

PILOT PERFORMANCE ON NEW ATM OPERATIONS: MAINTAINING IN-TRAIL SEPARATION AND ARRIVAL SEQUENCING

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Abstract

Cockpit Display of Traffic Information (CDTI) may enable new Air Traffic Management (ATM) operations. However, CDTI is not the only source of traffic information in the cockpit; ATM procedures may provide information, implicitly and explicitly, about other aircraft. An experiment investigated pilot ability to perform two new ATM operations — maintaining in-trail separation from another aircraft and sequencing into an arrival stream. In the experiment, pilots were provided different amounts of information from displays and procedures. The results are described.

Introduction

An Air Traffic Management (ATM) operation is a set of actions whose goal is to achieve a desired outcome within an air traffic flow. Examples of ATM operations are maintenance of in-trail spacing and sequencing into arrival streams.

The installation of Cockpit Display of Traffic Information (CDTI) in aircraft cockpits has increased the amount of information available to pilots. While it provides continuous and compelling information about the dynamics of surrounding air traffic, CDTI is not the sole source of information in the cockpit.

Air Traffic Management (ATM) procedures may also provide information to pilots. A procedure is a set of proscribed actions required of each person in the ATM system to execute an operation. Regulatory bodies mandate one procedure for a given operation even though, theoretically, many different procedures may be viable for the given operation. By creating a single procedure for a given operation, a shared set of knowledge and expectations are created between pilots, and between pilots and controllers. However, procedural information is based on expectations and can not capture off-nominal actions.

The increase of information, either from displays, procedures, or some combination of both, may enable pilots to perform new ATM operations. An experiment has been conducted in which pilots performed two potential near-term ATM operations: maintaining in-trail separation during arrival and merging with another arrival stream. The objective of the study was to examine pilot performance to determine the feasibility of the two ATM operations and the information requirements necessary to perform them.

Experiment Design

Airline pilots flew the Georgia Tech 'Reconfigurable Flight Simulator' through a series of fictitious arrival routes. During each arrival, pilots were asked to maintain in-trail

separation from other aircraft as well as merge into an arrival stream.

Pilots began each arrival run at approximately 80 miles from the final approach course intercept. The run was ended when the pilots were in position for vectors to the final approach course.

At the start of each run, an air traffic controller cleared the subject for the arrival. The subject was then issued an identification corresponding to the aircraft the subject was to follow followed by an in-trail spacing distance to maintain from that aircraft. A typical controller command to the subject at the start of the arrival was, "GT123, you are cleared for the LENOX1 arrival. Maintain 10 miles-in-trail behind BA382." The subject received one additional in-trail spacing distance command. This command reduced in-trail separation from ten miles down to eight miles.

A final controller command to the subject supported the merging operation. As the subject intercepted the waypoint preceding the merge intersection, the controller issued a command to the subject identifying an aircraft the subject was to cross behind and continue to follow after the subject's crossing of the merge point. Once again, an in-trail spacing distance accompanied this instruction. A typical command to a pilot about to perform a merge was, "GT123, cross behind QW221 at HUMAN, maintain 4 miles in trail behind QW221."

Throughout the run, the controller issued similar in-trail spacing and merge instructions to surrounding aircraft. The issuance of these instructions was to simulate or approximate the availability of Partly Line Information (PLI) under normal conditions. The controller did not issue airspeed, altitude, or heading changes. The only commands issued were those designed to support in-trail spacing or merging during the arrival run.

Apparatus

Subjects flew arrival scenarios on the Georgia Tech 'Reconfigurable Flight Simulator.' Subjects were seated in front of a 21-inch monitor that housed a Primary Flight Display (PFD), Electric Horizontal Situation Indicator (EHSI), and a virtual Mode Control Panel (MCP). An additional field, when accessed, presented a copy of the current STAR on the screen.

Using the mouse, the pilot was able to interact with the cockpit systems. The subject flew the aircraft through the virtual MCP using mouse clicks to operate the various airspeed, heading, altitude, and vertical speed settings. A range selector on the EHSI allowed the pilot to view surrounding air traffic at 10, 20, 40, 80, and 160 miles ranges. When the subject clicked on the field labeled 'Click Here for STAR,' the STAR appeared on the left side of the display. The STAR retracted upon release of the mouse button.

