

EXPERIMENTAL ANALYSIS OF THE INTEGRATION OF MIXED SURVEILLANCE FREQUENCY INTO OCEANIC ATC OPERATIONS

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Technical capabilities for improved surveillance over the oceans are currently available through the use of satellites. However, all aircraft operators will not equip simultaneously because of the high costs required. Consequently, as these CNS systems are integrated into oceanic air transportation architecture, the controller will have to manage the current low frequency surveillance in parallel with enhanced surveillance. The cognitive effects of the mixed equipage environment were studied through experimental analysis. The results confirm that there are human performance issues with integrating mixed surveillance capabilities, which may result in safety and efficiency limitations.

Introduction

The effects on human performance capabilities of integrating position information from dissimilar sources, with significant differences in update rate and reliability, have not previously been addressed. However, there are plans for such integration into oceanic air traffic control (ATC) operations in the near future (Federal Aviation Administration, 2002).

Oceanic ATC Surveillance

Since air traffic over the oceans is out of radar coverage surveillance presently consists of pilots reporting their position over high frequency (HF) radio at designated waypoints, which occur approximately once every hour (Civil Aviation Administration, 2002). All HF communication is conducted through a third-party communication relay service (e.g., ARINC in the United States). This indirect surveillance process is shown in Figure 1. HF radio is unreliable due to the interference of solar storms and other anomalies. The above limitations result in a high amount of latency and unreliability associated with the current surveillance process.

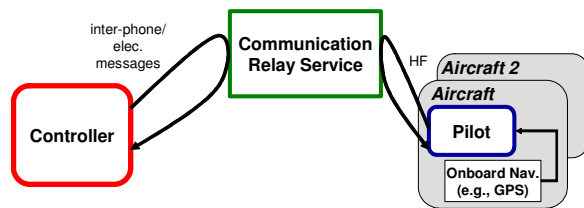


Figure 1: Current surveillance is conducted by pilots reporting their position, over HF radio, through a third party communication relay service.

Traditionally the position reports have been displayed to the controller through the use of paper flight strips. The strips are organized into columns, with each

column representing a position reporting point. This allows the controllers to monitor the aircraft by comparing time at waypoint. Currently the majority of oceanic traffic follows standard routings that are usually deconflicted. Therefore, in the present system the controllers nominally ensure separation at the waypoints and assume separation minima will be maintained in between.

Satellites have introduced the opportunity for improved surveillance. One such opportunity is provided by addressable automatic dependent surveillance (ADS-A)¹. ADS-A automatically sends flight information, through a satellite communication link, to specified addressees (typically ATC ground stations) at specified intervals. The intervals are determined by contracts between the aircraft operators and the ATC centers. The ADS-A surveillance process, shown in Figure 2, significantly improves the frequency of surveillance updates and increases reliability.

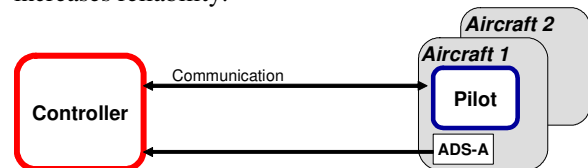


Figure 2: Future oceanic surveillance involves ADS-A reports through a satellite communication link.

For ADS-A capability aircraft operators must retrofit their aircraft with onboard avionics equipage. The high cost of the equipage restricts many aircraft operators from acquiring this new technology. Consequently, oceanic airspace will consist of mixed surveillance capabilities in the near-term.

¹ ADS-A is referred to as ADS-Contract (C) in Europe.

Spatial situation displays are being integrated into oceanic ATC workstations to take advantage of ADS-A and other opportunities for improved surveillance and decision support. Currently, aircraft surveilled by pilot position reports are represented on the spatial display. Their position is represented as a continuous projected path based on an extrapolation of the filed flight plan, any changes made to the flight plan, and computer models. Once ADS-A surveillance information is integrated with the pilot position reports, the controllers may have difficulty distinguishing between the aircraft equipped with high and low frequency surveillance. This may cause the controllers to treat all aircraft as if they were equipped with low frequency surveillance (lowest common denominator effect).

