

A DISPLAY CONCEPT FOR STAYING AHEAD OF THE AIRPLANE

Eric N. Johnson, Lockheed Martin Aeronautical Systems, Marietta, Georgia

David C. Hansen, Lockheed Martin Aeronautical Systems, Marietta, Georgia

Abstract

A display concept for depicting past, present, and future situation data in a consistent manner is presented. Anticipated advantages include better planning and improved operator workload management. Issues associated with the concept are discussed.

Introduction

For generations, flight crews have been trained to “stay ahead of the airplane”. That is, they have been trained to always be prepared for their next task and to make plans and decisions prior to the latest available moment. To accomplish this, the highest level of situation awareness is a prerequisite: the crew must be able to predict the future situation and be cognizant of its implications. Conventionally, this requires an expert. The expert can use this ability to smooth-over high workload periods, and can constantly reevaluate their decisions based on new information prior to fully implementing decisions.

Advances in airborne processing capabilities and datalink communications may

enable a new type of human interface to be used in the future flight deck and air traffic control facilities: one in which the current system state and predicted states can be presented to the operator in a cohesive and intuitive manner. In the concept presented here, the conventional notion of the horizontal situation display with flight plan, traffic, and weather information is extended by an ability to depict a predicted situation at a future time, based on the current situation, flight plans, and weather forecasts. A number of design issues associated with such a concept are discussed (in particular the accuracy of predicted information) in the context of enabling the human operator to make complex decisions with enhanced safety.

Background

Current Practice

Airspace users rely on a variety of sources for information about the past, present and future situation. Today, there is considerable variety in presentation of this information, depending on the source. Table 1 is a sample of these data sources. This situation is illustrated by looking at the ways a pilot gets

Table 1. Typical Flight Deck Information Sources

Information	Past Data	Current Situation	Future Situation
Traffic	Not Generally Available to Flight Crew	ATC (voice), TCAS (situation display)	Flight Plan (paper, situation display), ATC (voice)
Weather	Weather Maps (paper)	Radar (situation display), ATC (voice), Pilot Reports (voice)	Forecasts (paper)

information about past, present, and future traffic and weather information during a typical flight.

Enabling Technologies

A variety of technologies are becoming available that are allowing more of the information described in the previous section to be available to flight crews. This potential has led many to propose changes to the National Airspace System (NAS) to take advantage of these technologies:

Datalink: Satellite Communication, Mode-S and other technologies are making it possible to reliably communicate a considerable bandwidth of digital data between aircraft and ground facilities, and even between aircraft.

Multi-Function Displays and Control: Reconfigurable Displays and Controls have come into common use in aircraft. These devices include reliable large-format color displays, alphanumeric keypads, function keys, and cursor control devices.

Airborne and Ground-Based Processing: Advances in computer processing are enabling more and more processing of data in the timely manner required for many aerospace applications. Considerably more data fusion, data prediction, alerting, and automation is potentially possible than is utilized today.

These technologies are enabling many to consider an overhaul of the ATC system to improve both safety and through-put. One current trend appears to be toward greater flight deck responsibility in flight path selection, often referred to as Free Flight. The use of predicted data may help operators with the task of evaluating options in a Free Flight environment.

Even without any new flight deck responsibilities, if flight crews can be given more of the information necessary to evaluate their progress, then it seems likely that safety will be improved due to the extra checks being

made on decisions. This must be accomplished without causing their workload to increase to a point of diminishing returns. Arguably that point has already been reached in the terminal area, where new flight deck information might only be of benefit if it inherently decreases workload.

The Predictive Situation Display

A primary purpose for situation information is to allow flight crews and controllers to make flight plan decisions. For example, the purpose of weather information is to allow flight crews and controllers to make plans that cause all aircraft to miss undesirable weather. In making these decisions, the current situation and forecasts are used to predict the outcome of flight path options.

The predictive situation display is proposed as a way to apply the enabling technologies discussed above to help operators with flight planning and re-planning tasks. In this concept, a “look-ahead” time is selected to be used for generating a predicted situation display. Where a conventional display shows the current state of traffic and other hazards (along with, say, lines depicting flight plans in some designs), this display could also depict the predicted position of traffic and other hazards for that future time. How this look-ahead time is selected is discussed in a later section.

A notional example of this concept is depicted in Figure 1. In this implementation, the display shows current states in a de-emphasized manner (in this case as dotted lines) and predicted future states in a more conventional manner. This allows the user to easily visualize the negative outcome of a possible flight plan. Some form of strategic alerting system might have just given a warning that this was the predicted outcome, but here is a way to depict the outcome in a more useful manner.

