Is ACARS and FANS-1A Just Another Data Link to the Controller?

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Abstract. This report investigates issues surrounding TBO procedures for the current aircraft fleet when requesting deviations around weather. Air and ground procedures were developed to stringently follow TBO principles using three types of communication: Voice, ACARS, and FANS. ACARS and FANS are both text-based communication systems, but FANS allows uplinked flight plans to be automatically loaded into the FMS, while ACARS does not. From the controller perspective, though, all flight plan modifications were completed using a trial planner and delivered via voice or data comm, making FANS and ACARS similar. The controller processed pilots' request and approved or modified them based on traffic management constraints. In this context, the rate of non-conformance across all conditions was higher than anticipated, with off path errors being in excess of 20%. Controllers did not differentiate between the ACARS and FANS data comm, and showed mixed preferences for Voice vs data comm (ACARS and FANS).

1 Introduction

The U.S. government, through the Joint Planning and Development Office (JPDO), has developed a plan to overhaul the nation's air traffic control system called the Next Generation Air Transportation System (NextGen)[1, 2]. The FAA's NextGen Implementation Plan calls for a shift to automation supported trajectory based operations (TBO), where all aircraft remain on their ground-approved trajectories [3]. The advantage to TBO is that the trajectories can be vetted by conflict detection and resolution systems to aid the controller in maintaining safe and efficient aircraft separation and scheduling [4]. Successful implementation of TBO will require sound concepts of operations and new tools [5]. However, often neglected are the essential elements in the infrastructure behind the concepts: an efficient and reliable air/ground communication system.

The present research aims to address the issue of air/ground communication in the context of TBO. In today's clearance-based operation, controllers frequently issue vectors of indeterminate duration via voice in order to resolve conflicts or allow aircraft to avoid weather. However, in future TBO operations, the controller will need

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to handle flight path modifications by updating the full trajectory in a “Host” computer, and then ensure that the aircraft conform to this new trajectory. These new tasks could have an adverse effect on controller workload; therefore, tools that will aid the controller in creating and updating trajectories are being developed (e.g., trail planners; conflict detection and auto-resolution tools) [6, 7]. These tools should aid the controller in creating trajectories; however, these new trajectories must be delivered to and flown by the aircraft. TBO poses a challenge for pilot-controller communications because significantly more information must be conveyed to all parties involved – ATC, flight deck, and automation (ground host computer).

Compounding the issue is the fact that, at the present time, only about 20% of current transport aircraft are equipped with the Future Air Navigation System (FANS). FANS includes data link communications (data comm) that is integrated with the aircraft’s flight management system (FMS). The controller station is equipped with tools that support the creation and exchange trajectory modifications in a digital form that is loadable into the Host and the aircraft’s flight management system (FMS). FANS has traditionally been used only in oceanic ATM environments. It is currently being tested on a limited basis by the European ATM Programme at the Maastricht Upper Area Control Center, and was tested on a limited basis at Miami Center [8]. Thus, for early implementation of TBO, we develop procedures for non-FANS equipped aircraft. One option is to take advantage of the much more prevalent Aircraft Communications Addressing and Reporting System (ACARS). This system is predominantly used for communication between an Airline Operation Center (AOC) and its aircraft, and is widely available on today’s transport aircraft. The main drawback of ACARS messages is that they are text-only and, therefore, are not loadable into the FMS.

2 Current Study

The present research had three goals and one critical assumption, all related to any near term implementation of TBO. The first goal was to develop flight deck TBO procedures for aircraft with different communication equipage levels, and to evaluate their effectiveness and usability in negotiations with the controller. The second goal was to evaluate and compare controller performance and workload in handling TBO operations across different percentages of flight deck equipage. The assumption was that advanced groundside tools supporting TBO will become available well before NAS-wide changes to flight deck equipage, as indicated in the FAA’s NextGen Implementation Plan. The three communication equipage levels were examined: 1) FANS, providing data comm integrated with the FMS; 2) ACARS, providing a non-integrated data comm; and 3) voice only.

