# An Operational Concept and Evaluation of Airline Based En Route Sequencing and Spacing

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**This paper describes an operational concept for airline operations centers (AOC) to implement desired arrival sequences and spacing over an en route arrival merge fix and reports the results of an initial field-test. The operational concept is termed Airline Based En route Sequencing and Spacing (ABESS). ABESS allows the AOC to set up arrival flows for transition into advanced flight procedures such as Continuous Descent Arrivals (CDAs) or Flight Deck-Based Merging and Spacing (FDMS) using flight-deck equipage with ADS-B capabilities. ABESS is similar to other operational concepts and tools that shape arrival streams such as the Self Managed Arrival Resequencing Tool or the Air Traffic Management Automation system. ABESS allows the AOC to shape arrival stream and spacings via uplink of direct speed advisories. This operational concept received an initial evaluation during a field-test at the UPS AOC in Louisville Kentucky in October 2006. The results of this initial evaluation indicate the feasibility of the procedures and identify software, accuracy, and procedural requirements for concept implementation.**

## I. Introduction

Flight operations to an airport frequently require merging flights into common arrival streams for orderly delivery to an arrival route and approach procedure. 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. 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 ATM efficiency and airline costs. In the case of express package operations (e.g. UPS, 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 desired spacing and sequence. If spacing

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isn't properly achieved early in the arrival flow, additional speed and vector instructions may be needed in the final en route sectors or at low altitudes in the Terminal Radar Approach Control (TRACON) airspace. These additional instructions increase flight crew and ATC workload as well as fuel consumption and flight time. Additionally, for passenger carriers, aircraft that arrive too early (at an occupied gate), or too late, can unnecessarily increase operating costs, increase passenger delays and affect planned connections.

The ABESS concept of operations[3] allows the AOC to play an active role in achieving a desired arrival spacing interval for the aircraft in their company. The concept is one of several ongoing activities aimed at developing enhanced arrival procedures. Another is the Tailored Arrivals project, which includes the coordination of waypoint arrival times by ATC and uplink of clearance information to the flight-deck via data-link[1]. Initial tests of this concept within the NAS have been performed in the Oceanic domain. Unlike Tailored Arrivals, under ABESS operations it is the AOC that uses new ground tools to deliver flights to the final en route sector. ABESS operations have leveraged predecessor concepts such as the Self Managed Arrival Resequencing Tool (SMART), which allowed airlines to adjust their departure times as well as to provide speed adjustments during the en route phase of flight, in order to achieve desired arrival rates at the airport[2]. SMART pre-departure adjustments were tested in operational trials. Despite their similarities, there are several differences between the SMART and ABESS concepts. (1) in ABESS, en route speed adjustments are made to achieve desired spacing at the en route merge fix. (2) No pre-departure changes are made in ABESS. (3) ABESS sets up spacing prior to the en route merge fix, and therefore prepares, but does not implement terminal arrival operations.

Finally other tools are available from various vendors that may provide functionality to support parts of the ABESS operations. Such other tools differ in requirements of aircraft equipage, specifically concerning implementation of required time of arrival. Future implementations of ABESS, however, will require integration with air traffic management functions, possibly through integration with the TMA system.

Under ABESS, the AOC sends speed advisories to flight crews via data link such as Aircraft Communications Addressing and Reporting System (ACARS). Flight crews acknowledge and then follow those speed advisories to establish the desired arrival sequences and achieve the approximate arrival spacing. Flight crews currently have the ability to fly speeds at their discretion, provided ATC hasn't given a specific speed instruction. Under current operations, flight crews also receive speed requests from the AOC. With ABESS the frequency of speed requests from the AOC may increase but other operations will remain the same. The required flow of information between ABESS entities is shown in Figure 1.

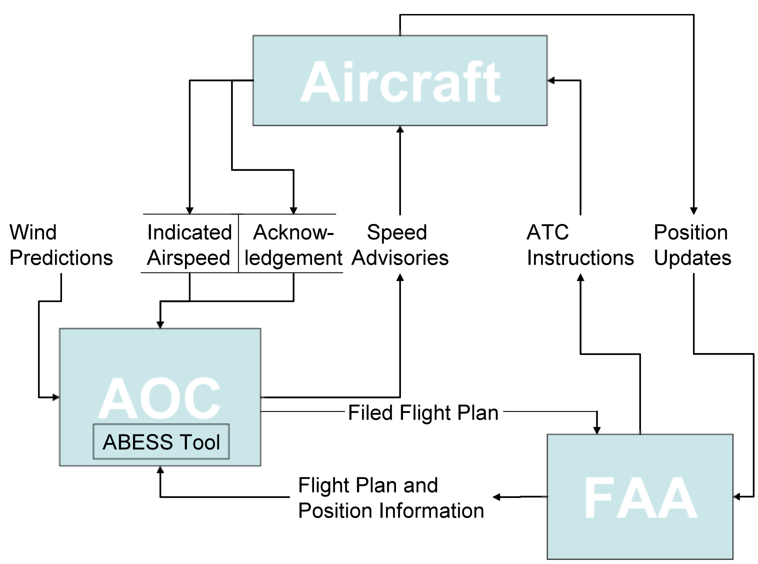


**Figure 1. ABESS Information Flow**

The expected operational benefits from ABESS consist of an increase in aircraft efficiency through the use of early, high altitude, and minor speed adjustments that avoid costly low altitude maneuvering. In addition, ABESS can provide appropriate spacing for the initiation of new applications such as FDMS or CDAs. Other expected benefits include the realization of desired arrival sequences that are optimized for airlines. Since ABESS operations can achieve desired spacing by the airline and/or ATC, ABESS may reduce both ATC workload (by reducing the need for ATC maneuvering) and radio frequency congestion (by reducing the number of ATC maneuvering instructions). Finally, ABESS may increase the safety of operations by reducing the likelihood that aircraft come in proximity with each other during merge operations.

ABESS also allows for the creation of airline desired arrival sequences. Under current operations, AOCs do not provide their desired arrival sequence to ATC. Instead, the AOC attempts to achieve its arrival sequence goals through departure time scheduling, speed, and flight routing. Additionally, ATC currently lacks knowledge of airline flight priorities. Therefore, a discrepancy may exist between the ATC-implemented arrival sequence and the airline-desired arrival sequence. As an alternative to current operations, ABESS involves a more active role by the AOC in supporting arrival sequencing and spacing.

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. The ABESS target spacing between successive aircraft is always greater than the 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 aircraft are handled by ATC who, if needed, adjust the spacing intervals. The flights can, when appropriate flight deck equipment exists, transition to a new FDMS procedure[4], to maintain or achieve the desired arrival spacing over subsequent fixes and ultimately on final approach. In addition, ABESS can transition into continuous descent arrivals[5] (CDAs).