Primary Experiment

The primary experiment investigated how pilots used information derived from displays and procedures in order to perform the ATM operations of maintaining in-trail spacing and arrival sequencing. Three display variants and three procedure variants were tested in the primary experiment. All nine factor-level combinations were tested. Due to concerns of pilot fatigue, each pilot was asked to fly six of the nine combinations in the test matrix as well as a seventh scenario detailed in the description of the secondary experiment. 12 pilots were tested, completing a total of 72 runs in the primary experiment. Each display/procedure combination was tested exactly eight times.

Displays

Displays were based on the (EHSI) with traffic information overlaid on top. As such, the traffic information was shown directly with the navigational information relevant to flying a STAR, such as waypoints.

Baseline Display. This display provided information about traffic using the symbology currently employed by the Traffic alert and Collision Avoidance System (TCAS II). As shown in Figure 1, a white unfilled triangle represents the position of the ownship. Unfilled white diamonds represent the horizontal positions of other traffic. Aircraft altitude is shown to the right of, and either above or below the diamond. If the altitude is shown above the aircraft, that aircraft is currently at a higher altitude than the ownship. Conversely, altitude measures displayed below the aircraft reveals the aircraft is at a lower altitude than the ownship. An up or down arrow corresponding to a vertical climb or descent rate greater than or equal to 500 feet per minute resides next to the aircraft when appropriate. In addition to this traffic information currently available with TCAS, callsigns for the surrounding aircraft were located directly above each respective white diamond.

Display with Speed. This format, as shown in Figure 2, additionally shows the current speed of each surrounding aircraft. Speed information is shown textually to the left of the aircraft symbol. Following the same convention used for altitude, the speed of an

aircraft flying slower than the ownship is shown below and to the left of the aircraft symbol; an aircraft flying faster than the ownship has its speed displayed above and to the left of the white diamond

Display with Speed and Autopilot Targets. In addition to the information found on the previous two displays, this display adds target speeds and altitudes of the other aircraft. The target values were the speeds and altitudes currently specified in each aircraft's autopilot. Target values that have not been attained by an aircraft are shown in magenta text inside a magenta box. Upon target capture, the magenta box moves to capture the actual speed or altitude and the magenta text for the target value disappears until a new autopilot setting is made at which point, the text reappears and the magenta box shifts again to capture it.

Procedures

Procedural support was given in the form of Standard Terminal Arrival Routes (STAR). Each STAR specifies waypoints and altitudes each aircraft is expected to follow throughout an arrival. STARS may additionally depict aspects of the traffic situation such as the expected speeds of aircraft. STARS currently

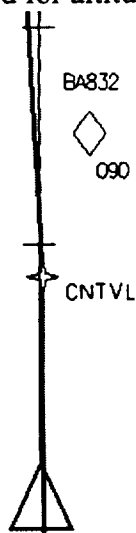


Figure 1. Detail From the 'Baseline' Display, Showing One Other Aircraft (Diamond) In Front of the Ownship (Triangle)

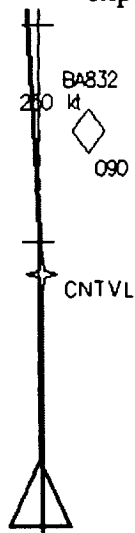


Figure 2. Detail From the 'Display with Speed', Showing the Addition of Speed Information About the Other Aircraft

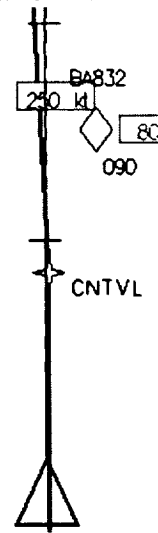


Figure 3. Detail From the 'Display with Speed and Autopilot Targets', Showing the (Captured) Target Speed and (Not-Captured) Target Altitude

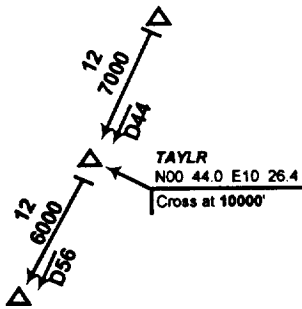


Figure 4. Detail From a 'Baseline STAR', Showin Waypoints and Altitudes

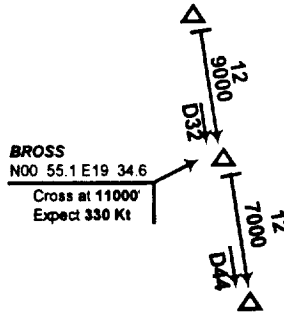


Figure 5. Detail From a 'STAR With Speed', Showing Waypoints, Altitudes, and Expected Speeds