Although several studies have assessed communications with different FANS and ACARS protocols, none have examined off-nominal situations [9, 10, 11], and none were aimed at full TBO operations, and the associated problem of keeping all aircraft on trajectory during operations in the presences of convective weather. Thus, the third goal of this study was to examine controller/pilot data comm communication during TBO with convective weather, where there is a greater likelihood that pilot goals (e.g., weather avoidance) and controller goals (e.g., efficient traffic management) will diverge resulting in negotiation. These negotiations may be more difficult because most transport flight decks use onboard weather radar, while the ground uses NextRad, resulting in very different views of the weather.

In this simulation, the controller was responsible for managing ~1-1.2X traffic in a high altitude sector in Kansas City Center's airspace. The sector is on the eastern boundary, adjacent to Indianapolis Center. The primary sector traffic was modeled after normal day time traffic flows, along with UPS arrivals into UPS's HUB at Louisville International Airport. The major impediment to normal sector traffic flow was significant convective weather near the eastern border of the sector. Controllers were responsible for aircraft separation and traffic management, while pilots were responsible for weather avoidance. Additionally, controllers were responsible for maintaining trajectory-based operations, if at all possible. To accomplish this task they were instructed to minimize vectoring of aircraft by creating flight plan modifications using a trial planner and delivering the modified trajectories via voice or data comm. Although from the controller perspective, sending and receiving information from a FANS and ACARS aircraft required the same actions, they were briefed on the flight deck procedures for loading and executing data comm clearances on each flight deck, and were aware of the possible differences in pilot response time when using FANS versus ACARS.

3 Communication Procedure Development

Initial procedures for the flight deck and controllers were developed by the authors, one of whom is a current airline pilot, and another who is a former air traffic controller. The procedures were then vetted by two retired controllers and two pilots (one current and one retired airline pilot). The goal of all procedures was to keep an updated flight plan trajectory in a ground-based "host" computer, and to make it possible for the aircraft to closely adhere to those flight plan trajectories. A large number of assumptions and justification for our procedures are provided in Lachter, (in press), and are too numerous to describe in this paper. In general, the procedures were designed to reduce workload/complexity on the controllers DSR, and to aid both the controllers and crews in coordinating and approving flight path deviations.

4 Method

4.1 Participants

Four controllers (two per week) and sixteen commercial airline pilots (eight per week) were paid participants in this HITL simulation. Because the focus this paper is on controller performance, we limit our description to the controller participants. Controllers were retired TRACON controllers with at least 19 years of service. All were trained on, and familiar with, advanced ATC tools. The controllers received a week of training on en route and arrival operations in ZKC and ZID centers.

4.2 Controller DSR

The controller display was presented on a 32” high resolution monitor and was configured to support traffic managed in ZKC 90, see Figure 1. Two aircraft symbols with two colors were used to display the three equipment types. Dynamic NextRad weather was displayed near the eastern sector boundary. The controller DSR was equipped with advanced conflict detection, out to 8 minutes, and auto- and manual resolution tools coupled with a trial planner. See Prevot [6], for a complete description of the MACS DSR.

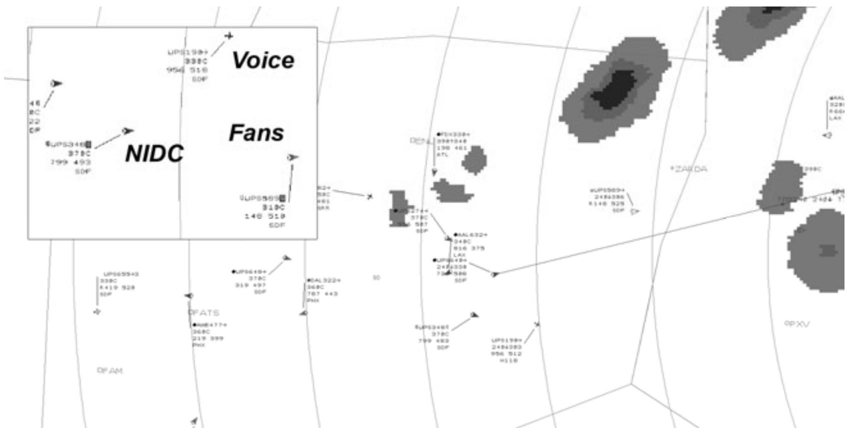

Fig. 1. DSR display of equipage type and data comm portal – FANS, green chevron & data tag; ACARS, gray chevron, green data tag; Voice, gray aircraft symbol and yellow data tag. Note data link pending bracketing callsign UPS589.