The ABESS and FDMS concepts are currently being developed in a working group consisting of FAA, NASA, MITRE, and industry participation and are described in more detail in [3] and [4].

ABESS consists of three phases: Setup, Conduct, and Termination, see Figure 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 ABESS operator uses an ABESS sequencing and spacing tool (ABESST) that provides speed advisories. The operator also monitors the flight progress and weather information, monitors the ABESST for speed advisories, uplinks speed advisories to flight crews, and receives their responses. Operator tasks during the termination phase consist of uplinking a final advisory to the flight crew and monitoring for completion.

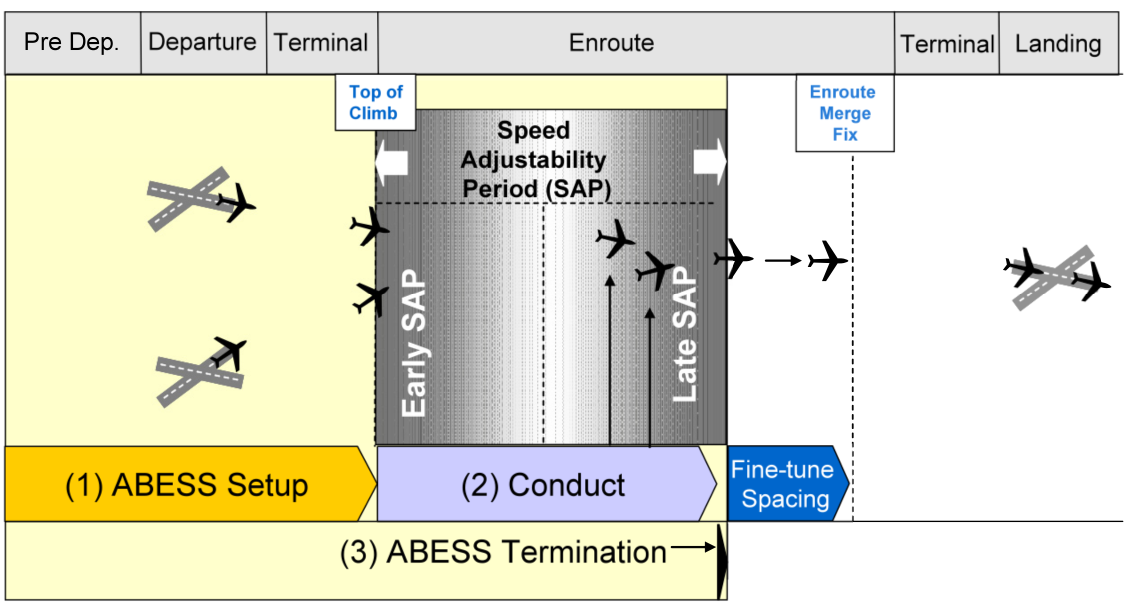


**Figure 2. Overview of Airline Based En route Sequencing and Spacing (ABESS)**

ABESS operations require a ABESST, which initially is expected to be at the AOC. It may only have access to currently available surveillance data initially, resulting in lower accuracy due to infrequent update rates. However, tool accuracy is expected to improve with improved position accuracy in the future with technologies such as

Automatic Dependent Surveillance-Broadcast (ADS-B) which is one promising source of improved surveillance information, see Figure 3.

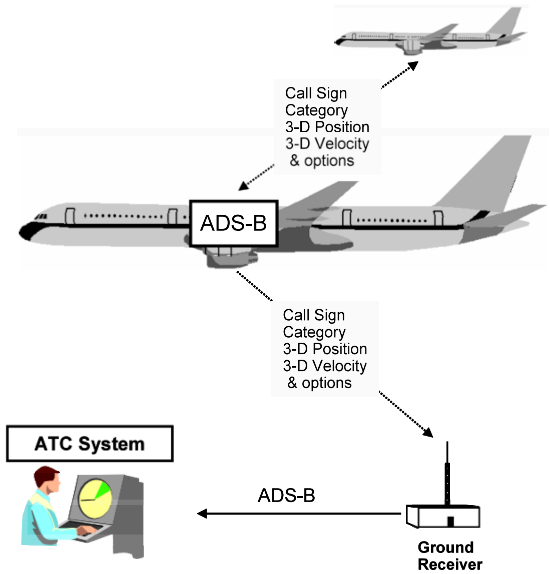


**Figure 3. ADS-B Air-to-Air and Air-to-Ground Transmission**[6]

The Federal Aviation Administration (FAA) intends to implement ADS-B surveillance and other capabilities within the National Airspace System (NAS) in limited installations by 2007 and system-wide by 2020. Adoption of ADS-B is expected to increase cockpit and ground capabilities.

## II. Operational Evaluation of the ABESS Concept

The ABESS concept of operations received an initial evaluation during a field-test at the UPS AOC in Louisville, Kentucky. The objectives of the operational evaluation were four-fold.

1. Determine the feasibility of the operational concept
2. Determine information display requirements
3. Determine algorithm and procedural requirements for concept acceptability

The operational environment for the test was provided by UPS. The UPS main operations hub and AOC is located in Louisville, Kentucky near Louisville International Airport - Standiford Field (SDF). A subset of UPS traffic into SDF was selected for the evaluation. For the selected set of flights, the AOC had speed control and could route flights over a single arrival merge fix. Flights were relatively uninfluenced by other aircraft because they arrived at SDF during a period of relative low traffic. Therefore, the merge fix was almost exclusively crossed by UPS flights during the test period, which simplified the testing situation.

The general routing of ABESS participating flights is shown in Figure 4. ABESS flights were part of the last arrival push into SDF between midnight and 2:00 am local time. These flights bring cargo for the nightly UPS sorting operations at SDF. These fifteen to twenty flights depart daily from the Western United States, and fly toward SDF between flight levels 330 and 390. Participating aircraft were mostly Boeing 757 and 767 with a few Airbus 300 and DC 8's. The approximate flight speeds were between 0.78 and 0.84 Mach (M). The AOC filed the flight plans over a common en route merge fix Centralia (ENL) in Kansas City airspace. Flights reached this fix prior to their initial descent toward SDF.

