analysis for which no speed

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[2] During the test it was observed that different controllers followed slightly different spacing goals, ranging between 8 NM to 12 NM, so that 10 NM seems more like an informal approximation than a fix rule.

advisories were executed as changes in speeds would have impacted the actual crossing times. Data for the first two days are only shown here to provide a comparison with the remaining days and only results for the regular ABESS test days should be considered.

Because of the lack of wind information on day one and the high number of reroutes and therefore, low number of ABESS flights on day two, fix crossing time predictions were worse on days one and two (average of 82 sec signed[3] error and 162 sec unsigned[4] error) than on the remaining days (average of 26 sec signed error and 44 sec unsigned error). Therefore, the first two days are only shown here for comparison and provide confirmation that the tool worked as expected.

This average prediction accuracy is similar to that in [3], who reported average prediction errors of less than 30 sec for the last 100 min prior to the metering point. This finding at first hand, appears to confirm generally the predictability of undisturbed en route flight paths at least under the tested conditions and is encouraging for the type of long term trajectory modeling that NextGen concepts require.

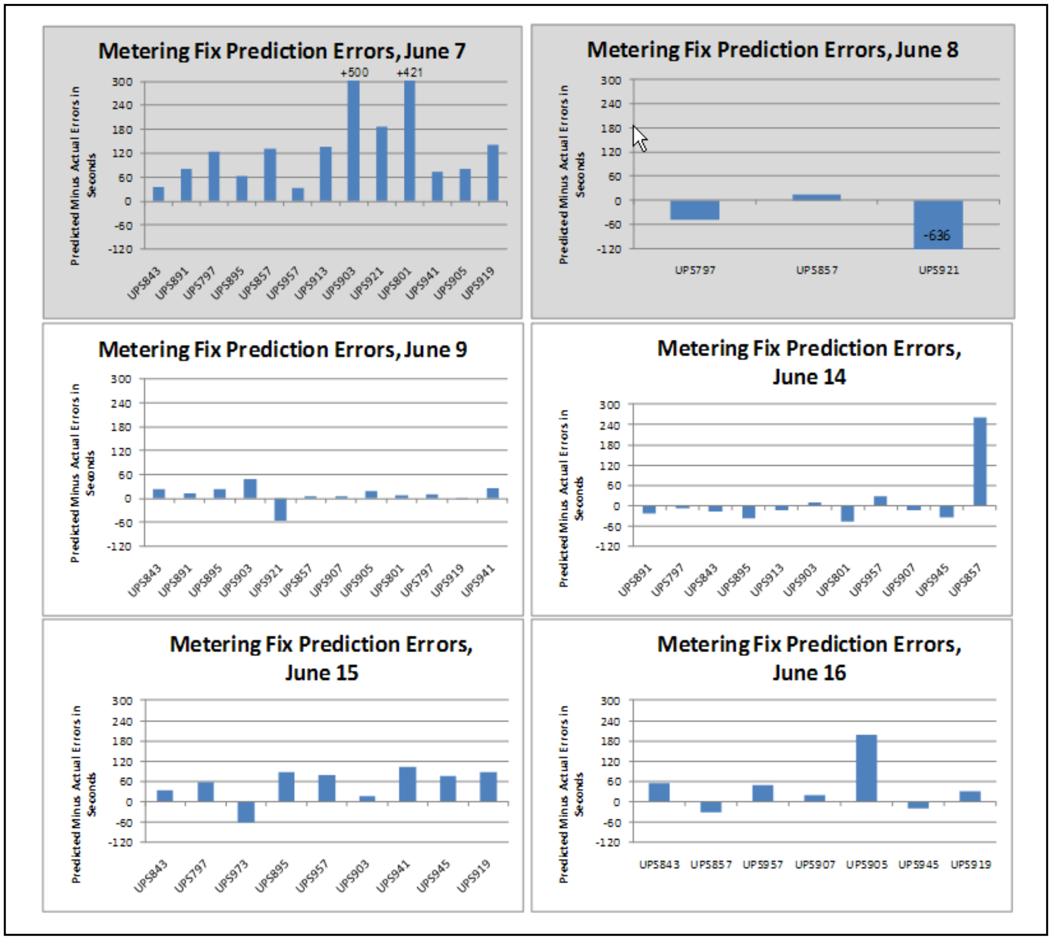

Figure 5. ABESS En Route Metering Fix Crossing Time Predictions per Flights

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[3] Signed errors contain positive and negative values that may reduce themselves to zero, when averaged. Signed errors are useful for the identification of (early or late) prediction biases.