Based on field studies of current operations and human-centered systems analysis, other human factors issues are hypothesized to emerge when mixed surveillance capabilities are integrated into common airspace. These issues are increased controller workload, decrease in situation awareness, and the possibility that controllers will choose to maneuver aircraft equipped with high frequency surveillance when in conflict with unequipped aircraft, which will negate the advantages of equipping. The present study investigated these issues further through a part-task experimental analysis.

Experimental Analysis

For this study air traffic controller trainees ran three scenarios on a PC-based simulator. The scenarios were modeled after the current, near-term, and far-term future oceanic operations.

Participants

The participants for the experiment were nine air traffic controller trainees. The experiment took place approximately three weeks prior to their full ATC certification. A questionnaire was administered to determine the level of participants' operational control experience. As part of their air traffic controller training the participants controlled in the ATC operational environment under the supervision of fully certified controllers for an average of 24 months (SD=0.899). Their experience was in Enroute Centers and Approach Centers (TRACON and Tower).

Air Traffic Control Simulator

A PC-based low fidelity ATC simulator was developed at MIT for this experiment. As shown in

Figure 3, generic oceanic airspace was simulated and displayed through a spatial representation. This display was modeled after the spatial displays currently used at oceanic ATC facilities.

The display consists of aircraft targets, datablocks, jet routes, and fixes. A circle with a radius equal to the minimum separation surrounds each aircraft target. The circle can be removed during the simulation by right clicking the aircraft icon. The datablock includes the aircraft callsign, equipage information (ADS or non-ADS), altitude, and speed. The aircraft position on the spatial display is updated once per surveillance update. Consequently the variance in surveillance update rates, during the mixed equipage scenario, is reflected on the traffic display.

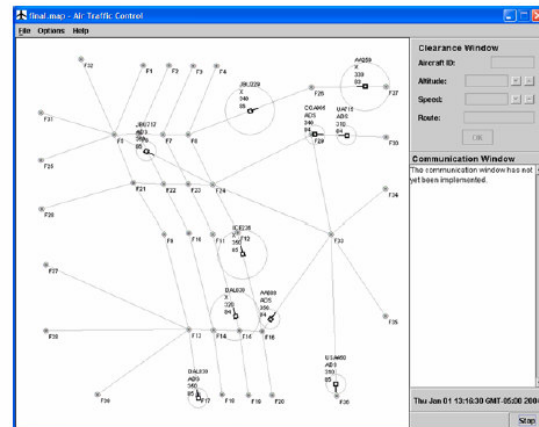


Figure 3: PC-based simulator used for the experimental analysis .

Experiment Design

The participants were presented with three, five to seven minute scenarios. For each of these scenarios there was moderate traffic and the airspace geometry was varied, however the level of complexity was held constant. Four conflicts were built into each of the three scenarios in random order. The conflicts were changed in a superficial manner to maintain consistency across the scenarios, but not result in a "training effect". These conflicts included two merging conflicts between two aircraft, a head on conflict, and a more complex conflict, involving four aircraft that were all converging at one point. There were also three pilot requests, which were easy to medium difficulty. The responses to the pilot requests were not used in the analysis.

Independent Variables The independent variables were surveillance frequency (low, high, and mixed) and separation minima (modeled after current and future operations). The three scenarios are described

in Table 1. One of the scenarios consisted of aircraft equipped with low frequency surveillance (1 update per 30s) and separation minima of 50 nm. In another scenario all of the aircraft were equipped with high frequency surveillance (1 update per second) and separation minima was reduced to 20 nm. The third scenario consisted of a 50% mix in surveillance equipage. In this scenario separation minima was reduced to 20 nm only for aircraft equipped with high frequency surveillance.

Table 1: Design of the three scenarios.