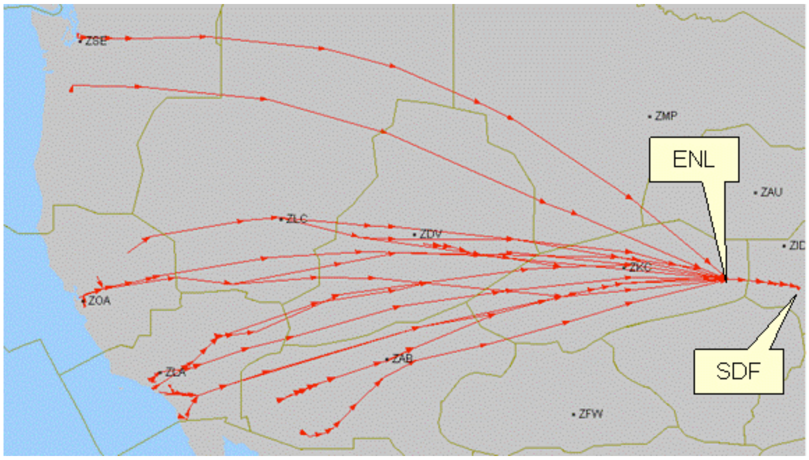


**Figure 4. Route of Flight for ABESS Flights during One Day of Field-Test**

A prototype ABESST was developed and used for the ABESS concept evaluation. The ABESS modeled flight trajectories using aircraft position, flight plan, and wind information to predict merge fix crossing times and then derived speed advisories to deconflict flights over that merge fix[††]. The ABESST displayed a list of flights over a selected fix. For each flight, the ABESS tool displayed the common merge fix, callsign, departure airport, departure time, flight status, flight level, predicted fix crossing time with and without speed advisory, current indicated airspeed on board of the aircraft, and, if available, a speed advisory. Previously uplinked speed advisories were also displayed. The ABESST only provided speed advisories when they were within a predetermined speed envelope for the flights, between 0.78 Mach (M) to 0.84 M for B757 and B767. The speed advisory algorithms did not attempt to close gaps in spacing between the flights. Therefore, if flights were predicted to be spaced above the minimum target spacing at the merge fix, the tools did not provide speed advisories. Also, because this was the first test of the tool, it was expected that AOC operators would check, and as appropriate, adjust the speed advisories to their operational needs.

### A. Test Procedure

The test was performed between October 2nd and 13th, 2006 at the UPS Airline Operations Center (AOC) in Kentucky, Louisville. The objective of the data collection was to evaluate the operational feasibility and human-computer interface issues of ABESS from the AOC, ATC, and flight crew perspective. Therefore observers were located at the UPS AOC, at the Kansas City En Route Traffic Control Center, and at the UPS ramp area where they interviewed ABESS participating flight crews.

The test was conducted in a room adjacent to the main AOC control room to facilitate operations between the ABESS operators, AOC dispatchers and dispatch supervisors. The ABESS operators had access to four tools in addition to the ABESST: a graphical display of the traffic situation (Flight Explorer); UPS in-house software that allowed communication with flight crews; a system that provided information about airport surface operations (the Surface Management System, SMS), allowing operators to see traffic movement on the ground, including ramp locations; and finally, information about scheduled arrival demands was provided by the Flight Schedule Monitor (FSM). AOC dispatchers were in the loop about the uplinked speed advisories and received acknowledgement messages back from the flight crews. ABESS operations were also coordinated with the AOC dispatch supervisors.

There were three external data sources for this test. The first was a live Aircraft Situation Display to Industry (ASDI) data feed that transported a subset of Enhanced Traffic Management System (ETMS) data to the UPS AOC. That data feed

[††] A second tool was also tested during the field-evaluation. This tool developed its sequence information and speed advisories based solely on a calculation of each aircraft's closure rate with the merge fix. Since flight plans or predicted winds were not taken into account, this tool works best when aircraft were flying more or less direct routing in approximately similar wind fields. The tool provided approximate spacing guidance under a variety of conditions during the test, however there are no current plans to develop it further because of its limited applicability for more general merge situations.

provided position reports once per minute, plus flight-plan and flight-amendment information. Secondly, rapid update cycle (RUC) wind data were downloaded hourly from the National Oceanographic and Atmospheric Administration to incorporate appropriate wind information for trajectory predictions. Finally, the indicated airspeed information was downlinked from flights on a continuous basis and was fed into the ABESS tool.

Prior to the first test day, the ABESS operators received training on the ABESS concept and tools in an initial briefing. The testing started every evening with the setup of the ABESST. Flight plans had been collected during the day and AOC dispatchers filed the flight plans for ABESS flights that included the ENL fix in Kansas City airspace as merge fix. Test activities started when the first set of flights departed at around 10:00 pm.

During the test, one operator mainly handled the management of speed advisories and decided which speeds to uplink to the flights. This first operator mainly interacted with the ABESST. The second operator used UPS in-house communication software to uplink speed advisories via ACARS to flights. An example for an advised speed of 0.83 M is "Fly 0.83 M, if unable refer to ABESS bulletin".

## III. Results

During the six days of full operations, operators sent 46 speed advisories to ABESS flights. All speed advisories were accepted by the flight-crews. Seven of the advisories were speed increases, the remaining advisories were speed decreases. More speed decreases were uplinked to flights because the ABESST only advised speed decreases. Any additional speed increases were manually added by the ABESS operator. On average the advised speed change was 0.02 M, the minimal advised change was 0.01 M, and the maximal adjustment was 0.043 M. The ABESST provided many more speed advisories than were uplinked by the flight crew. It was therefore expected that the AOC operators would not uplink all speed advisories but actively select among the advisories to be uplinked.

### A. ABESS Operator Feedback

Operational feedback from the ABESS operators was obtained over the two-week test period. In addition to informal feedback sessions and general observers' notes, ABESS operators filled out a nightly questionnaire that queried them specifically on that night's operation. The questionnaires were supplemented by an informal interview session, during which the operators had an opportunity to elaborate on their answers. There were two ABESS operators working collaboratively every night and each filled out his/her own questionnaire.

