Prospects for Reduction of Separation Standards in Oceanic Airspaces with Satellite Services

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ABSTRACT

For many years air traffic controllers have relied on infrequent position reports to maintain separation between aircraft flying along oceanic routes. As traffic continues to increase at a record-setting pace on virtually all major oceanic route systems, technologies and procedures of the past will have to be modified in order to accommodate the projected traffic volume. Recent advances in the use of satellites for air navigation and air traffic control offer a means to solve the problem of increasing capacity while improving safety. This paper will examine, from the control system perspective, how satellites will influence the ATC system of the future.

1.0 Introduction

The use of satellites will improve aircraft navigation in oceanic airspace, and will allow air traffic controllers to reduce communication delay and offer better services. Each of these changes will increase the safety of the air traffic control (ATC) system. A portion of the safety improvement will undoubtedly be translated into separation reductions, thereby increasing system capacity and efficiency while maintaining an acceptable level of safety.

2.0 Oceanic Separation

The current North Atlantic (NAT) ATC system can serve as a reference for demonstrating the safety benefits expected from the use of satellite-based navigation and surveillance systems. The NAT ATC system has the most reliable and consistent set of records on navigational performance in oceanic airspace, a data base extending back to 1980. From this data base, functions and parameters describing current system performance are generated to aid in monitoring overall system safety.

The minimum navigational performance specification (MNPS) for the North Atlantic region was established by setting a system safety goal and deriving parameters for navigational performance and system performance needed to meet that goal under the constraints of changing traffic demand. It is necessary to bear in mind that some of the data used in the analysis described below applies only to NAT operations; the conclusions drawn from it therefore also apply only to the NAT environment, and may not be generalized to other oceanic airspaces. Each oceanic system should be evaluated according to its own characteristics.

2.1 Lateral Separation Expectations

Initial reductions of lateral separation will likely be driven by two satellite-based developments: provision of Automatic Dependent Surveillance (ADS), and demonstrated improvement in navigational accuracy. Their combined effect is far more significant than the individual effect of either one.

Step 1 of the FAA's ADS program will give controllers automatically updated position reports, checked for conformance with their associated flight plans; but it will not replace the existing system of indirect communication between pilots and controllers. Improvements implemented under step 1 are expected to reduce the rate of large navigational errors: for example, by quickly detecting and correcting those resulting from incorrect waypoint insertions, one of the most frequent causes of large errors.

The FAA has briefly studied the effect of reductions in the rate of large navigational errors on the probability of lateral overlap. The lateral overlap probability directly affects the risk of collision; hence a reduction in this probability is translated one-for-one to the collision risk estimate. Since there are many factors which can effect the risk estimate and which change in relation to separation reductions, a thorough examination of separation reductions should include these aspects.

The navigational systems considered in the FAA's study were assumed to just meet NAT MNPS requirements (i.e. their lateral errors had standard deviations of 6.3 nmi); and their lateral errors conformed to a double-double exponential distribution. The sensitivity analysis was conducted to show the effect of incrementally reducing the proportion of large navigational errors. In this exercise it was more important to notice where the changes in overlap probability occured than to be concerned with the magnitude of the changes. It was found that noticeable changes in overlap probability occurred in the interval of separations from approximately 40 nmi through 60 nmi.

Figure 1 shows the effect on lateral overlap probability of improvements in the accuracy of on-board navigational systems (i.e. of reductions in the magnitude of "small" errors). Again, lateral positional errors are assumed to conform to a double-double exponential distribution. Marked differences in overlap probability do occur over the interval (along the route separation axis) where reductions in overlap probability might be expected. Again, it is less important at this point to project the magnitude of the safety improvement than to notice the range over which it would occur, i.e. where route separations are between 25 nmi and 40 nmi.

The preceding paragraphs imply that reductions in the number of large navigational errors and improvements in navigational accuracy have different effects on lateral overlap probability. The performance of future oceanic ATC systems depends on the percentage of ADS-equipped aircraft, on the way controllers (supported by automated equipment) use ADS-derived information, and on the distribution and extent of improvements in navigational accuracy. Both navigational accuracy and rate of large errors contribute greatly to the mathematical description of the navigational performance distribution, which is used to determine the probability of overlap. The introduction of satellite-quality position-locating systems (e.g. GPS) in the general population of aircraft will have a profound effect on the distribution of nominal navigational accuracy; however substantial benefits will not be realized until there are also reductions in the rate of large errors. Figure 1 shows that at current separations, if navigational accuracy increases while the rate of large errors remains unchanged, the risk of collision decreases very little.