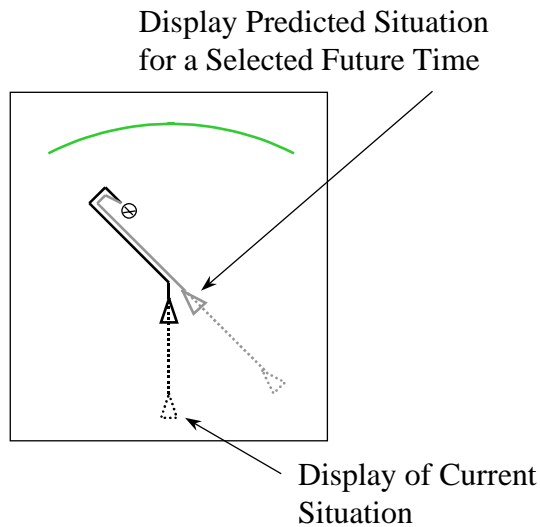


Figure 1. Depicting Predicted Situation for a Future Time, Notional Horizontal Situation Display (in Example, a Predicted Traffic Conflict is Depicted)

If the predicted information is adequate, this pre-planning can be arbitrarily far in the future. That is, the look-ahead time can rise and fall as the integrity of predicted information changes. If the predicted information changes dramatically, then the new outcome is presented and the re-planning can begin. The use of predicted information will be discussed more in a later section.

The predictive situation display is proposed for showing the current and predicted-future state of:

- Ownship Navigation
- Other Traffic
- Weather (reports and forecast)
- Airspace (special use)
- Threats (for military use)

The use of this preview technique to depict these classes of information will be discussed below.

The advantages of this approach for displaying information are three-fold:

(1) Consistent portrayal of current, forecast, and past situation information: This is identified as a positive way to apply the previously mentioned enabling technologies to improve the flight crew's ability to do planning tasks, both in terms of accuracy (correctness) and frequency.

(2) Workload management: The capability to selectively plan ahead is recognized as a technique to reduce workload at times of peak workload, such as at approach and landing. By planning for the approach while en-route, the workload in the approach is potentially reduced. In addition, the increased workload at times when the crew might otherwise become complacent or bored is a potential secondary benefit.

(3) Error detection and predictive alerting: Giving the flight crew the opportunity to selectively evaluate flight plans provides them the opportunity to catch their own errors or the errors of others in the system. Also, this can give them warning of impending alerts before they are actually triggered, potentially improving response (time and accuracy) if the alert cannot be avoided all together.

On the Use of Predicted Information

Fundamental to the usefulness of predicted information are accuracy and uncertainty. Predicting the location of an aircraft that is following a flight plan tens of minutes in the future can be quite accurate. Indeed, it might be predicted with nearly as much accuracy as knowledge of its current location. However, between now and that future time that aircraft can *potentially* make major or minor changes to its flight plan. It may have an emergency, or weather may not be as expected. This reduces the accuracy of predicted data.

Figure 2 is an illustration of the uncertainty of predicted data. The more that is known about the system the more accurate our predictions are expected to be. The more predictable the agents in the system are, the

more accurate predictions will be. Irregardless, the accuracy of predicted data will generally get worse farther into the future – eventually becoming useless for planning purposes at some point. Because one cannot know the accuracy of predicted data until the future becomes the present, one can instead estimate uncertainty in the predicted data. This is a measure of how accurate the data is expected to be. In a highly dynamic environment, the uncertainty can be very high. In figure 2, uncertainty is low for past and current data, and generally increases for future data.

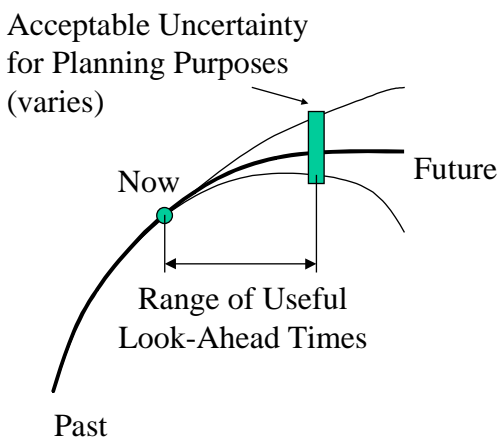


Figure 2. Accuracy of Predicted Data Generally Gets Worse Farther in the Future

With the concept of the predictive situation display presented here, where one selects a look-ahead time which can be adjusted between the current time (to see current data) to a future time (to see predicted data), we allow the flight crew to work at the time horizon that makes sense given the prevailing conditions. In the worst case situation, they would be working with data that is in the very near term, even current, because the situation has become highly dynamic and chaotic. In other conditions, they can plan far ahead, and then start looking for problems in the plan they and others have devised.

To give the flight crew some feedback about uncertainty, uncertainty estimates might

be displayed. Another possibility is limiting the look-ahead time. A third option is to rely on the trained human pilot, perhaps the best qualified element in the system to evaluate uncertainty.

