FLIGHT PLAN PROCESSING STUDY

KENNETH A. COBB

STANFORD TELECOMMUNICATIONS, INC.
SEIC CONTRACTOR

AUGUST 1, 1986

FLIGHT PLAN PROCESSING STUDY

I. Introduction

Flight Plan Processing is the process by which aircraft flight data is excepted, stored, and processed in order to 1) construct and maintain a database that are traffic controllers can use in planning air traffic movement in their sectors and 2) construct and maintain converted fixes, route segments and trajectories.

The FPP capability of the AAS must meet long-term strategic fuctional performance requirements. The four functions performed by AERA are 1) Trajectory Estimation, 2) Flight Plan Conflict Probe, 3) Airspace Probe, and 4) Sector Workload. The most critical functions are Trajectory Estimation (TJE) and Flight Plan Conflict Probe (FPCP). Trajectory estimation expresses each aircraft's estimated trajectory as a set of connected segments through four dimensional (xyzt) space. This estimate is based on the aircraft's flight plan. FPCP compares aircraft trajectories to determine when to alert the controller that two aircraft may lose separation.

A previous study done by MITRE performed a Monte Carlo similation of FPCP missed and false alerts for encounters between pairs of aircraft in level, linear flight. The results addressed FPCP performance as a function of the following factors:

a. Geometry of the encounter
b. Longitudinal uncertainties
c. Lateral uncertainties
d. FPCP thresholds
e. TJE thresholds

The role of Flight Plan Processing in the AAS is to support the strategic functions such as Metering, Weather data, and Automation functions. The two major errors which greatly challenge the efficiency of FPP capability are 1) Wind errors introduced and nature, and 2) Pilotage error, human errors introduced by the pilot. This study will examine closely issues being explored and work completed thus far by MITRE, and where Flight Plan Proccessing is headed in the future.

II. Analysis

In August, 1984, the MITRE Corporation presented an analysis of the two major components of the AAS Flight Plan Processing function. That study was one of the few studies to be performed on the Flight Plan Processing. The focus of that study concentrated on Flight Plan Conflict Probe (FPCP) and Trajectory Estimation (TJE), the most critical functions. Flight Plan Conflict Probe compares aircraft trajectories to determine when to alert the controller that two aircraft may lose minimum separation. Trajectory Estimation expresses each aircraft's estimated trajectory as a set of connected segments through dimensional (xyzt) space. The estimate is based on the aircraft's flight plan. The estimate of position and velocity is modified or resynchronized if the aircraft's tracked position is more than a certain distance ahead or behind its position (according to the trajectory). Estimates of wind velocity are incorporated into the trajectory's longitudinal velocity estimate.

Performance was studied as a function of five different variables:

1) Encounter geometry
2) Separation criteria defining a conflict
3) Quality of wind velocity and surveilance data
4) Longitudinal conformance (resynchronization)
5) Lateral conformance threshold

The primary tool used by MITRE was a Monte Carlo simulation of parts of the FPCP and TJE. Also, the scenarios used for simulation involved aircraft in level, linear flight.

The key actions of Trajectory Estimation and Flight Plan Conflict

Probe are as follows: TJE creates a trajectory for each aircraft as flight plan information becomes available. The trajectories are represented simply by vectors in xyt space. The trajectory is used to predict ground speed, and is computed from an estimate of true air speed and an estimate of wind velocity. Surveillance report of the aircraft's postion are received every few seconds as the flight proceeds. The reports are smoothed by an alpha-beta tracker. The tracker uses different parameter values depending on whether or not a turn is anticipated. Periodically, the current tracker position is compared to the predicted position. If they differ by more than a given threshold, the trajectory is revised. This comparison process is called Conformance Monitoring. The revision of the trajectory is called resynchronization. Resynchronization causes a change in both the estimated position and ground velocity of the aircraft. The reports include the latest wind effects. When a new trajectory is calculated for an arircraft due to a new flight plan, resynchronization, or other reasons, the trajectory is checked by FPCP for conflicts against all other aircraft trajectories. This check is called the Situation Monitor, which operates automatically, without controller intervention. If predicted separation between the updated trajectory and another aircraft's trajectory becomes small enough soon enough, a message is displayed to the controller. This situation is called a conflict. If predicted separation becomes small enough but not soon enough, FPCP Situation Monitor calculates the notification time at which the separation will become small enough soon enough. As expected, separation prediction deteriorates in quality as look-ahead time increases. Finally, a manually invoked version of FPCP, called Trial Plan Probe, may be used by the controller to help determine whether a proposed flight plan amendment may result in loss of separation.

