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Airline Based En Route Sequencing and Spacing Field Test Results

Observations and Lessons Learned for Interval Management

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***Abstract*— Airline Based En Route Sequencing and Spacing (ABESS) is a concept of operations that allows airlines to adjust the cruise speed of airplanes during the en-route phase of flight to meet a predetermined inter-aircraft 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 (FIM). 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 was fielded and tested between 2006 and 2010 during regular UPS operations. Test operations were completed in 2010. The field tests demonstrated flight trajectory predictions of up to 100 minutes that allowed the detection of up to 90 percent of spacing conflicts. The field tests also helped identify 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 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, more 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 appropriately spaced, or preconditioned, prior to the descent phase so as to provide safe separation. It is assumed that OPDs would primarily benefit commercial carrier aircraft that have flight systems capable of flying such approaches.

Merging streams of arriving traffic contributes to the overall sequence of aircraft arriving at an airport. In order for the merge to be successful, an appropriate inter-aircraft spacing must be achieved. The spacing must be sufficient to account for additional, downstream aircraft that may also need to be included in the stream, while remaining above the minimum required separation. Currently, Air Traffic Control (ATC) establishes the spacing by issuing speed, altitude, and heading 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 sequence and spacing. 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.

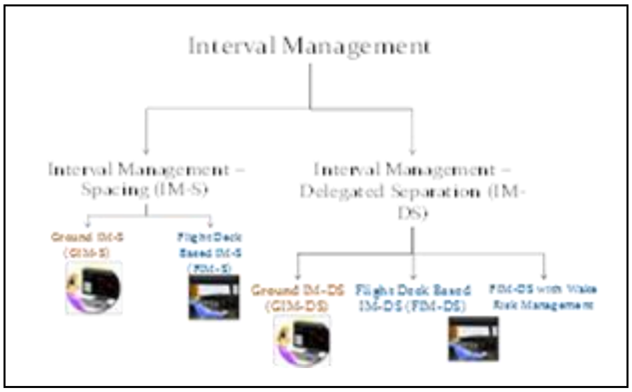

Figure 1. Overview of types of IM applications

IM contains two flavors that reflect considerably different roles and responsibilities of flight crews and air traffic controllers. IM for Spacing (IM-S) reflects concepts that remove spacing tasks from controllers who still stay responsible for separation. IM for delegated separation (IM-DS) goes one step further and moves some separation responsibility from controllers to flight crews. 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 well upstream of 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. 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]. The FAA has concluded its ABESS research and development activities in 2010.

There are several related concepts that provide similar functions to IM-S. The Attila trial concept consists of airline operations centers issuing flights metering times at the TRACON boundary to the flight crew [6]. The Attila concept is similar to the ABESS concept that is described in this paper but relies more on flight deck capabilities to meet specified arrival times that were specified by Attila, whereas the ABESS concept provides speed advisories to uplink to the flight crew. Also, the Attila tool was conceived as operational tool, whereas the ABESS tools that were tested in the events described in this document were intended as research tools to investigate concept feasibility and constraints for requirements definition.

In the tailored arrival concept, ATC provides aircraft with descent clearances that maintain the required spacing but allow for some altitude and speed flexibility beginning at cruise altitude [7,8]. Similarly, the 3D Path Arrival Management (3D-PAM) concept provides aircraft with metering constraints over the TRACON boundary while en route ATC provides aircraft with strategic and tactical descent advisories that maintain the required spacing and meet the Meter Point Time constraints, but allow for some altitude and speed flexibility beginning at cruise altitude. [9,10].

A. ABESS Concept Description

Under ABESS, the AOC sends speed advisories to flight crews to space flights 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 beginning approximately 90 minutes, and ending approximately 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.