ABESS operators were asked how many speed advisories they issued to the flight crew (M = 7; SD = 1.8) and how many of the uplinked advisories were rejected by the flight crew (none). When asked whether the number of advisories that they uplinked were too many or too few, they responded that the number was about right (M = 3.1; SD = 0.3; Too Few = 1, Too Many = 5). Overall, operators found it reasonable to uplink about seven advisories across sixteen aircraft. Furthermore, the advisories themselves seemed reasonable to the flight crew, as flight-crews accepted advisories without any modifications

When ABESS operators were asked how many of the advisories suggested by the tools were inappropriate, they reported that there was a significant number of inappropriate advisories (M = 3.5; SD = 0.5; None = 1, Too Many = 5), suggesting that the ABESS tools needed to improve in presenting the appropriate number of advisories. In particular, the operators commented that the advisories should be given only when the advised speed differs from the current speed by more than 0.01 mach. This is also the minimal speed change that the flight crew can manually enter. In a related question, the operators indicated that they had a difficult time determining whether the advised speeds should be uplinked to the flight crew (M = 3.8; SD = 0.9; Easy = 1, Difficult = 5). In general, the operators had a difficult time determining whether they should be proactive and issue advisories further away from the meter fix with the possibility that they might need to take another corrective action later or to wait until the traffic situation seemed stable before issuing an advisory. They rated that the number of speed advisories in total and per flight suggested by the ABESS tool were appropriate (for both ratings, M = 3.3; SD = 0.5; Too Few = 1, Too Many = 5), which was interesting since the tools actually gave them continuous updates to the advisories. In the field test, the tools seemed to identify a stable set of aircraft pairs/clusters that needed speed advisories, so it is possible that the operators were rating the appropriateness of these aircraft pairs/clusters.

The used ABESST configuration required it to be a two-person operation because the ABESST did not send the advisories directly to the flight crew but required the transfer of information back to a computer terminal with ACARS uplink capability. ABESS operators rated the workload associated with the ABESS operations to be acceptable (M = 3.5; SD = 0.8; Not at all acceptable = 1, Very acceptable = 5). Finally, they thought that the aircraft achieved their desired spacing successfully (M = 4; SD = 0.6; Not well at all = 1, Very well = 5), although they commented that it was difficult for them to tell using only Flight Explorer as their primary traffic situation display.

After the ABESS operators filled out the questionnaires, they also participated in follow-up interview sessions with a researcher to comment on that night's operation. They were asked about the particular circumstances that led them to reject the advisories from the tools. ABESS operators listed following reasons:

- Some of the advised speeds were too small of a change – e.g. less than 0.005 mach or meter fix arrival time difference less than 30 sec.
- There were often multiple solutions to a "gaggle" of aircraft that arrived at the merge fix together. While the ABESS tool suggested a particular solution, the operators decided to go with another one.
- Advisories were ignored prior to 750 NM from the merge fix. The advised speed differences were often too small and the advisories were less stable.
- Advisories were ignored until the next update of indicated airspeed information from the aircraft to facilitate accurate advisories.
- In some cases, the advisories were ignored further out to see if the advisories would disappear on their own.

Overall, minimum coordination was necessary with dispatchers, dispatch supervisors, and other members in the AOC. During the first night, the ABESS operators uplinked speeds without explicit coordination with the dispatchers, which didn't cause any problems. Instead of an explicit coordination, they briefed flight control, union lead, and union president of the overall operation to facilitate coordination and collaboration with all dispatchers. On the second week of the test, however, the operations manager requested that the ABESS operators coordinate with the lead dispatcher before sending the uplinks. The coordination was then changed slightly to contact the lead dispatcher after sending the uplinks, which worked smoothly as well. Other than working through these procedural issues, there was only one instance of explicit coordination that routed an aircraft from Seattle to fly via a different en route merge fix for a more direct routing.

In particular, ABESS operators requested that the procedures spelled out exactly how much freedom they had to change aircraft speeds without adversely affecting the overall airline operation.

When asked about the overall safety and efficiency of the ABESS operations, both operators did not think that the ABESS operations significantly impacted overall safety or efficiency during the test period. This may be because of two reasons. First, it was difficult for the operator to evaluate the efficiency of their speed advisories without having data about air traffic control vectoring and fuel burn. Second, the operators modified the ABESST provided speed advisories and adjusted them to the operational requirements so that it was difficult to attribute any changes in efficiency to the tool. They both thought that the overall acceptability of the ABESS operations was high, although the operators commented that the data from the tools needed to be more stable and reliable for the operations to be fully acceptable. They also found the starting and end point of ABESS operations to be very acceptable, as well as the spacing interval achieved at the meter fix. As indicated above, the spacing at the meter fix could not be attributed to ABESST performance alone because operators modified the ABESST speed advisories before uplinking them to the flight crew. The assessment of the achieved spacing was therefore not to be distinguished between tool and operator performance. They were also asked if the spacing interval should be given in miles or minutes. One operator wanted it in miles and the time-based spacing as a back-up while the other operator thought that more testing is needed to determine the better choice.

Overall, the ABESS message set that was uplinked via ACARS seemed to be acceptable. Both ABESS operators thought that the phraseology was very acceptable and didn't see any issues with them. The flight crew acknowledgement was also easy to understand, mostly because they usually accepted the uplinked speeds without any further queries or modifications. One operator thought that it was easy to relay the speed advisories to the appropriate flight crew while the other thought it was somewhat difficult, mainly because the mechanism for uplinking speeds required multiple steps of reading the advisory from the ABESS tool and transferring it to the software used to send the ACARS message to the aircraft.

### B. ATC Feedback

Operational feedback from air traffic controllers at the Kansas City Air Route Traffic Control Center (ZKC ARTCC) was obtained during a two-day visit at that facility during the second week of the test. Researcher observations focused on ZKC sectors 30 and 14 (see Figure 5) where ATC manages the spacing for arrivals into SDF during the midshift. In ZKC 30 the initial, gross spacing adjustments are made and in ZKC 14 the final spacing adjustments are made for transition into Indianapolis (ZID) ARTCC.