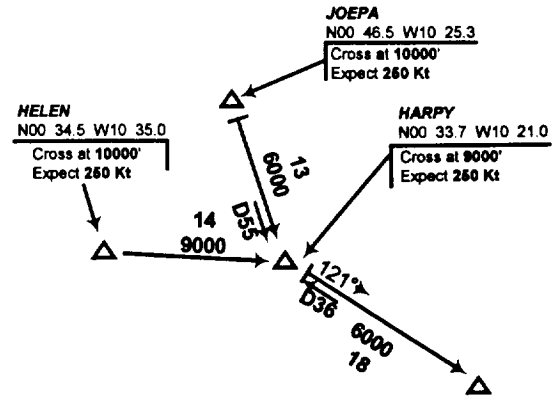


Figure 6. Detail From a 'STAR with Speed and Merging Path', Showing the Addition of Merging Paths (at HARPY intersection)

exist in paper form, but were available to the pilot on the video display. For the experiment, the STAR format currently in use and two modified versions were used as the three procedural support levels given to the pilot.

Baseline STAR. This procedure showed the latitudes, longitudes, and altitudes of a series of waypoints the pilot was to follow along the arrival (Figure 4). Other information such as distances between waypoints, radio frequencies, and airport locations were also shown.

STAR with Speed. This format included the same information as the Baseline STAR with the addition of an expected speed associated with each waypoint, as shown in Figure 5. The expected speeds associated with the sequence of waypoints that lead to the airport represent the normal deceleration profile on that arrival. The expected speed is presented not as an ATC restriction, but rather as a rough estimate or recommendation for airspeed at a particular waypoint during average conditions along the arrival.

STAR with Speed and Merging Path. This format shows the same information as 'STAR with Speed', as well as a depiction of the

merging arrival. In Figure 6, the two arrival segments merge at the 'HARPY' intersection.

Secondary Experiment

The final test run by each pilot was made with the 'deviant scenario.' Similar to the primary experiment, the pilot was given one of three display variants. Unlike the primary experiment, each pilot was given the STAR with the maximum level of information depicted on it (STAR with Speed and Merging Path). The pilot was asked to perform the same operations as before – maintaining in-trail separation and sequencing. The run began as normal with the pilot attempting to achieve the commanded in-trail separations. At the merge point, the pilot was given the usual command to follow behind an aircraft while maintaining four miles-in-trail. The aircraft the pilot was instructed to merge flew 50 kts slower than the expected speed of 250 kts that was published on the STAR. This represented a conceivable error where the pilot of the other aircraft slowed too early to a speed expected later in the arrival.

Subjects

All 12 subjects were current commercial airline pilots. Total flight hours ranged from 6000 to 16000 hours. Ten of the

12 had experience in glass cockpits. Seven of the 12 had some form of experience trying to perform self-separation by referring to cockpit displays in military operations. Eleven of the 12 subjects background training was military. Five of the subjects were captains and seven were first officers. The subjects had flown Boeing 727, 737-800, 757, 767, MD80, MD88, and MD90 aircraft.

The subjects were taken through a briefing that explained the experiment and the expectations of the subjects. Following the briefing, subjects were trained on the simulator and the task until they felt comfortable.

Experimental Measures

Position measures were taken for several aircraft every second throughout the experiment: The subject pilot's aircraft; the aircraft ahead of the ownship; the aircraft behind the ownship; and the two aircraft that will fly in front of and behind the ownship at the merge. Any separation violations committed by the pilot were also recorded and time-stamped. Range changes on the EHSI's range selector were recorded and time-stamped. Similarly all aircraft state changes made through the MCP were recorded at the time of the mouse click on the respective MCP control and access to the STAR was recorded.

A set of subjective questions examined pilot opinions about the displays, procedures, and ATM operations following each test run. A more comprehensive set of questions followed the overall experiment.

Experiment Results

In total, 84 runs were flown, 72 in the primary experiment detailing display/procedure combinations and 12 in the secondary experiment examining the deviant scenario. No runs were removed from the data set. The 12 deviant runs will be discussed separately from the 72 regular runs.