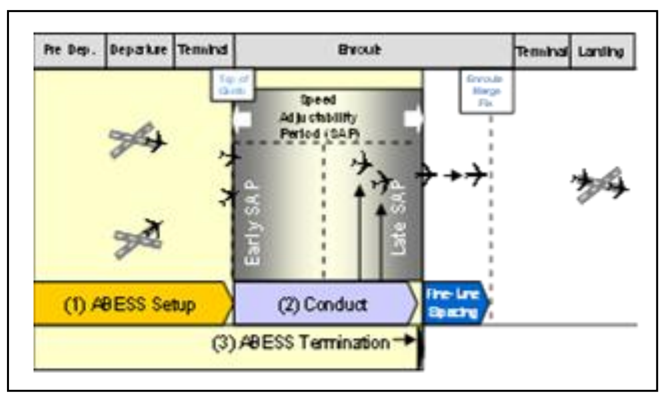

Figure 2. Overview of ABESS operations

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 transition flights to OPDs. Flights with FIM equipment may be transitioned to Flight Deck Based Interval Management (FIM). In the second case, the flight crew uses onboard equipment to achieve and maintain the desired spacing.

Information that is needed for the conduct of ABESS is shown in Fig. 3. The minimum requirements for the conduct of ABESS 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 flight's speed envelope. Finally, the flight's confirmation of 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.

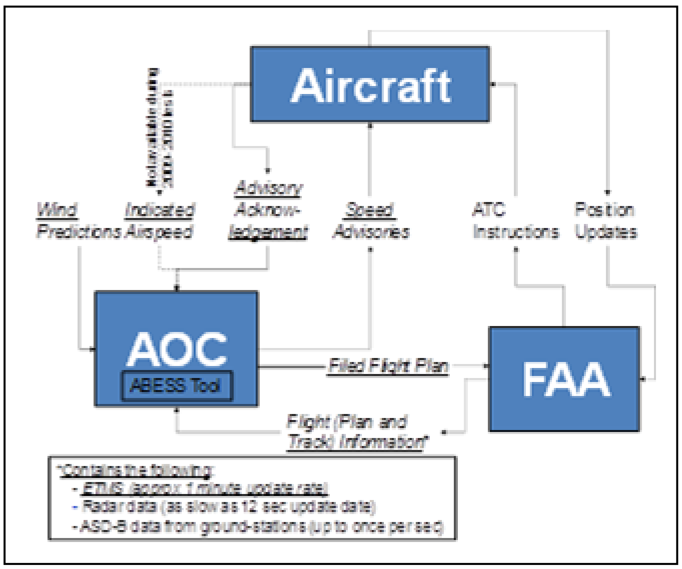

Figure 3. Information requirements for ABESS

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 delays into the system 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 estimated behavior of an aircraft based on its currently active flight plan, and airspace characteristics that are known to the computer. The trajectory includes fix crossing times that are used to predict the spacing conflicts between flights at those points.

The trajectory modeler receives information from multiple sources. Aircraft position information is 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, the higher update rates and accuracy that are available via ADS-B position reports are preferred. Flight plan related information, including updates and amendments, was received via ETMS. Wind information is received from the National Oceanographic and Atmospheric Administration (NOAA) in the form of Rapid Update Cycle (RUC) hourly weather products.

During the first test in 2006, the MITRE CAASD tool utilized a trajectory modeler that had been designed for use in traffic flow management tools. This trajectory modeler was optimized for the prediction of movements for large sets of traffic and did not have the level of prediction accuracy needed for the determination of conflict free trajectories. Therefore this trajectory modeler included simplified assumptions and parameters about airspace characteristics. During the remaining tests from 2008 on, the MITRE CAASD tool utilized a trajectory modeler that had been designed for use in an ATC tool, the User Request Evaluation Tool (URET). This trajectory modeler was designed to achieve the level of prediction accuracy needed to determine conflict free flight trajectories.