The controllers also had a separate touch-screen computer used to measure real time workload and flight plan acceptability. Participants were asked to rate their workload on a 1-5 scale once every minute throughout the trial. Following a flight plan change, participants were asked to rate the quality of the flight plan. An additional paper-and-pencil workload questionnaire was administered after each trial; a post-simulation questionnaire was administered after the final trial.

4.3 General Procedures

The HITL simulation spanned two consecutive weeks with different controller and pilots each week. Each week began with one day devoted to training, three days scheduled for data collection, and a final day for make-up trials and debriefing. Participants were briefed on both flight and ground operations near convective weather. Additionally, controllers were briefed on managing optimized profile descents with merging and spacing during arrival operations into Louisville.

4.4 Scenarios

Thirty-two 20-minute scenarios were run. Experimental controllers managed traffic in a high altitude sector (ZKC 50) west of Louisville KY. In each scenario, two experimental flight decks (dual pilot) flew west to east through this sector reaching a storm front on the eastern side of the sector. Experimental flight decks were arrivals headed for Louisville International Airport (SDF). Their top of decent (TOD) which varied by flight levels was near the eastern edge of the sector. Pseudo-pilots managed all additional traffic to bring the traffic sector count to between 16-20 aircraft at all time; ~ 1 to 1.25X traffic load.

There were four starting conditions at the beginning of the scenario, as defined by the location of the weather and traffic. The weather for each of these four starting conditions evolved in one of four ways so that neither the controller nor pilots could make assumptions about the optimal path through the weather until they have monitored the storm system development.

4.5 Experimental Design

The experimental design consists of two fixed factors (Airspace Mixture and Aircraft Equipage) and three random factors (scenario, crew, and controller). Airspace mixture was the number of equipped aircraft in the sector, set at three levels: predominantly Voice (80% Voice, 20% FANS), predominantly FANS (80% FANS, 20% Voice) and predominantly ACARS (60% ACARS, 20% Voice and 20% FANS). These three conditions were intended to reflect three possible ways of managing the current majority of aircraft in the NAS that are equipped with ACARS. The Airspace Mixture factor should affect the controller's workload while the Aircraft Equipage factor affect individual experimental aircraft, see Brandt, [12].

4.6 Communications Procedures

To maximizing adherence to TBO objectives, communications procedures were designed to keep aircraft on the flight plans in the host. Thus flight plans were communicated as closed loop trajectories with a specified point to depart from, and return to, the original flight path. Procedures were developed in which proposed trial plan amendments included a push point two minutes ahead of the aircraft, allowing time for negotiation, implementation, and possibly rejection of the proposal before any maneuver began. During training it became apparent that, for Voice aircraft, communicating this added waypoint increased controller workload disproportionally. Thus, the procedures were modified so that, maneuvers were off the nose for Voice aircraft and controllers amended the flight path in the host after the maneuver if the displayed symbology showed the aircraft to be off-path.

4.7 Controller Procedures

Data comm messages were logged and ordered on the DSR display based on when they were received. They are also coded in the aircraft's data tag. However, the controller has discretion as to when each message was handled. To reply to the message the controller normally selects the portal in the data tag which shows the route for FANS aircraft, and highlighted the ACARS or voice aircraft in the list. For voice aircraft controllers had to handle the request immediately or copy/remember the request and ask the aircraft to standby. The procedure for modifying the host flight plan using the trial planner was generally the same for all aircraft. The current path is modified by selecting the portal in the aircraft's data tag, then selection a point on the original path and dragging that point to a location that is clear of weather and is conflict free. The path automatically snaps to a named fix if one is proximal to the desired location. The controller then uplinks the new trajectory to the aircraft, if data comm equipped, or delivers the clearance via voice if not equipped.