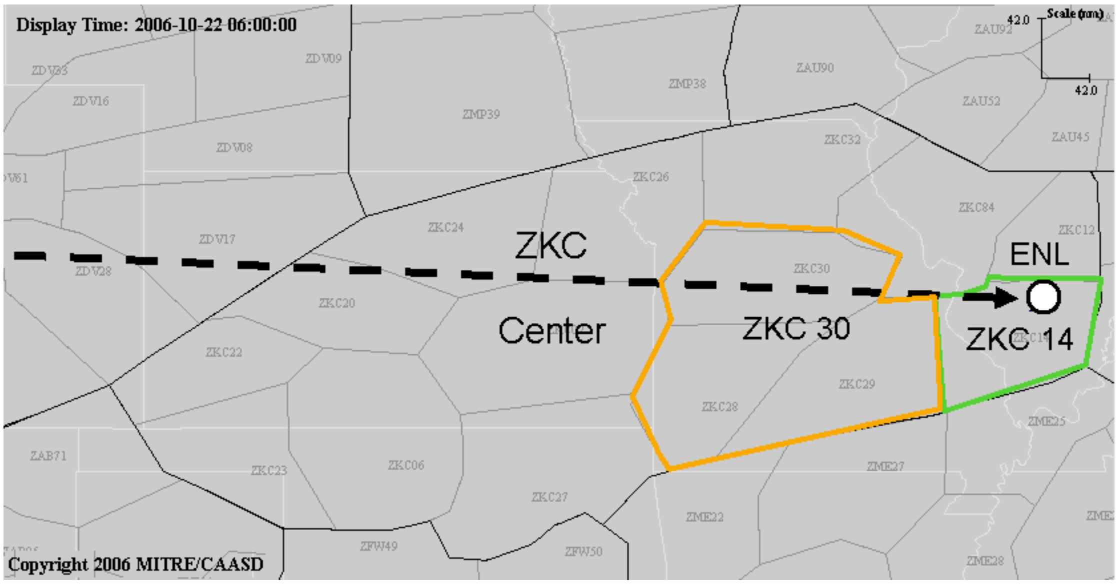


**Figure 5. Kansas City ARTCC with ZKC30+ and ZKC14+.**

Controllers seemed not to notice operational differences over the ABESS test period despite the flight crew making speed adjustments, even though UPS had filed more flights over ENL than usual. They offered several reasons for this.

First, the location of the Jet Stream frequently impacts flight behavior. This could have caused a variability of overall numbers of flight in which ABESS flights were indistinguishable. Traffic volume in ZKC30 during the test period was the same on average during the weeks before and after the test, see Figure 6. In that Figure, the line "Before" indicates the traffic during the last two weeks of September, plus October 3rd. "During" indicates the 7 days of the field trial, and "After" indicates the third week of October.

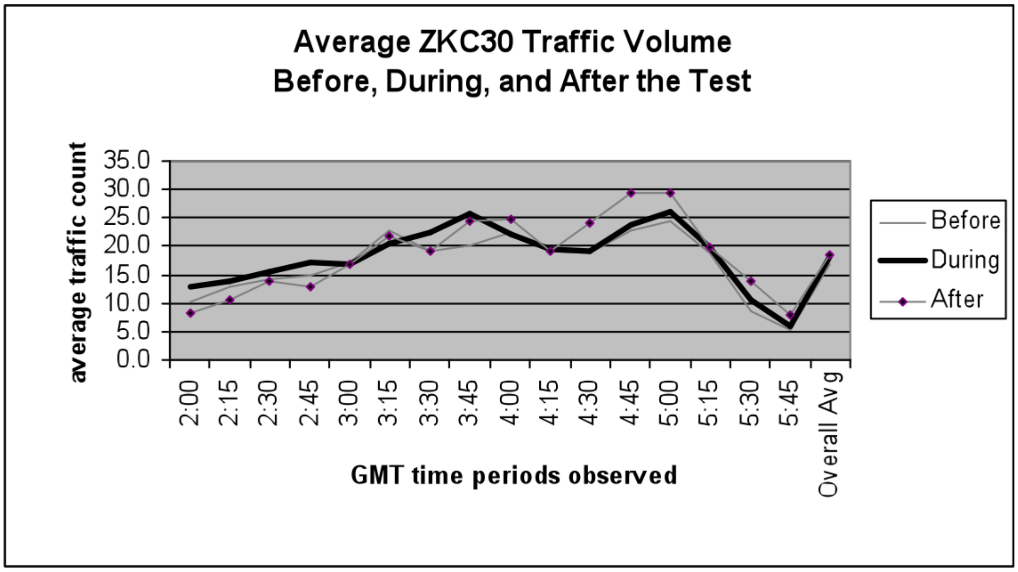


**Figure 6. Average ZKC30 Traffic Volume Before, During, and After the Test**

Correspondingly, controllers did not report noticing differences in their workload for spacing during the test period. Because of the variability of winds, and the increase in flights being just as likely to have been caused by the Jet Stream, the amount of vectoring for spacing was similar to other periods. Assessment of flight times for flights during the weeks before and after the period indicates that UPS flights generally have less than 30 seconds of delay, which is often caused by vectoring. In measuring the minutes of delay per flight, the flights experienced similar delays in the weeks before and after (see Figure 7). The only difference was that controllers in ZKC 30 waited longer to implement spacing changes during the test, in deference to UPS who had informed them about the conduct of ABESS to facilitate smooth testing procedures.

The fact that controllers did not notice any negative operational impact of flight crews adjusting their speeds during the en route phase of flight based on AOC input is an important finding of this ABESS evaluation.