B. *Speed Advisory Algorithm and Graphical User Interface*

The ABESS tool provides speed advisories to the ABESS operator if two or more flights are predicted to cross their metering point within the minimal spacing target (e.g., 150

[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.

seconds). The speed advisories allow flights to stay at or above their desired spacing minimum but do not reduce their spacing. Speed-ups are only provided to the leading aircraft in a sequence of aircraft. Slow-downs are provided to flights that are following a lead 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. Once the appropriate speed advisory is selected, the ABESS operator uplinks it or informs the flight's dispatcher to uplink it. The ABESS operator then enters the flights crews' response into the ABESS tool and consequently, the tools does not provide new speed advisories for this flight. The operator can select different speed advisory solutions and for each solution, views the proposed speed advisories for all flights that are part of the spacing conflict.

The ABESS GUI displays additional information, including flight identification, aircraft type, departure airport, predicted spacing, predicted fix crossing times, flight plan information, and indicated airspeeds. New speed advisories attract the operators attention with visual but without auditory cues.

III. ABESS TESTING

The ABESS concept was tested in a series of test events in which different software systems and input data were used. Tests were performed during regular UPS operations at the UPS Global Operations Center (GOC) in Louisville, KY. The test flights arrive late at night from the Western United States into Louisville. The flights' SAP overlapped roughly with Kansas City En Route Air Traffic Control Center (ZKC) airspace. At the tested time of day, little non-UPS traffic were in that area which allowed for a good test environment. 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.

The UPS GOC coordinated all ABESS operations with the respective en route air traffic control centers through which the flights passed and requested that the centers do not change the flight routes. Specifically, controllers were requested not to clear flights to fly direct to their terminal fix, which, otherwise, would have represented standard controller procedures.

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

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 the first two weeks of October 2006 and included two different ABESS test tools. One tool had been developed by MITRE CAASD, the other had been developed by the National Aeronautics and Space Administration (NASA) Ames. While essentially providing similar functionality, the two tools were different in their displays and trajectory calculations. The MITRE CAASD tool calculated speed advisories based on an internal trajectory modeler, whereas the NASA tool calculated speed advisories without trajectory modeler, assuming straight line distances between aircraft to the spacing point. The NASA tool did not utilize wind information or other flight plan information and was only applicable for single traffic stream from a single direction.

The methodology and results of this ABESS test are described in detail elsewhere [2], and are here only summarized. Air traffic controllers found ABESS operations acceptable. 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 GOC for their spacing tasks, and no interference of ABESS operations on other operations such as traffic crossing the ABESS stream was observed.

Flight crews followed the speed commands, accepted all of the 46 uplinked speed advisories and in interviews after the ABESS test generally indicated that they found operations acceptable.

The ABESS operators at the UPS GOC found ABESS operations and the coordination of speed advisories to the flights generally acceptable. In that test, two operators indicated that they found the accuracy and reliability of speed advisories too low. Therefore, operators generally delayed the uplink of speed advisories until they had achieved additional evidence using a traffic display that the speed advisories seemed appropriate. Operators also indicated that they thought that the ABESS tool provided too many speed advisories. Accordingly, operators uplinked a much smaller number of speed advisories. MITRE CAASD's ABESS tool predicted crossing times during the last 100 min prior to the fix on average within 60 sec of their actual crossing time.

Overall, the results of the first test demonstrated general operational feasibility of ABESS while also pointing to the need to improve ABESS tool performance toward fewer and more accurate speed advisories.

B. May/November 2008 ABESS Test

The next ABESS test at the UPS GOC occurred in May and November 2008 with two changed and updated ABESS tools. One ABESS tool had been developed by Mosaic ATM, Inc. That ABESS tool was able to calculate flight trajectories internally or, alternatively, receive trajectory information from a research prototype of the Traffic Management Advisor (TMA) at NASA AMES to determine speed advisories. The second tool was an updated version of MITRE CAASD's ABESS tool that contained a new user interface, a new speed advisory determination algorithm, and a trajectory modeler which had been adopted from existing air traffic control software, the URET tool.