[4] Unsigned errors consist of absolute values that do not reduce themselves to zero when averaged (e.g., one error of + 2 and one error of – 2 minutes result in an average unsigned error of 2 minutes. However, unsigned errors remove bias information. Because of the advantages and disadvantages of signed and unsigned averages, they are frequently used together for analysis.

B. Metering Conflict Predictions

The ABESS tool predicted metering conflicts if the predicted spacing over the metering point fell below the desired spacing goal of 120 sec. The desired spacing goal was input by the operator at the beginning of the operations. The desired spacing goal was set higher than the spacing during normal operations where controllers usually space flights at approximately 10 NM. Ten NM correspond to approximately 70 sec for flights flying at 500 knots ground speed. Two aircraft are referred to here as conflict aircraft when their predicted spacing was less than 120 sec.

In a post event analysis the number of true conflicts was determined. Over the four nights of regular ABESS operations, there were 142 true spacing conflict aircraft (42 conflicts on 9 June, 28 on 14 June, 41 on 15 June, and 31 on 16 June). ABESS predicted the spacing conflict for all but 3 of these true conflicts. This corresponds to a conflict detection rate of 92 percent.

The nuisance detection rate was calculated by subtracting the number of true conflict aircraft and successful speed advisories from the number of aircraft with predicted spacing conflicts that the ABESS tool detected.

Obviously, nuisance detections should be kept to a minimum because such incorrect conflict detections may reduce operator trust in the tool and are likely reducing the tools usefulness. During the four nights of regular ABESS operations, a nuisance detection rate of (142 – 32 – 4) / 142 = 75% was determined. This number is high and indicates that of all conflict detections only 25% turned out to be true.

The causes for this high nuisance rate are most likely caused by data input instability; especially the variability of groundspeed, and wind predictions as described in [3]. To address the high nuisance rate, some of the data input instability could be reduced using improved data smoothing algorithms. In addition, specific heuristics could be developed that allow the identification of sudden prediction changes, resulting in nuisance conflict detections and alternatives to avoid them. For example, cases where the predicted fix crossing times fluctuate by a few seconds and thereby move inside and outside a predicted spacing conflict with another aircraft could be identified and handled by a specific “nuisance detection policy.” Also, the use of improved position report timing information as associated with ADS-B reports could be used to better determine the time of applicability of position reports and therefore reduce some source of variability associated with inaccurate timing information. This information had not been previously incorporated into the ABESS trajectory modeler. Finally, one of the major contributors to nuisance detections is the lack of accurate wind predictions.

C. Speed Advisory Determination

Once the predicted spacing fell below 120 sec, the tool provided the operator with speed advisories to resolve that spacing conflict. The tool provided “global” solutions in this case, because the speed advisories resolved not only the conflict between the two aircraft with the immediate predicted spacing conflict but also between all other aircraft in that stream. This was particularly important for chains of multiple, closely spaced aircraft. However, solving metering conflicts for such tightly spaced aircraft solely through speed advisories sometimes required changing the speed of aircraft beyond their allowable speed envelope. If that happened, the ABESS tool could not find a global solution and therefore, did not provide any speed advisories. In that case, the ABESS tool displayed a list of possible speed advisories and associated predicted metering time changes for each flight. The operator would then pick the speed advisory that resulted in a desired change in crossing times and in this way removed the predicted spacing conflict. This second process of speed advisory determination was “non-global,” as it had to be repeated for every conflict pair.

The processes of determining global and non-global speed advisory solutions resulted in different apparent operator workload. Specifically, the non-global solution apparently required higher workload because it involved an iterative process by the operator to resolve one conflict at a time and then check that no other spacing conflict was created.