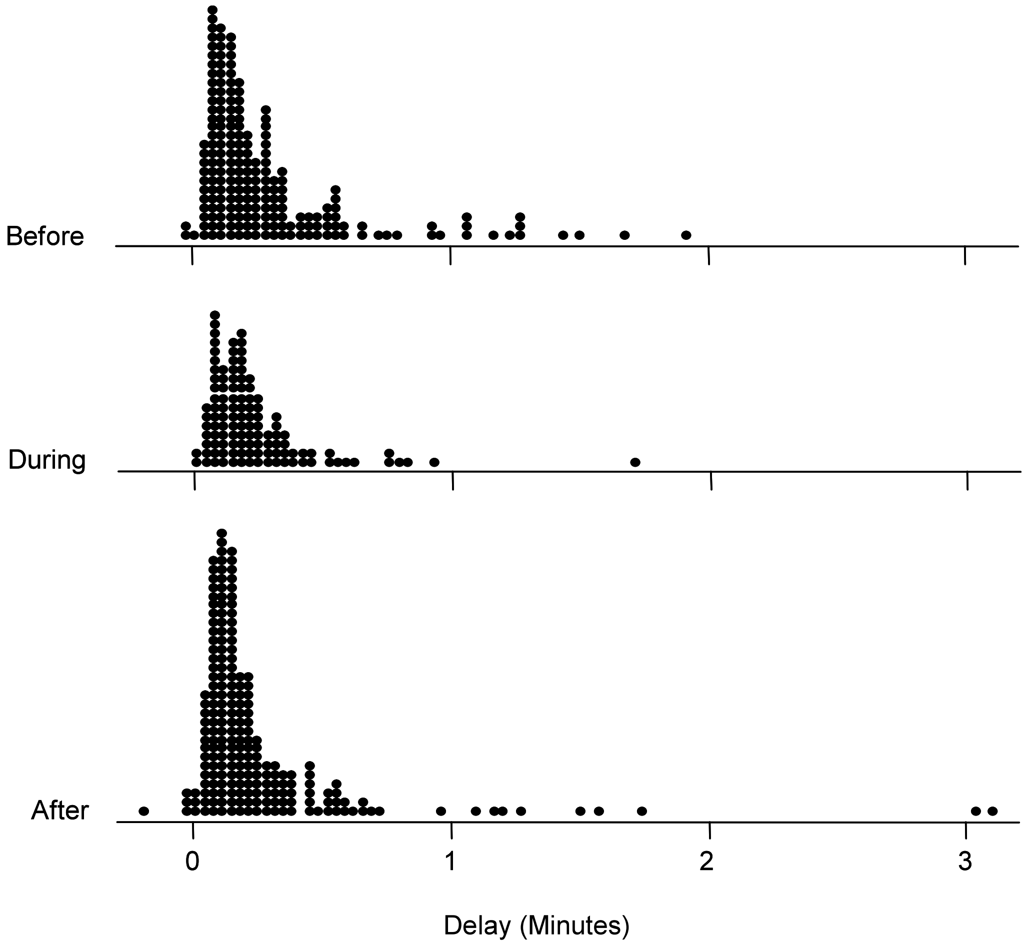


**Figure 7. Minutes of Delay per Flight Before, During, and After the Field-test**

**C. Flight-crew Feedback**

ABESS bulletins had been distributed among flight crews on flights that could participate in ABESS. The ABESS bulletin described the ABESS procedures, message formats and response protocol, along with the post-flight questionnaire, as two addenda to their flight dispatch paperwork.

Overall the participants reported that the flight bulletin prepared them well for the ABESS procedure (Mean rating 4.5, where 1= Not Well and 5 = Very Well) and that the communication protocol used to respond to ABESS uplinks was acceptable (mean rating 4.5, where 1 = Unacceptable and 5 = Acceptable). Crews reported that the number of speed advisories received was acceptable (mean rating 4.5, where 1 = Not Acceptable and 5 = acceptable), and that they did not receive any inappropriate speed uplinks.

Flight crews were asked to rate the workload of the ACARS message monitoring task on a scale from 1 (easy) to 5 (difficult). A majority of crews, 16 out of the 17 that responded, rated the workload as easy. One flight crew rated the workload as normal (3 of 5). A majority of flight crews rated the workload of responding to the ACARS uplink as easy (14), one rated the workload as normal (3 of 5) between easy and normal. Overall flight-crews did not report that responding to the uplink increased their task load.

Of the 16 flight crews that completed this question, 11 reported that they entered uplinked speeds into the FMS, while 5 flight crews reported that they loaded the speeds into the mode control panel. When speeds are entered into the FMS, the system calculates a top-of-descent based on the current speed and not based on the planned speed which may have been calculated before the AOC recommended speed change.

Flight crews who participated in the ABESS field test were asked to comment on changes in communication with ATC, flight efficiency and the perceived safety of the ABESS operation and procedures, see Figure 8. A majority of flight crews (14) reported no impact on ATC communication as a result of uplinked speed advisories.

One pilot reported that a flight-crew had been contacted about their current speed and that the flight-crew had responded with "Mach .xx, assigned". A majority of crews reported that flight operations were more efficient during the ABESS field test compared to normal operations into Louisville's Standiford Airport. Finally, a majority of flight crews (15) reported no impact on the safety of en route and arrival operations.

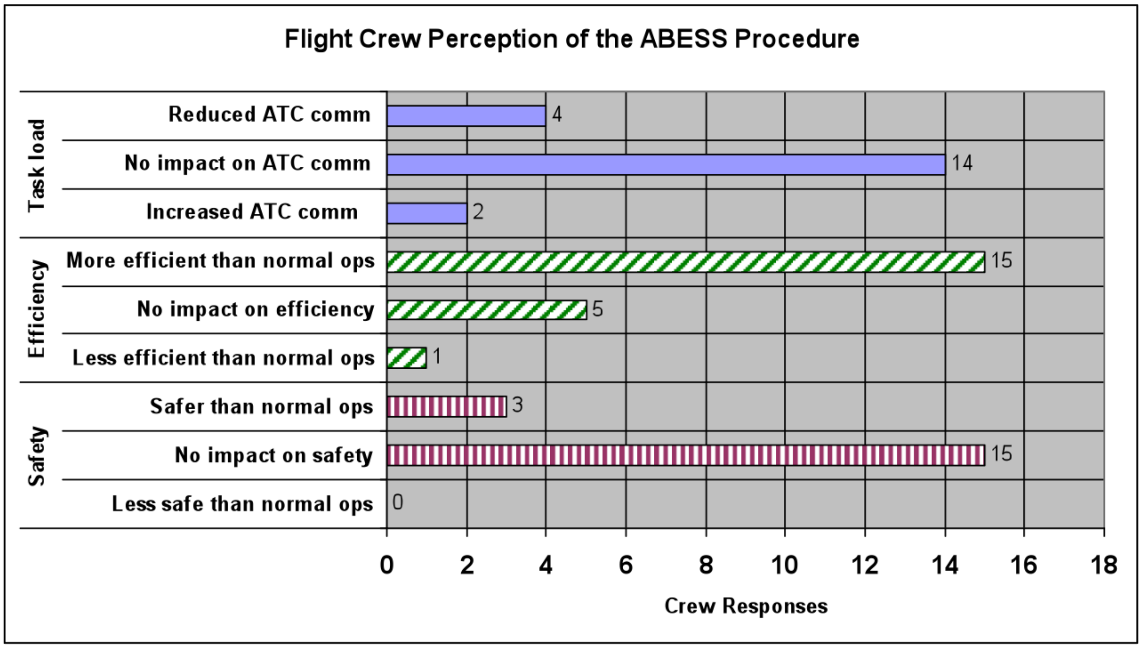


**Figure 8. Flight Crew Perception of the ABESS Procedure**

One of the operational goals during the ABESS field-test was to facilitate the set-up of a spacing interval of no less than 15 nautical miles (NM) between aircraft over the merge fix. The 15 NM spacing should facilitate the conduct of CDAs which require this amount of initial spacing to insure that the spacing remains adequate throughout the descent without ATC intervention. During the test, two circumstances had an impact on achieving this goal. First, operators modified tool-provided speed advisories. This appeared to be due to a lack of trust in the tool's accuracy, mainly due to occasionally unstable tool performance. Second, operators uplinked speed advisories later than originally advised by the tool. This delay of uplinking advisories resulted in reduced effectiveness of the advisories. Because of both factors, the actually-achieved spacing cannot be attributed to ABESST performance alone but must be attributed to the decisions and speed advisory modifications made before uplinking the speed advisories.

Flights selected for ABESS operations were filed to fly over ENL, the major ABESS merge fix during the field-test. Flights that were filed over fixes other than ENL were excluded from the analysis. Flights that were filed over ENL but then received a direct routing to a different fix were also excluded from the analysis.