4.8 Dependent Variables

In addition to the workload and route quality ratings described earlier, there were two dependent performance variables: the miles added to the original trajectory by the path modification (path stretch), and the percent of time the aircraft was not in conformance with the host trajectory (non-conformance was defined as when the aircraft was at least 1 mile off path, or off track by 15 deg from the nominal trajectory). For this paper we will only present controller data (see Brandt, in press for the flight deck data).

5 Results and Discussion

5.1 Performance

Our initial analyses show little difference in performance between conditions. ANOVAs showed no significant differences between different flight deck equipment or different equipage mixtures in terms of the trajectories flown, path stretch to avoid weather, or time off path. The lack of effects on path stretch and amendments was not too surprising since the factors that drive flight path changes (e.g., weather, conflicting traffic, distance to top of descent) were built into the scenario and may have overwhelm any influence of communication method. However, the absence of any effect on non-conformance was somewhat surprising, since it was expected that the FANS condition should have performed best and the Voice worst. This was not found, but a surprising overall level of non-conformance was found.

When non-conformance was examined as a function of individual controller and Aircraft Equipage, the mean non-conformance rate was at or above 20%, cresting 45% in one case. These were very high numbers. The controllers also differ both in overall performance and in how Aircraft Equipage affected their ability to keep aircraft on their trajectories (Fig. 2). For two controllers, Voice aircraft are off path much more often than FANS or ACARS aircraft, while for the other two, Voice aircraft are off path less often than FANS, nearly as little as ACARS.

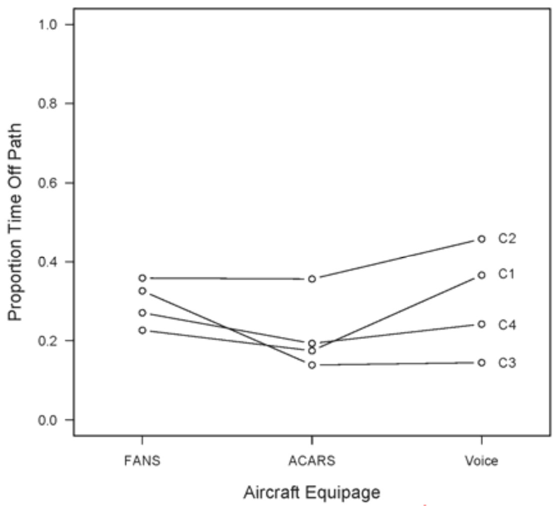

Fig. 2. Proportion of time off path by controller

For all four controllers, ACARS aircraft were off path less frequently than either Voice or FANS aircraft. The higher non-conformance by the Voice aircraft may be explained by the requirement for controllers to create modifications "off-the-nose" of the Voice aircraft (immediate turns), or by controllers giving an OK to a request before actually entering it into the host. Either of these procedures introduces delays between the creation in the host and implementation of the trajectories on the flight deck. For the ACARS aircraft, the controller was instructed to use the trial planner to create trajectories. The trial planner automatically inserted a push point located two minutes ahead of the aircraft. When uplinked the crew would need to manually enter the amendment, with the instruction to just turn the aircraft onto its first leg when the push point was reached if the amendment had not been fully entered. The crews reported that this procedure was cumbersome (see Brandt, in press) and may be responsible for the 20% non-conformance. Finally, the significant amounts of non-conformance with FANS procedure may have been due to the downlinked FANS routes also being off-the-nose. When the controller approves them they are subject to the same delays between creation and implementation that were present with Voice aircraft.

5.2 Workload Ratings

At the end of each trial, all participants rated their workload (1 low to 5 high) on four criteria: Overall and Peak Workload associated with maintaining separation and with handling weather avoidance requests.