Numerous measures were taken to determine pilot ability in performing the two ATM operations. Quantitative analysis was based upon separation data obtained during representative sections of the arrival. Additionally, separation violations were analyzed with regard to the display/procedure support available to the each pilot during the arrival run in which the violation occurred. Analysis was also performed on pilot responses with regard to the perceived feasibility of performing in-trail separation and sequencing into an arrival stream, but has been discussed in a previous paper [1].

In-Trail Separation

A common segment of each arrival was chosen in which to calculate in-trail separation measures. During the interval for which separation measures were taken, the pilot was asked to achieve and maintain a separation distance of 8 miles-in-trail – a reduction from the prior separation requirement of 10 miles-in-trail. The average separation achieved by each pilot was obtained for the interval. Next, the individual averages for each pilot were grouped according to the display/procedure support provided. An average separation value was calculated from the individual averages. These results are shown graphically in Figure 7. It should be noted that the average separation values will be above 8 nm since separation at the start of the interval was 10 nm.

An Analysis of Variance (ANOVA) performed on the data revealed the presence of significant display/procedure interactions ($F=2.77$ $p<.04$). Based upon this result, a one-way ANOVA was run on the nine display/procedure combinations. The one-way ANOVA found significant variation within the nine combinations ($F=1.93$ $p<.10$).

Another measure of pilot ability to achieve the commanded separation during the chosen arrival segment was obtained by taking the absolute value of the difference between the

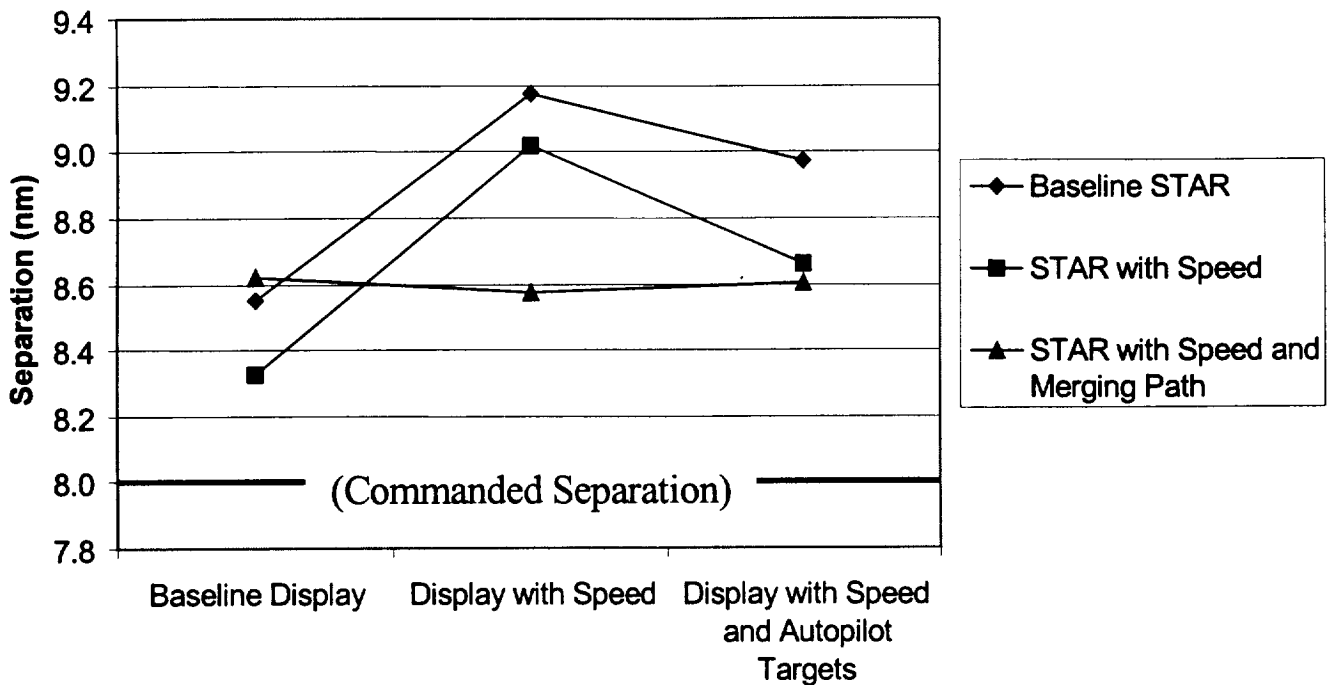


Figure 7. Average In-Trail Separation as a Function of Display and Procedure

separation the pilot had achieved at the end of the interval from the commanded value. Table 1 summarizes these results. As shown in the table, 34 runs (47.2%) achieved within .25 nm of the commanded separation distance. 50 of the 72 runs (69.4%) were within .50 nm.