During testing on one test day, the ABESS operator had to select speed advisories in a non-global manner. This surprised the operator because, based on his previous ABESS training, he had expected the tool to provide global solutions. Therefore, he started utilizing a “careful” speed advisory selection heuristic by attempting to reduce the number and size of speed advisories and attempting to use the smallest possible speed changes. This actually resulted in difficulties in achieving the desired spacing. On the following test nights, the operator utilized a more pro-active heuristic that involved larger speed changes for flights.

The operator had to determine if a given solution was feasible for the flight deck. In order for a speed advisory to be feasible, it needed to be flyable, i.e., not be outside the flyable airspeed envelope. The ABESS tool received current ground speed information, but during this test, did not automatically receive airspeed information from the aircraft. The flights’ dispatcher could request airspeed information via a separate communication. Apparently, to ensure speed advisory feasibility, the ABESS operator found it necessary to compare a flight’s speed advisory with the flight’s indicated airspeed. To get this information, the ABESS operator had two possibilities:

1. The operator could request a flight’s indicated airspeed from the dispatcher, compare it with the speed advisory and, if it exceeded the flight’s current indicated airspeed, select a different speed advisory.[5]

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[5] Note that the indicated airspeed is a number that fluctuates considerably on the flight deck. During a recent flight deck observation it was determined that the display of indicated airspeed fluctuated between -0.001 and +0.006 around the commanded Mach speed. Also, the flight crew could only select Mach speeds of up to two digits behind the comma (e.g., 0.80) while that the reported Mach speed that was distributed via the ACARS system is reported with three digit accuracy (e.g., 0.809). This occasionally caused confusion for flight crews. If a speed advisory asked to reduce an aircraft’s actual speed from 0.809M to 0.800M, the flight crew would not be able to enter that as their current commanded speed was already at 0.80M.

2. Alternatively, the operator would rely on the estimated indicated airspeed that ABESS displayed for each flight. This estimated indicated airspeed was based on internal calculations that utilized information about current winds as well as filed speed and ground speed to estimate the speed that a flight would follow. This estimation process however, depends on the correctness of various assumptions and was observed to be sometimes inaccurate. This was observed specifically, as expected, on June 7 where no wind information was available to the ABESS tool.

Overall, the speed advisory selection process during this test was relatively workload intensive for the ABESS operator. For actual daily operations, a more streamlined process is required. Specifically, the ABESS speed advisory algorithm should provide speed advisories for flights even if no global set of speed advisory solutions were available for all aircraft. In that case, global solutions should be indicated for those flights for which they are available. For the remaining flights, the speed advisories should approximate the desired spacing so that ATC interventions can remain at a minimum. Second, indicated airspeed should be available to the ABESS tool and used to determine which speed advisories to display to the ABESS operator. Even better than indicated airspeed for this purpose may be the availability of commanded speed because indicated airspeed fluctuates considerably and is only an imperfect indicator for the speed that the flight crew is intending to fly.

D. *Speed Advisory Coordination*

The process of getting speed advisories from the ABESS tool to the aircraft and for confirmation to return to the tool operator involved several steps. After a speed advisory was provided and accepted by the ABESS operator, the operator sent an instant text message to the dispatch supervisor. The supervisor then distributed the speed advisory to the appropriate dispatcher, who then uplinked the message and relayed the flight crew response back to the dispatch supervisor. The supervisor then provided the message back to the ABESS operator who entered the feedback into the ABESS tool. The average delay time between the ABESS operator initiating a speed advisory communication and receiving feedback was 12 min. Generally, the chain of communications between the ABESS tool and the flight crew consisted of four links which led to occasional communication breaks.

E. *Observed Spacing at Fix*

For four speed advisories (17% of all 23 examined speed advisories),[6] the speed advisories helped the aircraft achieve the target spacing or go beyond it. There were a number of cases where the speed advisories did not achieve the intended spacing:

1. There were 13 cases where the predicted spacing and the actual spacing, after uplink of speed commands, were insufficient. For one flight, UPS 921 on June 14th, this occurred because the flight could not make the uplinked speed adjustment due to turbulence. Also, Flight UPS919 reported not being able to implement the speed advisory. After removing these two flights, 48% of all ABESS speed advisories did not lead to spacing at or above the desired spacing minimum.