Surveillance Frequency	Separation Minima
High (1 upt/s)	20 nm
Low (1 upt/ 30s)	50 nm
Mixed	Mixed

Dependent Variables The dependent variables focused on the human performance impact on the controller since benefits to the system rely on the capability of the controller to implement the reduced separation safely. The first variable of interest was workload. Because of time constraints, approaches to measuring workload that would lengthen the experiment time, such as NASA-TLX or a secondary task, were not possible. Instead a subjective rating on an anchored five point scale by the participants of the difficulty of each scenario was used in addition to a difficulty ranking of the three scenarios. Another dependent variable was situation awareness, which was measured by use of the performance-based testable response method (Pritchett, 1996). Controller trust is vital for acceptance and implementation of changes to the ATC system. Trust was evaluated by the participants rating their confidence in aircraft position information for aircraft with high and low surveillance frequencies on an anchored five point scale. The final dependent variable was the surveillance type of the aircraft the subject maneuvered during a mixed conflict. This was evaluated only during the mixed scenario. It was hypothesized that the participants would choose to maneuver aircraft equipped with high frequency surveillance when faced with a mixed conflict.

Results

Each of the dependent variables was analyzed using a one way ANOVA. The ANOVA analysis was used to test for statistical significance in the difference in the means of the three scenarios. To further compare the scenarios with mixed and high frequency surveillance a t-test was used. The Bonferoni correction was used to adjust for the additional test.

Scenario Difficulty

The results from the difficulty rating showed a significant positive effect of surveillance frequency, $F(2, 8)=4.795, p=.018$. Using the related-pairs t-test, a significant difference was identified between the high frequency and mixed scenario pair, $p=.002$. These results, shown in Figure 4, demonstrate that integrating high and low frequency surveillance does not result in an improvement in workload from the current operations.

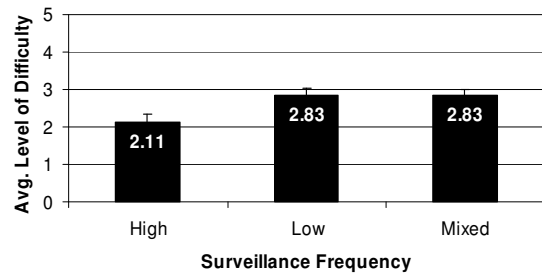


Figure 4: Results from participant rating of the difficulty of each scenario on an anchored scale of 1 to 5, with 5 being the most difficult. Standard error bars are given.

The post-experiment ranking of the difficulty of the three scenarios also revealed a significant effect consistent with the post-scenario ranking, $F(2, 8)=7.44, p=.003$. As shown in Figure 5, 67% of the participants found the mixed scenario to be the most difficult.

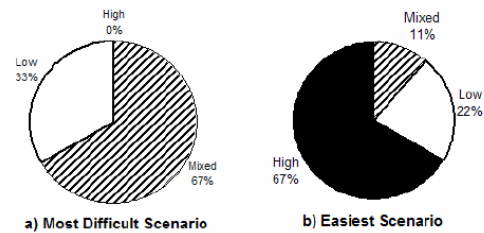


Figure 5: Results from participant ranking of the three scenarios.

Situation Awareness

Situation was measured by scripting four conflicts and measuring performance, to determine if participants were aware of the conflicts and how quickly they recognized and resolved them. There was a non-significant increasing trend in the number of conflicts resolved. Low significance was expected because of the conservative culture amongst air traffic controllers. Priority on resolving conflicts is valued much more than efficiency.

There was also a non-significant trend in the time to recognize the four scripted conflicts in the three scenarios, $F(2, 8)=2.400$, $p=.115$. The trend can be seen in Figure 6. There was not a significant trend evident in the time required to resolve the conflicts.

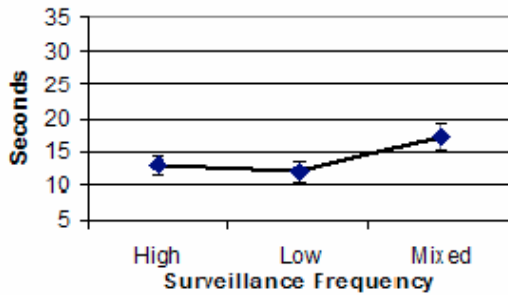


Figure 6: The average time it took the participants to recognize the four scripted conflicts in the three scenarios. Standard error bars are given.