### D. Results: Prediction Accuracy

After removing flights that did not fly over the merge fix ENL, the merge fix crossing times that the ABESS tool predicted were compared with actual merge fix crossing times. The accuracy of these predictions is essential for the ABESS tool to provide accurate speed advisories.

Prediction accuracy was determined by comparing the flights' predicted fix crossing times approximately every minute with the time of the "actual" crossing of the fix crossing longitude.

Figure 9 shows the results for approximately 40 flights[‡‡] during the last 160 min prior to the fix crossing for three days of operations during the first week of testing. The analysis was limited to the last 160 minutes because the availability of predictions for flights above 160 minutes dropped significantly. Included test data are from the nights

[‡‡] The number of flights is approximate because crossing predictions were not available for every flight in every minute and the number of flights therefore varies slightly from minute to minute.

of Oct 2-3, Oct 3-4, and Oct 5-6[§§]. Data from Oct 4-5 were excluded because most flights were filed over a different fix from ENL. The ABESST predictions seem to stabilize by 100 minutes prior to the fix crossing time. In the last 100 min time period, the average fix crossing prediction errors varied between -0.9 min (56 sec earlier than the actual fix crossing time) to 0.18 min (11 sec later than the actual fix crossing time). The error distribution is approximately symmetric as Median and Mean are close to each other during the last 100 min. Standard errors stay generally below 2 minutes and are indicated by the black dashed lines.

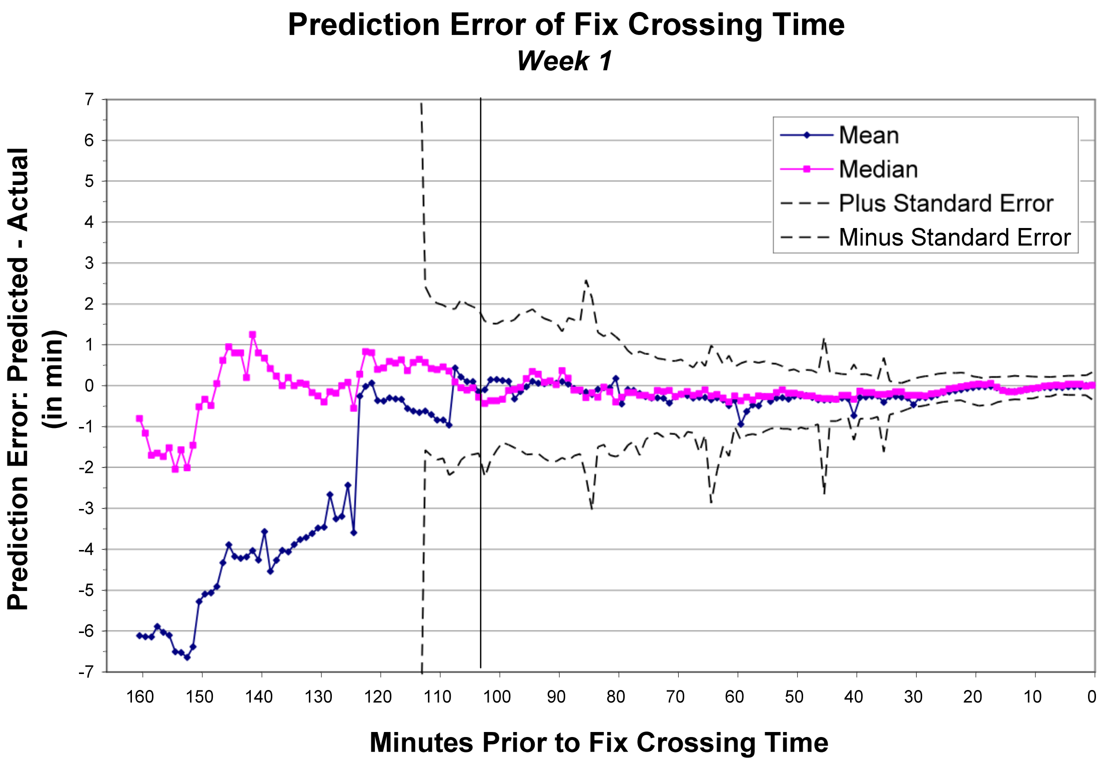


**Figure 9. ABESST Prediction Errors for Merge Fix Crossing Time for Week 2**

For the same set of 40 flights, the accuracy of sequence predictions is shown in Figure 10. Again, the included test data are from Oct 2-3, Oct 3-4, and Oct 5-6. The minimal sequence position prediction errors are 2, when ignoring a non-error of 0. The errors of the sequence position predictions ranged between 0 (non-error) and 8. During the last 100 min prior to crossing, the average sequence position prediction error was 1.66 incorrect predictions per minute, but these incorrect predictions were often the same incorrect predictions that persisted over time instead of 1.66 incorrect predictions that created new aircraft sequence every minute.

[§§] Data from the second week are not included here because significant variations in data-feed reliability had been observed.