2. There were six cases where speed advisories were given while the predicted spacing was at or above the target spacing (26%). It is not clear why a speed advisory would be provided in that case. Speed advisories should only have been provided in cases when the predicted spacing was below the desired spacing. Therefore, these cases require more analysis. It may have been the case that the predicted fix crossing times fluctuated between when the ABESS tool indicated a spacing conflict and when the operator actually uplinked the speed advisory.[7]

Overall, a considerable number of speed advisories did not achieve the desired spacing effect. For 48% of these speed advisories, the target spacing could not be achieved and for 26% of them, the post-analysis showed they had not need to be given. Some of this behavior may have been caused by a non-optimal speed advisory selection processes. The above identified fluctuations and variability of input data as well as non-perfect wind predictions contributed to situations where speed advisories did not achieve the desired spacing.

V. CONCLUSIONS

ABESS is a concept of operations that allows airlines to precondition their flights to achieve the required spacing for the conduct of OPD's and the conduct of Flight-deck based IM. This document summarized the concept and a series of four field-tests with UPS that tested the concept with an ABESS prototype tool. The document describes the resulting data, software, and systems architecture requirements that were found to be needed to achieve operational acceptability for the concept. Over the four-year test period, an ABESS prototype test tool was iteratively improved and demonstrated flight trajectory predictions up to 100 min in advance where fix crossing prediction errors were on average considerably less than 60 sec. These trajectory predictions achieved spacing conflict detections of 92% of all conflicts. Over the same time frame, the percentage of acceptable speed advisories that the ABESS prototype provided improved from 5% during the 2006 test to 23% in the 2010 test. However, the ABESS prototype still demonstrated a nuisance spacing conflict detection rate of 75% and did not remove all predicted spacing conflicts.

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[6] Only 23 of the 26 speed advisories were analyzed here. Specifically, only one of the two speed advisories for flight UPS907 and for UPS913 on June 15 is included. Also, flight 801 on June 15th is not included on this graph as these data were not available at the time.

[7] UPS flight 921 did not actually implement the speed advisory. This does not explain why a speed advisory was actually given if the predicted time was above the target spacing.

Therefore, though the overall feasibility of ABESS has been operationally demonstrated several times, the desired spacing performance has not been successfully validated. The two main shortcomings that were identified during the final tests continued to be the relative instability of trajectory predictions and associated high nuisance spacing conflict solutions and the lack of global spacing conflict resolutions in certain situations. To move the ABESS concept toward operational use, the identified shortcomings in the ABESS tool should be addressed to improve trajectory prediction stability and the speed advisory algorithm performance.

During the tests, different types of trajectory modelers were used as basis for the calculation of speed advisories. From a simple straight line-distance algorithm, over a higher level traffic flow management trajectory modeler, up to lower level trajectory modelers as they are used by air traffic control automation (as used in TMA and URET) were used. Based on the experiences with these trajectory modelers, it became apparent that significant work is required to update and maintain the appropriate adaptation that is able to balance and utilize the relative high level of ADS-B position accuracy with flight plan and environment information. Given the need for this fine-tuning, it is expected that a lower level trajectory modeler as they are currently in use in URET or TMA seems more appropriate for the purposes also for longer term trajectory predictions than higher level traffic flow management based algorithms.

Finally, it was determined that the availability of airspeed information was repeatedly identified as required for the successful completion of ABESS. If airspeed information was not automatically available to the tool, operators went to great lengths to receive airspeed information from the aircraft directly to ensure that the speed advisories generally made sense to the operator. Airspeed information that had been derived from predicted wind (RUC) information was in many cases of insufficient accuracy for the operator.

The observations and lessons learned from this research are expected to be useful the development of air traffic control automation tools requiring the longer term prediction of trajectories and fix crossing times such as extended metering for Trajectory Based Traffic Flow Management (TBFM) and other NextGen and SESAR projects.

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AUTHOR BIOGRAPHY

Peter M. Moertl completed his B.S. degree in psychology at the University of Graz, Austria in 1996 and his doctoral degree in applied cognitive psychology at the University of Oklahoma in 2002.

He is currently a Lead Human Factors Engineer at The MITRE Corporation’s Center for Advanced Aviation System Development in McLean, Virginia, USA. He performs human factors research and concept development for advanced flight-deck and air traffic control operations as well as ADS-B standards development.

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