Participant Confidence

There was a significant effect of surveillance frequency on confidence, $F(2,8)=21.951$, $p=.002$. As expected, the subjects rated their confidence in the position of aircraft with high frequency surveillance much higher than their confidence in that of aircraft with low frequency surveillance. The results are demonstrated in Figure 7.

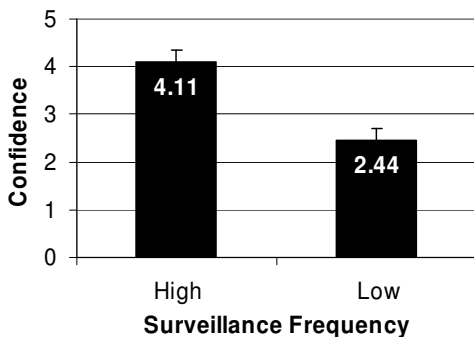


Figure 7: Participant rating of their confidence in the position information for aircraft with high and low frequency surveillance on an anchored scale of 1 to 5, with 5 being "Very Confident".

Aircraft Maneuvered

During the post-experiment survey, participants were asked which aircraft they were more likely to maneuver in a mixed conflict, aircraft equipped with high or low frequency surveillance. All nine participants responded they would be more likely to maneuver aircraft equipped with high frequency surveillance. This result matches the trend in their

performance during the mixed scenario. A significant difference was found between the number of high frequency and low frequency aircraft chosen to maneuver by the participants, $F(1,8)=20.455$, $p=.0003$. The number of high frequency and low frequency aircraft that each participant chose to maneuver to resolve the four conflicts in the mixed scenario is shown in Figure 8. Some participants did not resolve all four conflicts because some of the conflicts were missed or averted with a previous maneuver.

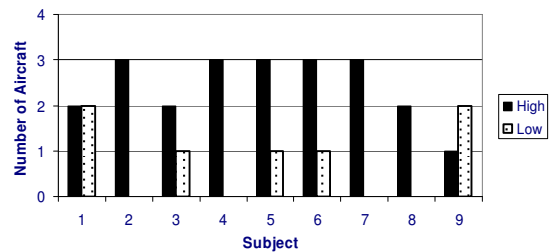


Figure 8: The number of aircraft each subject maneuvered to resolve the four scripted conflicts in the mixed scenario.

This result was expected based on the controller rating of their confidence in position information for aircraft equipped with high and low frequency surveillance. Maneuvering aircraft with frequently updated position information creates a more robust resolution to a mixed conflict.

Conclusions

The results from the part-task experiment confirm the hypothesis that controller cognitive limitations will negatively impact the advantages achieved by integrating aircraft equipped with improved surveillance into oceanic ATC operations. Safety may be compromised due to a potential increase in controller workload and degradation in situation awareness. The efficiency benefits associated with improved surveillance also may not be achieved because controllers will nominally maneuver aircraft equipped with the highest frequency surveillance, taking the aircraft off of their planned path, to resolve mixed conflicts.

Airspace segregation and display support are proposed to alleviate the human performance costs associated with the mixed surveillance environment. Airspace segregation reduces the complexity for the controller by removing the need to apply different strategies based on individual aircraft capabilities. Each airspace region will have a set of required equipage capabilities associated with the region.

This allows the controller to apply the same procedures and control strategies within each airspace region. Airspace segregation is currently used for aircraft equipped with reduced vertical separation minima (RVSM) and required navigation (RNP). The majority of flight levels over the oceans are dedicated to RVSM equipped aircraft. Standard routings, such as the oceanic track structure (OTS), are dedicated to aircraft equipped with RNP-10².

Further research needs to focus on strategies for segregated operations and the display support required to support these operations. These strategies need to be consistent with the RNP concept, since the concept is included in plans for future reductions in separation minima. Additional studies into how to display various surveillance frequencies on a single display are also needed.

References

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Gordon-Smith, M. (2003). RNP promises significant economic benefits to the airline industry. *ICAO Journal*, 58(3):23–25, 33–34.

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² Aircraft certified for RNP-10 must maintain a cross-track and along-track navigational accuracy of 10 nm, 95% of the time (Gordon-Smith, 2003).