A figure of merit for the Flight Plan Processing capability is the FPCP's ability to decide whether to display an alert if and only if it is appropriate. Two types of poor performance would be 1) a missed alert, failure to notify the contrioller when two aircraft in fact approach each other too closely, and 2) a nuisance alert, notification of the controller, when in fact the two aircraft would not approach closely. For level aircraft, the issue of missed and nuisance alerts is solely a function of the horizontal separation criteria. FPCP may also be unacceptable by frequently changing its mind - repeatedly declaring and cancelling an alert for a given pair of aircraft. FPCP changes its mind only at resynchronization. This problem is less critical in scope than the previous problem of missed and nuisance alerts.

The two real world sources of errors affecting the accuracy of the FPCP for level aircraft are longitudinal uncertainties and lateral uncertainties. Errors in estimates of aircraft longitudinal positions and velocities originate from the following various sources: 1) Longitudinal wind velocity uncertainties, 2) Longitudinal uncertainties associated with unpredictability of future vertical maneuver profiles, 4) Temperature uncertainties, 5) surveillance errors, 6) Loss of precision due to coordinate conversion, and 7) Pilot errors. Of these many sources of errors, wind velocity uncertainties are thought to be dominant. Surveillance errors are smoothed somewhat by tracking. Additionally, pilot errors occur especially during turns.

Wind errors, whether correctly of uncorrectly measured, have a complex effect on an aircraft's flight. Changes in wind velocity are reflected in a change in aircraft velocity with respect to the ground. Wind measurement involves a magnitude and a direction, and is expressed as a vector. The error in wind measurement, the difference between true and measured wind, is also a vector. A complex interplay exists between trajectory information, which provides the latest information about the airspace just exited and is updated by resynchronization, and wind grid information, which provides estimated information about the airspace just being entered, in that, to some extent, the two sources are redundant. But each supplies information that is not available from the other.

For simulation purposes, the effect of the cumulative variation in winds upon aircraft longitudinal position was represented as a power spectral density. The along-route spectral component of the power spectral density was expressed mathematically using a roughness parameter to indicate prevailing conditions concerning wind velocity variation. Values of this paramenter represented calm conditions, typical of high-altitude cruising, with long route segments where wind velocity is relatively constant, and turbulent conditions, typical of lower altitudes where shorter route segments are flown. Thus, an aircraft's true longitude air speed at time t was represented as the weighted sum of its true longitudinal airspeed at time t , and the perturbing component of wind over the interval t to t according to the power spectral density, using the appropriate previously mentioned roughness parameter.

In order for the wind model to compensate for imperfect knowledge of wind velocity, a reduction in the overall variation was assumed for wind velocities on certain spatial scales, when the power spectral density was computed. The power spectral density, in effect, integrates over wind velocity variations at all frequencies to obtain an estimate of the cumulative energy imparted to the aircraft. Wind grid information allows the low-frequency variations to be predicted with some degree of accuracy. A wind velocity estimate is available every time an aircraft travels a distance equal to the wind grid reloluton. The time interval between these measurements is inversely proportional to this distance. The shorter the segments, the better the fit. Wind errors, thus, are more severe for slower aircraft.

The effects of the distance of the wind grid resolution, the RMS error of the wind vector, and the age of the measurement, combine to determine a single parameter which governs the behavior of longitudinal position uncertainty due to wind velocity uncertainty. The simulation model used assumed that the TJE uses all information theoretically available in the wind grid of a given quality and applies it to predict future aircraft longitudinal position and velocity. The three parameters previously mentioned and the roughness parameter were used to specify wind measurements and uncertainty.

The results from the simulation examined five sets of factors:

1) Scenario Geometry (encounter angle and aircraft velocity rates)
2) SEPH (horizantal separation criteria and look-ahead time)
3) Longitudinal Uncertainties (chiefly the effects of wind conditions)

4) Lateral Uncertainties

5) Resynchronization Threshold and Surveillance Jitters

Two yardsticks used to discuss and interpret results are crispness and conservativeness. Crispness measures how steeply the curve measuring minimum reported separation distance vs. alert percentage, falls from near 1 to near 0. Contrastly, conservativeness measures the FPCP's propensity to give alerts, or how far to the right the curve lies.

Scenario Geometry: The results indicate that the velocity ratio of the two aircraft, not the absolute velocites, influence FPCP's performance. The encounter angle also has a pronounced effect on FPCP's performance. The velocity ratio influences FPCP's performance mainly for the encounter angle less than 60 degrees. Finally, FPCP's performance is not sensitive to the magnitude of the two aircraft's velocities, given the velocities ratios remain constant.