Additional work is needed to suggest a statistical distribution function describing future navigational performance. The use of satellites will affect both the mathematical form of the function and its parameters.

Figure 2 shows the combined effects of reducing the rate of large errors and improving nominal navigational accuracy. If the rate of large errors is not reduced, then even the use of navigation systems with 0.5 nmi standard deviation is insufficient to support any appreciable reduction in lateral separation (as long as the current safety goal is maintained). Substantial improvement in the safety goal clearly requires a major reduction in the rate of large errors. Significantly improved safety (and the potential to also reduce separation standards) would result from a 75% reduction in the rate of large errors, combined with the use of navigation systems having standard deviations of 0.5 nmi, 1 nmi, or 2 nmi.

The MNPS requires the close monitoring of system safety. Timely feedback on system performance is used to adjust system variables reflecting factors such as increased demand, and to thereby maintain a proper balance between safety and capacity. This feedback has traditionally consisted of data on the rate at which large errors occur. Because the proposed safety goal is so stringent, a system meeting that goal could tolerate very few large errors. It would take several years of accumulated measurements simply to determine whether the proposed system were in conformance with the safety goal. This is an unacceptable feedback period, as it admits the possibility of operating the system (and exposing the flying public) for several years at an unacceptably high risk.

Satellite-based technology can carry us into the future and meet increased safety demands while also improving efficiency; but several challenges must be overcome in order to harness the technology. The aircraft which make up the fleet must significantly improve their navigational performance. New monitoring provisions are needed -- provisions which yield accurate, reliable indicators of the system's status, and which convey necessary safety information.

2.2 Longitudinal Expectations

Traditionally, longitudinal separations in oceanic environments are evaluated by using a collision risk model. One input to the model is a distribution function describing the gain (or loss) of separation between pairs of aircraft. The model estimates the probability of longitudinal overlap, and proceeds to estimate the risk of collision due to the loss of planned longitudinal separation. The presence of ADS and satellite-quality position-locating services will affect the gain-loss distribution function, and therefore affect the model's results.

There is substantial variability in the gain or loss of separation. Several factors in the environment contribute to this variability:

1) differences in winds aloft experienced by individual aircraft;

2) inherent or allowed variations in speed due to tolerances in flight management systems or to aircrew performance;

3) differences in the accuracy of aircraft position-keeping along the planned route; and

4) air traffic control system feedback and response.

A satellite-based system could improve control or monitoring of aircraft positions. Improved control would reduce the variability of longitudinal separation, and therefore reduce the probability of overlap. Increased frequency of position updates would confirm previously projected positions and reduce uncertainty in projecting future positions. The minimum inter-aircraft spacing could be reduced, as controllers would be far more likely to detect and correct any substantial erosion of along-track separation than they do in today's system.

The FAA recently collected and processed some oceanic data in an attempt to test the hypothesis that differences in the wind experienced by two aircraft traveling along the same route would strongly influence the gain or loss in separation between them. It was expected that as aircraft spacing decreased, the winds experienced by the aircraft would be more closely correlated; and the variation of the spacing between them would therefore decrease. An examination of the variance of inter-aircraft spacing revealed no such correlation. It seems likely that the effect of differences in winds aloft is confounded with other variabilities of at least the same order. Subsequent investigation into the potential causes of changes in inter-aircraft separation revealed that on-board control systems (flight management systems) may allow greater variation from assigned airspeed (Mach number) than had been expected.

The goal of five-minute separation between aircraft traveling along the same oceanic route seems to be attainable. Reaching it requires satellite-based navigation and surveillance systems; but it also requires strict conformance to flight plans. Modern flight management systems allow far greater control of their aircraft than is now exercised by the ATC system. That stricter control will be needed to exploit the accuracy afforded by satellite navigation systems and the increased surveillance update frequency yielded by ADS.

2.3 System Control

Working groups of the International Civil Aviation Organization (ICAO) are considering the adoption of a new, more stringent target level of safety (TLS) for determination of oceanic separations. The proposed TLS is effectively an order of magnitude less than the one currently in force. To achieve that TLS it will be necessary to have both ADS and satellite-quality position-locating systems. Furthermore, ATC services must carefully control the relative positions of aircraft in order to counteract those collision risks which increase as aircraft positioning systems (horizontal and vertical) become more accurate. Such is the case, for example, with collision risks arising from route assignment errors or undetectable deviations from assigned route. That is, the control system must use frequent ADS position updates to dependently assign relative aircraft positions, and thereby prevent aircraft from coming into proximity -- much as air traffic controllers, aided by radar, already do for domestic airspace.