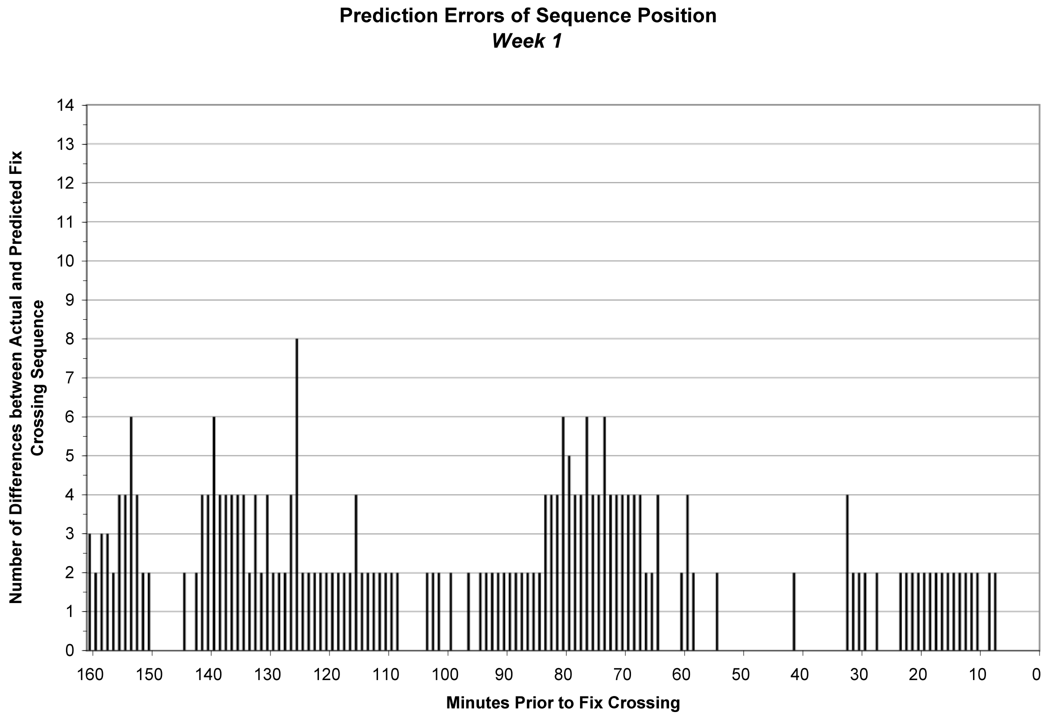


**Figure 10. ABESST Sequence Prediction Errors for Week 1.**

## E. Results: Number of Speed Advisories

The ABESST provided 427 speed advisories on operational testing days during the first week, and 453 during the second test week. This count includes advisories that were given at least one minute after another speed advisory for a flight and that were different from the previous speed advisory. This total of 880 advisories were provided to a set of 85 ABESS flights during the operational testing period. These flights could receive speed advisories for about 90 minutes each. This results in approximately one advisory every 10 minutes per flight. The number of speed advisories was significantly higher than the number of actually uplinked speed advisories which was 46. The reduction of the discrepancy between the number of ABESST provided speed advisories and number of actually uplinked speed advisories was identified as a major development requirement for the ABESST.

## F. Results: Spacing

Figure 11 shows the spacing of ABESS participating flights during the field-test over the ENL merge fix longitude over a period of 6 nights, from Oct 3-4 to Oct 11-12. Data from Oct 2-3 and Oct 12-13 are excluded because either no speed advisories were provided or heavy vectoring in ZKC effectively decoupled spacing performance from AOC-provided speed advisories. The figure includes data from 75 flights.

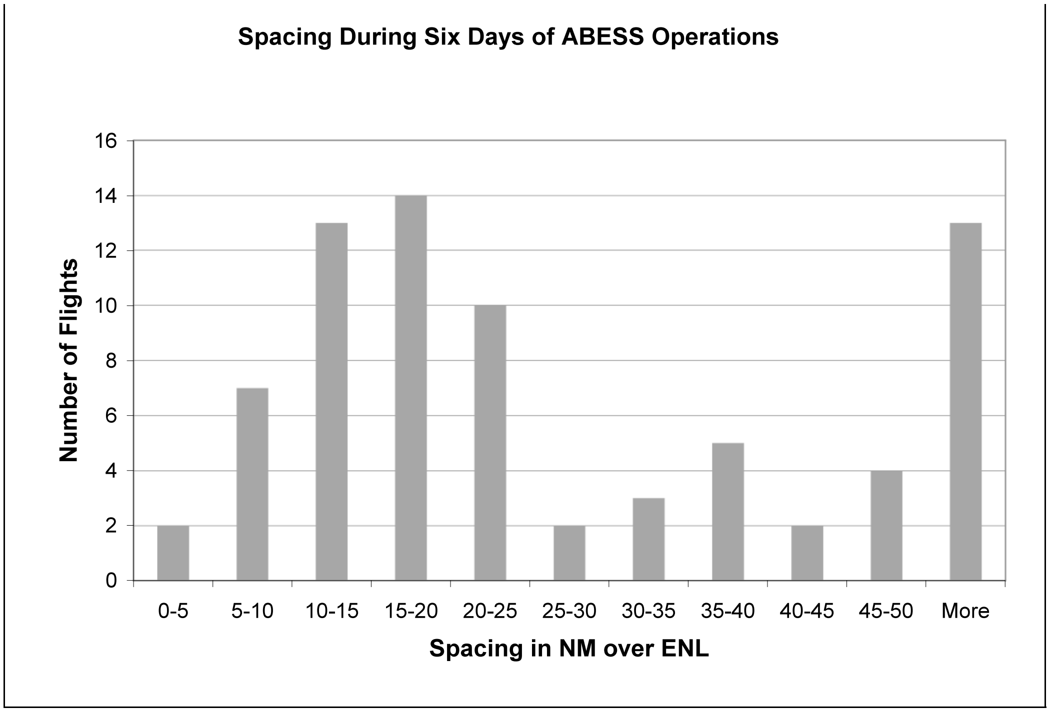


**Figure 11. Overall Spacing of Flights During Six Days of ABESS Operations.**

Figure 11 indicates that 22 flights did not achieve the target spacing of 15 NM (independent of the flight levels) at ENL. There were multiple reasons for this. First, ABESS operators delayed the uplink of speed advisories. This was in part caused by the high number of speed advisories that the ABESS tool provided, and partly because operators wanted to wait to make sure speed advisories were stable before uplinking them. Second, ABESS operators decided not to uplink several speed advisories likely because of insufficient trust into tool accuracy. It is noteworthy that this lack of user trust appeared despite analysis showing that speed advisories were based on relatively accurate merge fix crossing time predictions. This indicates that it was rather the number of speed advisories than the quality of advisories themselves that contributed to reduced user trust. Third, ABESS operators used a graphical display of traffic from a different tool that was based on once-per-minute, asynchronous position updates from flights. These asynchronous update rates made it difficult for ABESS operators to graphically determine the current spacing between flights. This points to the need to enhance the ABESS tool's display of speed advisories and position information.

Figure 11 also shows that many flights had spacing far greater than 15 NM. These results were simply due to the fact that the SDF arrival flows were not saturated and often had large gaps between arrivals.

## IV. Summary and Conclusions

This paper outlined an operational concept that allows airlines to adjust sequence and spacing of flights for advanced terminal operations such as CDAs or ADS-B applications for FDMS . The concept was evaluated in a field-test with the UPS AOC in Louisville, Kentucky where 46 speed advisories were uplinked to flights via ACARS. AOC operators found the overall concept, procedures, and required workload acceptable. They thought that the ABESST gave an acceptable number of speed advisories and thought that the ABESS message set related to the speed uplinks was acceptable. Operators generally requested more stable and reliable advisories from the ABESST and determined that active sequencing of flights was an important prerequisite for the procedure. Air traffic controllers found generally no impact of the procedure on their workload. Flight crews also did not report any perceived increase of workload as consequence of ABESS operations and welcomed the procedure as way to improve operational efficiency. Overall, the concept was generally considered successful and received support from all participants.

Test results point to requirements for increased stability of ABESST speed advisories and arrival sequence predictions. Communication procedures between ABESS operators and the flight-deck should eventually be simplified, by direct integration of an uplink capability into the system. Test activities are scheduled to continue in fall 2007.

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