After initially testing both tools in shadow mode, the ABESS operator at the GOC used the tools to determine speed advisories to uplink to the flights. Both tools were run successfully with the available data feeds but also showed limitations in accuracy and integrity of their respective trajectory modelers. The MITRE tool's crossing time prediction errors for randomly selected sets of flights were, when measured up to 100 min prior to the spacing point, within 2 min of true crossing times. However, as flights proceeded toward the fix, the errors did not converge toward the true crossing times which would have been an expected modeler behavior. This reflected integrity problems with the implementation of the trajectory modeler that had not occurred during dry runs and were likely caused by the unexpected variability in data formats of flight plan and position update data. The Mosaic ATM tool's internally determined fix crossing time predictions showed errors of around 20 min at 100 min prior to reaching the fix. However, the trajectory modeler showed the desired behavior of convergence as the flights approached the metering point. Overall, the tests allowed identification 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 between November 17 and 20, 2008. Again, trajectory information from NASA's TMA prototype was made available to the NASA ABESS tool that was running at the UPS GOC 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 for both tools.

C. 2009 Spring ABESS Test

Based on the findings from the previous tests, MITRE's ABESS tool was modified 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 actually uplinking speed advisories to flights. Fix crossing times for the set of ABESS flights were calculated and recorded. The software was run remotely at the UPS GOC 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 and were selected to determine practically possible accuracy, not typical accuracy. The categorized signed prediction errors in Fig. 4 show the median, 25%, and 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.

D. 2010 June ABESS Test

The ABESS testing in 2010 had several objectives. First, the updated ABESS tool's 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 was to 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 GOC and at the ZKC en route ATC facility. Their job was to observe 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 (e.g., 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 roughly 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 subsequent 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 in the following subsection.

[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.