Table 1. Pilot Separation Distance (n=72)

Pilots	Separation Distance Achieved
47.2%	<= .25 miles of commanded separation
22.2%	>.25 and <=.50 miles of commanded separation
12.5%	> .50 and <=.75 miles of commanded separation
18.1%	>.75 miles of commanded separation

Sequencing into an Arrival Stream

A common segment of each arrival was chosen for which merge separation measures were calculated. During the interval for which merge separation measures were taken, the pilot was to maintain a separation distance of 4 miles-in-trail behind a lead aircraft. The average merge separation achieved by each

pilot was obtained for the interval. Next, the individual averages for each pilot were grouped according to the display/procedure support provided. An average merge separation value was calculated from the individual averages as shown in Figure 8.

The average separations obtained during the merge fall between 3.5 nm and 4.4 nm. However, the ANOVA performed on the merge data indicated that these average merge separations were not statistically different from one another. No display, procedure, or interaction effects were statistically significant.

Deviant Scenario

The deviant scenario affected merge separation distance since the deviant aircraft slowed down before the merge point to 200 kts when its expected speed was 250 kts. The average separation for each pilot was calculated over the interval. Next, the individual averages for each pilot were grouped according to the display the pilot was given. Figure 9 presents the average separation values graphically. The average separation value was below the

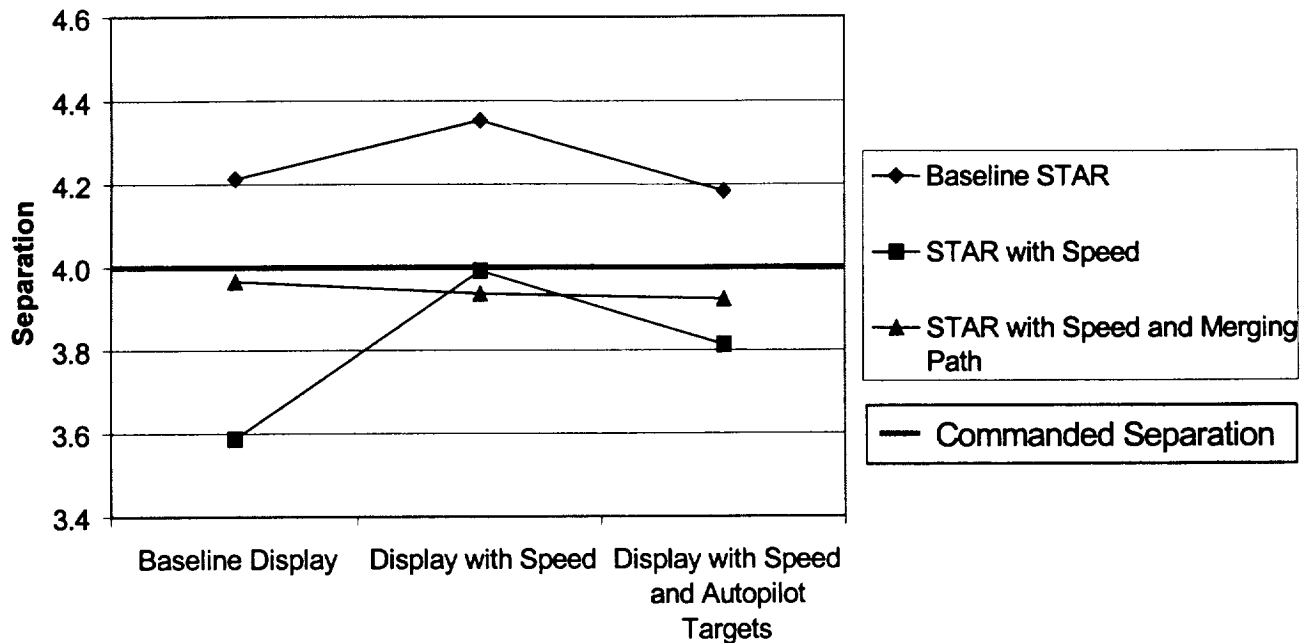


Figure 8. Average Merge Separation as a Function of Display and Procedure

required loss of separation value of 3nm and 1000 feet except for pilots who were given the Display with Speed. It is also worth noting that each of the 12 pilots violated the minimum separation requirement of 3nm at some point during the deviant scenario.