SEPH: The results indicate that crispness is independent of the magnitude of SEPH. Evidence is provided that suggests that the SEPH-curve should have a negative slope at longer look-ahead times rather than being constant. Also, a new technique is suggested to subsequently increase the average warning time to the controller at the cost of only negligible increases in the false alert rate.

Longitudinal (wind velocity) Errors: The results demonstrate that conservativeness tends to increase somewhat with increasing errors in wind velocity, and that conservativeness is largely independent of the wind grid resolution and of the age of the information. Crispness deteriorates with increasing error in wind velocity and increasing wind roughness. Resynchronization is sufficiently good that there is little to be gained by improving the wind grid until a certain point.

Lateral Uncertainties: The results show that as the lateral uncertainty increases, the crispness deteriorates. Only by attempting to predict lateral deviations can the crispness be improved. Taking best lateral deviation into account exacerbates considerably the deterioration in cripsness due to lateral uncertainties.

Resynchronization Threshold Value and Surveillance Jitter: The results show that crispness improves with decreasing values of the resynchronization threshold. Also, there is a lack of sensitivity of crispness to differing values of the surveillance error at low or moderate resynchronization threshold, and possibly there exists a correlation relationship at higher resynchronization thresholds.

III. Conclusions

Results from Mitre's simulation address FPCP performance as a function of the five following factors:

1) Geometry of the encounter angle
2) Longitudinal uncertainties
3) Lateral uncertainties
4) FPCP thresholds
5) TJE thresholds

Geometry of the encounter angle: FPCP's performance can be vastly improved by making SEPH a function of the encounter angle and the relative aircraft velocities. The encounter angle influences FPCP's performance very strongly. Also, it is the velocity ratio, not the absolute aircraft velocities, which influences FPCP performance.

Longitudinal uncertainties: There is a complex interplay between trajectory information and wind velocity estimates for each wind cell, the two sources of information used to predict longitudinal position and velocities. In calm weather, the use of wind grid data of a quality available now improves performace modestly compared to when no wind grid data is used. As weather conditions become more turbulent, reductions in grid cell size cause larger improvements in performance. Also, performance improvements for finer grids are dramatic for the most turbulent weather conditions.

Lateral uncertainties: For "worst case" deviations, in which each aircraft stays at the edge of its lateral conformance band, so that separation is minimized over all possible lateral deviations, each extra mile of increased lateral uncertainty causes FPCP performance to deteriorate in a roughly linear fashion. No other factor was found to influence performace in such a direct, consistent, and predictable manner. Therefore, it is recommended that the allowable lateral deviation from center line be kept as small as possible, and vary according to each aircraft's navigational capacity.

FPCP thresholds: With SEPH a constant with respect to lookahead time, FPCP performance deteriorates with increased lookahead times. SEPH should vary as a function of lookahead time. The slope should be level or slightly negative for short lookahead times, and negative for longer lookahead times.

TJE threshold: As the longitudinal resynchronization threshold is reduced, FPCP conformance steadily improves. However, there is a limit to how far the resynchronization threshold can be reduced, without being adversely affected by position jitter errors.

Relatively large FPCP performance gains may be achieved by the use of wind grid data of currently available quality, the optimization of the horizontal separation criterion as a function of encounter geometry and by a reduction of aircraft lateral deviations. Significant but smaller gains may be achieved by reducing the size of the longitudinal conformance (resynchronization) threshold, various improvements in the wind grid quality, and the optimization of the horizontal separation criterion as a function of lookahead time. Performance gains seem marginal at best for reduced surveillance jitter.

Further studies to be undertaken include: 1) addressing Trial Plan Probe issues more fully, 2) making refinements to algorithms to allow SEPH to be a function of the encounter angle and velocity ratio, and 3) covering horizontally maneuvering level aircraft and vertically maneuvering aircraft on linear routes. These studies will help to develop solutions to the many issues confronting Flight Plan Processing functions.

IV. References

1. Advanced Automation System (AAS) System Level Specification (SLS) - Design Competition Phase, FAA Document FAA-ER-130-005F, May 6, 1985.

2. Performance Analysis of AERA Algorithm : Phase I, Volume 1, MITRE Document MTR-84W108-01, August, 1984.

3. Performance Analysis of AERA Algorithm : Phase I Appendices, Volume 2, MITRE Document MTR-84W108-02, August, 1984.

4. Varela, John A., Automatic Flight Data Processing Seminar, The MITRE Corporation, Report No. M77-94, September, 1977.