Step 2 of the FAA's ADS program will provide the direct controller-pilot communication link needed to support timely separation services. Improved communication, navigation and surveillance, combined into an effective control system, should reduce the overall risk of collision and allow improvements in capacity. Today communications are subject to delays in processing that are not directly related to the actions of pilot or controller. The average delay associated with a message transmission is now 3 minutes; but since the distribution of delays is long-tailed and skewed, pilots and controllers always face a strong possibility that a very long communication delay will occur. Under step 2 of the ADS program, the nominal communication delay will be greatly reduced.

3.0 Conclusion

In a future environment, where significantly improved safety margins will be required, ADS, by itself, will not permit substantial reductions in lateral separation. Likewise, satellite-based navigation systems will not, by themselves, lead to a greatly improved ATC system; for if large errors persist at their current rate, improvements in nominal accuracy will not overcome their effect on the overall rate of collisions. Only when satellites are integrated into a control system that uses their ability to furnish highly accurate positional data and frequent surveillance updates, will they permit anticipated traffic increases while reducing the risk of collision enough to allow separation reductions.

Sensitivity of Lateral Overlap Probability to Nominal Navigational Accuracy

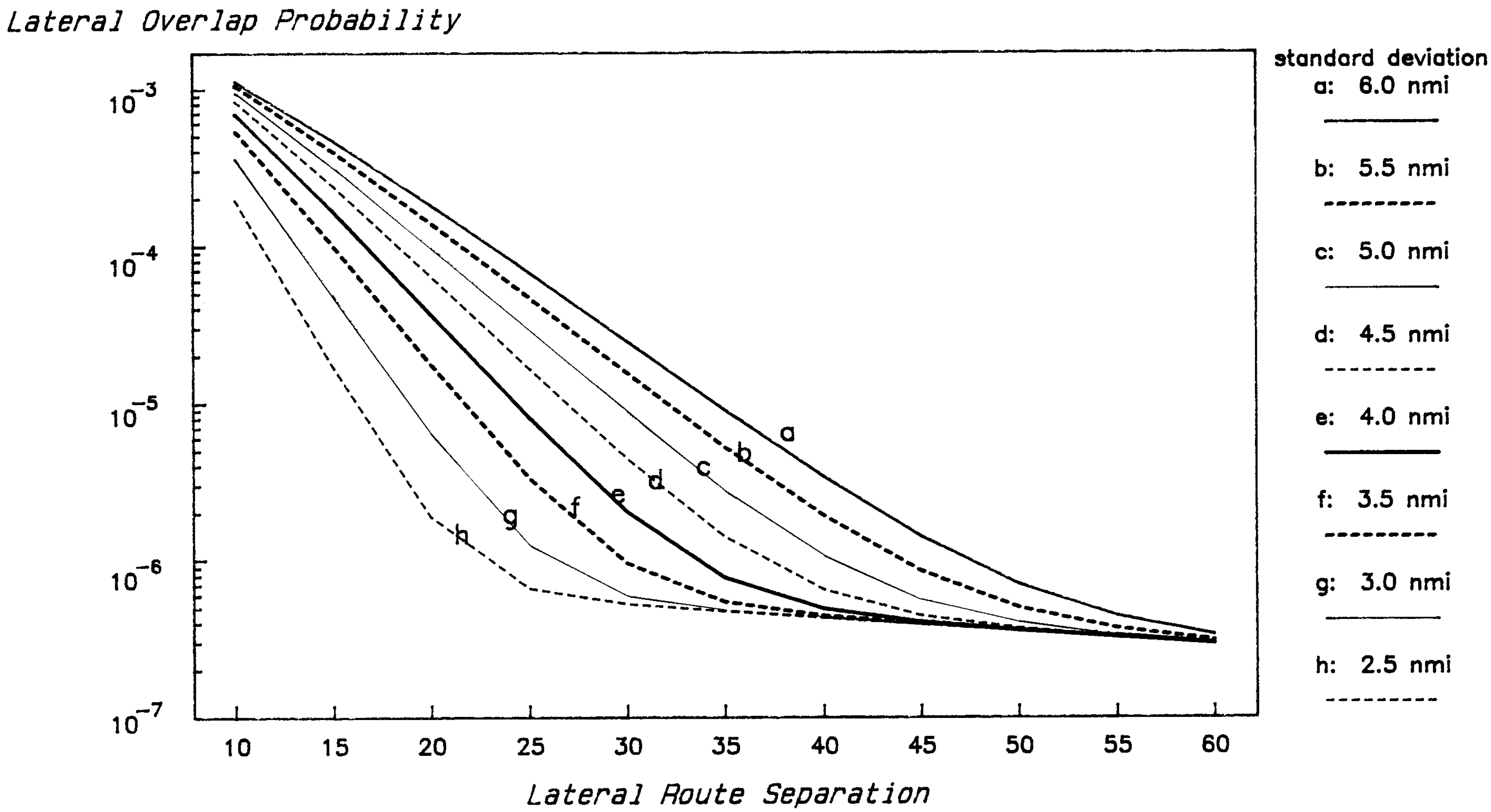

Figure 1

Sensitivity of Lateral Overlap Probability to Reductions in Large Errors (RLE) and Improvements in Nominal Accuracy