Discussion and Conclusions

Pilot performance as well as feedback on the two ATM operations presented in the experiment brings forth several considerations when potential ATM operations are to be examined.

As a measure of in-trail spacing, 69.4% of the pilots were able to achieve within .5 miles of the commanded in-trail spacing distance. Pilot perception of self-maintained in-trail spacing was that the operation could be performed, but with certain qualifications such as increased training, equipment enhancements, as well as display and procedural modifications.

The operational task of arrival sequencing was deemed more difficult by the test subjects than that of maintaining self-separation. Pilot performance on this operation may have been aided by the addition of a depiction of the merge route on the procedure. Although pilot ability in terms of maintaining the desired separations during the merge was acceptable, pilot perception as to the feasibility of the operation was less than favorable and substantial modifications to the structure of the operation as well as display, procedural, and ATC support were noted as possible requirements.

Results from the deviant scenario suggest that one pilot's departure from procedurized speeds may adversely impact the ability of other pilots to perform the maneuvers required of them in a merging situation. Evidence of this claim can be found in the fact that each test subject violated the required separation at least once during the deviant scenario.

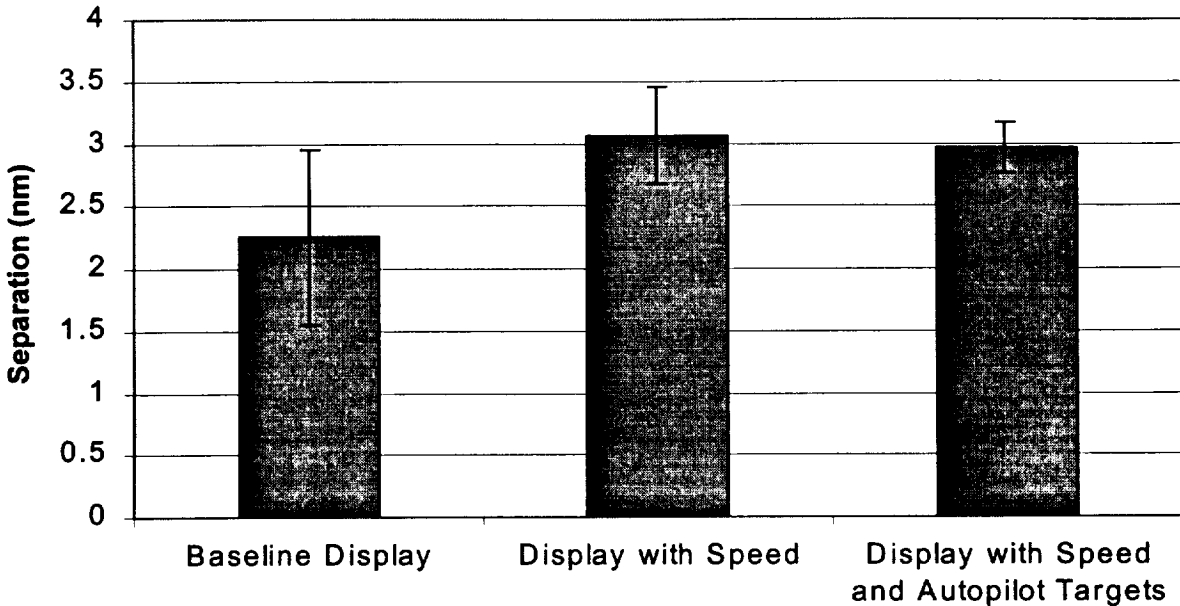


Figure 9. Deviant Scenario Average Separation Values (Error Bars Represent One Standard Deviation)

As revealed in the experiment, the consideration of new ATM operations may need to account for the ability of procedures to act as an information source to pilots. The results from the deviant scenario suggest that regardless of the information that was displayed on the CDTI, pilots were not able to adequately compensate for the deviant aircraft's failure to follow the published speed.

This may suggest a form of overreliance on the procedure with respect to pilots using the procedure as an information source. Although the procedure offered useful information to the pilot when all parties performed in accordance with their respective procedures, failure of one pilot to follow the procedure caused a major breakdown due to the presentation of the same information that was once helpful to the pilot.

Providing robustness to actions not anticipated by procedures may require more emphasis on displaying information or it may necessitate an oversight role for controllers.

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