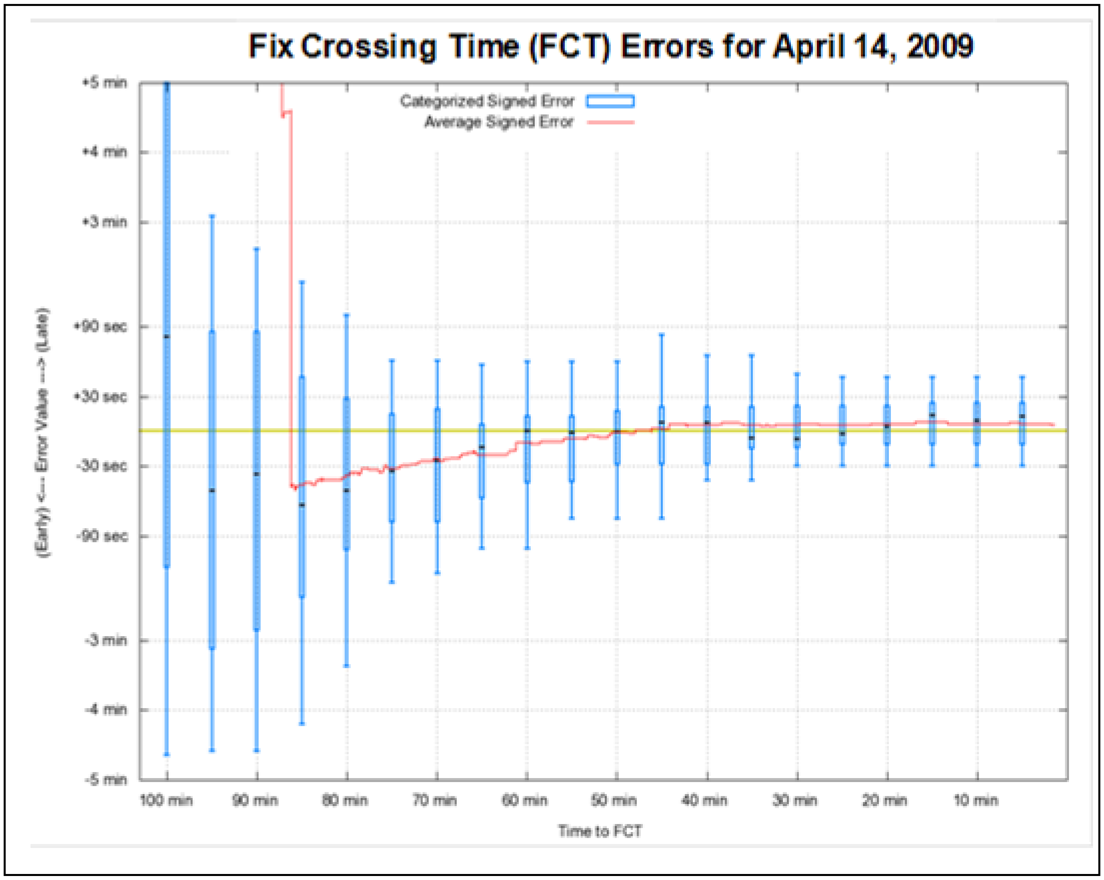

Figure 4. Average Fix Crossing Time Prediction Errors during the 2009 Test

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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).

[3] 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.

Only flights for which no speed advisories were executed were included in this analysis 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 causing a low number of ABESS flights on day two, fix crossing time predictions were worse on days one and two (average of 82 sec signed[4] error and 162 sec unsigned[5] 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 lack of wind information had the expected effect.

This average prediction accuracy is similar to that in [3], which reported average prediction errors of less than 30 sec for the last 100 min prior to the metering point. This finding is consistent with the notion that flight paths are predictable over longer periods of time and is encouraging for the type of long term trajectory modeling that NextGen's extended metering concepts require.

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

4 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.

5 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 displayed 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 operation. The desired spacing goal was set higher than the spacing during normal operations where controllers usually try to space flights at approximately 10 NM (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 June 9, 28 on June 14, 41 on June 15, and 31 on June 16). 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 to reduce 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 related to the variability of groundspeed, and quality of wind predictions as described in [3]. To address the high nuisance rate, some of the experienced 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 variability associated with inaccurate timing information. Finally, one major contributor to the instability of trajectories are inaccuracy of wind predictions [see 3].

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.

Global versus non-global speed advisory solutions differed in the associated operator tasks. Non-global solutions required more task steps because it required the resolution of each conflict at a time and then check that no other spacing conflict was created.

On test day one, speed advisories were presented in a non-global manner because of a data processing error for one flight prevented the display of global speed advisory solutions. The need to resolve each conflict at a time surprised the operator because, based on his 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 airplane's operating 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.[6]

[6] 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

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 was 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 even if theywere not available for all aircraft. In that case, global solutions should be indicated at least 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 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),[7] 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%). This could have been caused by fluctuating fix crossing time predictions between when the ABESS tool indicated a spacing conflict and when the operator actually uplinked the speed advisory.[8]

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. This results seems to be caused by the tools speed advisory selection processes as well as the identified fluctuations and variability of input data, including wind predictions errors.

V. CONCLUSIONS

ABESS is a concept of operations that allows airlines to precondition their flights to achieve the required spacing for the conduct of OPDs 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 tested flight trajectory predictions up to 100 min in advance where fix crossing prediction errors were on average considerably less accurate 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.

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

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.

[7] 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.

[8] 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.

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. A simple straight line-distance algorithm, a higher level traffic flow management trajectory modeler, and lower level trajectory modelers similar to those 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 used in URET or TMA seems so be the more appropriate solution.

Finally, it was determined that the availability of airspeed information seemed critical for the successful completion of ABESS. Without airspeed information in the ABESS tool, operators went to great lengths to retrieve airspeed information from the aircraft in an attempt to ensure that the speed advisories generally made sense for the flight crew. Airspeed information that had been calculated from ground speed utilizing predicted wind (RUC) data was, in many cases, insufficiently accurate for the operator.

The observations and lessons learned from this research are expected to be useful to 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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