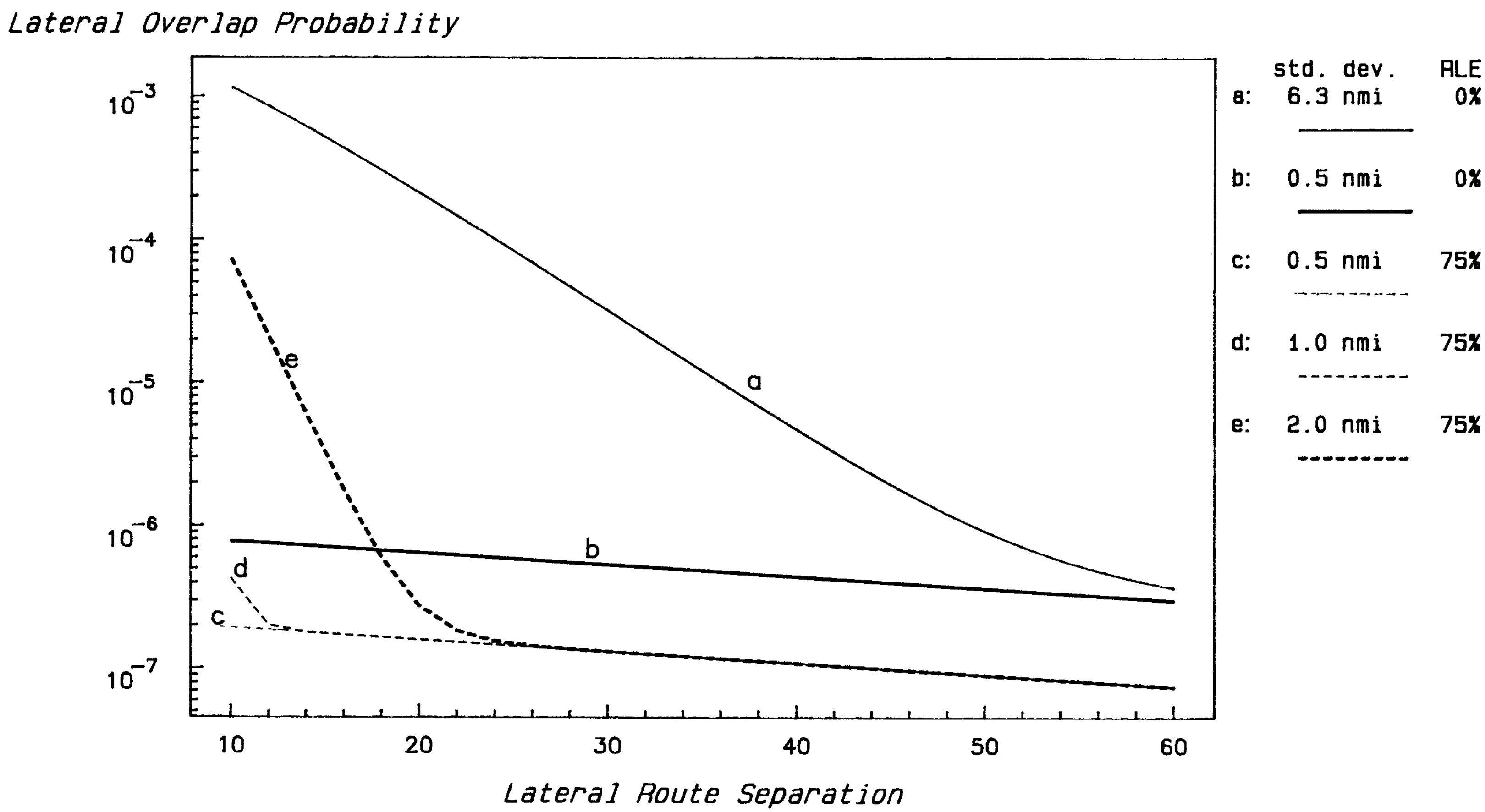

Figure 2