For controllers the four post trial workload ratings were obtained for each level of Equipage Mixture. These resulting 12 mean workload ratings clustered in a fairly restricted range (from 3.28 to 3.85). For the four measures, controllers' mean workload was highest in the Predominantly FANS condition, and was lowest for Predominantly Voice, with the exception of Overall workload associated with separation, for which Voice and ACARS were nearly identical. These trends were significant for the "Overall workload associated with separation" ($F(2,6) = 13.91$, $p < .05$) and "Overall workload associated with weather avoidance requests ($F(2,6) = 5.966$, $p < .05$).

Controllers were also asked to rate their workload every minute during the trial, also on a 1 low to 5 high scale. Interestingly, controllers rated their workload higher on this online measure than they did on the post trial questionnaire. Again, taking the means for each controller for each level of Equipage Mixture the range ran from 4.02 to 4.97, with two of the controllers rating all three conditions over 4.9. Differences between Equipage Mixtures were not found to be significant, presumably because of the ceiling effect. Similarly, there were no differences in RT to the workload probes.

5.3 Post Simulation Ratings

After the simulation, both pilots and controllers rated how much they agreed with 15 statements (1 - complete disagreement to 5 complete agreement) about each of the different communication procedures (e.g., "I felt adequately aware of what the pilots of ACARS/FANS/Voice aircraft were doing," and "Trajectory operations using solely ACARS/FANS/Voice is, in principle, a workable concept.").

No ANOVAs were conducted on controller ratings due to the very limited sample size (4), but the pattern is quite clear. Controllers generally rated the two data comm procedures identically. Two of the four rated ACARS and FANS identical on all 15 criteria. That is, they saw no difference in the two procedures. One controller gave FANS better ratings on three criteria, and the remaining controller gave ACARS a better rating on one criteria. In addition, only one of the four controllers agreed with the statement "I was very aware of whether an aircraft I was handling was integrated data comm (FANS-1A) or ACARS." Thus, it appears that our procedures were successful in allowing ACARS-equipped aircraft to be managed similarly to FANS aircraft from the controller's perspective.

While ACARS and FANS appeared very similar to the controllers, Voice, naturally was quite different. Yet the four controllers differed on whether Voice was preferable to the two data comm conditions (FANS and ACARS). Because FANS and ACARS were considered so similar we average them into one "data comm" rating for the following discussion. One controller rated the data comm conditions better than Voice on eight of the 15 criteria, while rating Voice better on none. A second controller rated the data comm better on six and Voice better on one. However, a third controller rated Voice better on eight and data comm better on none, and the final controller rated Voice better on one and data comm better on one. Thus, it appears that controllers varied in their relative preferences for Voice and data comm. However, it should be noted that they were relatively unfamiliar with the FANS and ACARS procedure. Thus, it is possible that any residual preference for Voice occurred because it was familiar and they were well practiced with it.

6 Conclusions

In our simulation environment, where aircraft can make requests, all equipage levels were off trajectory more than expected. Despite our emphasis in training that aircraft be kept on host trajectories, we occasionally observed that a controller appeared unconcerned if one or two flights were not conforming. This was probably due to fact that there were no ATM penalties for allowing aircraft to be off trajectories: no additional coordination with the next sector, no downstream schedules that needed to be met, and only losses of separation in the sector were of concern.

Because no class of aircraft can easily create flight plans that contain push points, controllers could not simply approve requests but must either create a new flight plan and send it back to the flight deck or adjust the flight plan in the host to match what the aircraft was actually flying. Either way, this additional step adds significantly to the controller workload, as reflected in the data.

As to the question of making FANS and ACARS similar to the controller, all data from the study suggest that we did just that from the controller's perspective - Two of the four controllers reported no difference in the two data comm procedures. One controller gave FANS better ratings on three criteria, and the remaining controller gave ACARS a better rating on one criteria. In addition, only one of the four controllers agreed with the statement “I was very aware of whether an aircraft I was handling was integrated data comm (FANS-1A) or ACARS.

It is possible that a mixture of data comm and voice could result in more acceptable response times while accruing many of the benefits of data comm (such as reduced transmission error, the ability to transmit more complex clearances, and a reduction in voice traffic). Several pilots in our study stated during the debriefing that their concerns about data comm would be greatly ameliorated if requests were acknowledged more promptly even if there was a delay in the actual response.

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