Control of the Look-Ahead Time

Issues associated with the selection of the look-ahead (or look-behind) time used to generate the predictive situation displays are discussed in this section. Overall, it is proposed that the flight crew select the preview time per predictive situation display manually. In this way, an individual crew member can plan as far ahead as appropriate for managing their workload or as procedures dictate.

Look-Behind

The predictive situation display concept may lend itself to depicting recorded data from the past as well as predicted information about the future in a single seamless display. This would be useful, for example, to look at trends in recorded weather data.

Time Slew

The preview time can be run at faster or slower than real time when going through recorded or predicted data. This is recognized as a useful way to show trends in the information. This would be particularly useful with weather and possibly with other information sources as well.

Changes to Predicted Information

Periodically, there will be a change to predicted data that can potentially change the desired flight path. This must be depicted in some manner. However, this may be as simple as a message that the weather forecast has changed – giving the crew the indication that they should re-check their plans. If they are currently viewing predictions for an affected future time, then that change can be depicted on the display immediately (just as, say, a weather

radar changes in real-time on many current situation displays).

Depiction of Flight Plan Consequences

In this section, several display issues associated with the use of the predictive situation display for the evaluation of flight plans are discussed by information type. This discussion includes traffic separation, weather, airspace status, and terrain clearance.

Traffic Separation Information

Depicting the flight plans of other aircraft as lines and curves on a display is not adequate for the task of evaluating flight plans with regard to traffic separation. This is due to the time-dependence of trajectories. This is true no matter where a proposed set of flight plans originated, be it the aircrew, or an air traffic controller.

One desirable design element is to indicate on the display the location of a predicted separation problem area. The aircrew task, if they chose to develop a resolution themselves, would be to revise their flight plan to ensure that they do not enter the separation problem area at all, or at least enter it at a different time (arrive before or after other traffic). Such a display is depicted in Figure 3.

The second and complementing element that the aircrew would ideally have is a way to visualize their solution space, that is the types of changes that can be made to their flight profile to resolve the conflict. The preview concept used in concert with the separation problem zone is shown in Figure 4. In this case the preview time has been selected to be just before the separation problem is predicted to go into effect. Here, the aircrew can check to see if they can go above or below the other traffic; they might go left or right slightly -- but a conflict might still occur at a new time; or they could pull in behind or in-front-of the other traffic – perhaps the preferred option in this case.

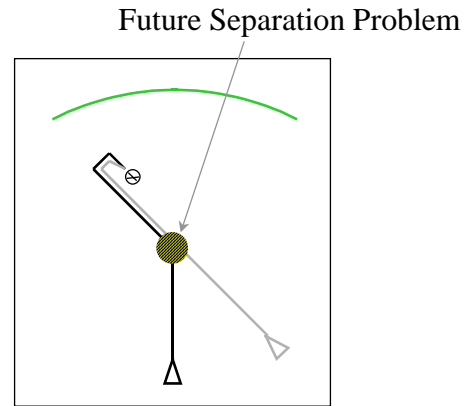


Figure 3. Traffic Conflict Information: Location of Conflicts are Depicted On a Notional Display, Enabling Aircrew to Visualize a Future Conflict

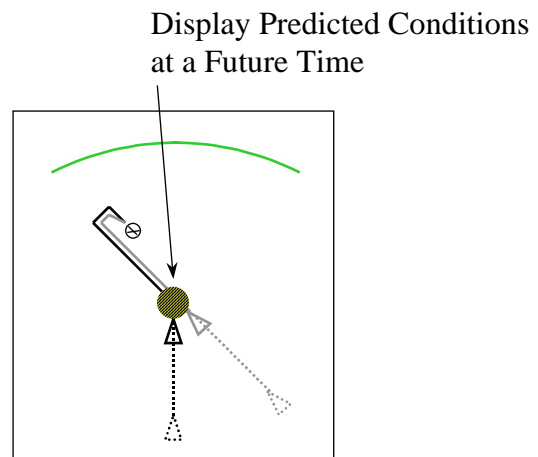


Figure 4. Traffic Conflict Information: Location of Conflicts are Depicted On a Notional Display, a Preview Time Selected Near Conflict Time

This raises the issue as to what flight plan the predicted data should be based on. For the purposes of evaluating options, it would be desirable to base predictions on other than the active flight plan, particularly for short-term or tactical decisions.

Weather Information

The depiction of on-board generated weather radar data and weather reports from various flight services and dispatch sources is

another primary driver of flight planning. Figure 5 depicts a notional weather situation display which combines on-board derived weather information and weather reports on a single display. The on-board derived data may be from a radar, the off-board data may be from a ground-based radar. Pilot reports and other information might also be depicted graphically when available.

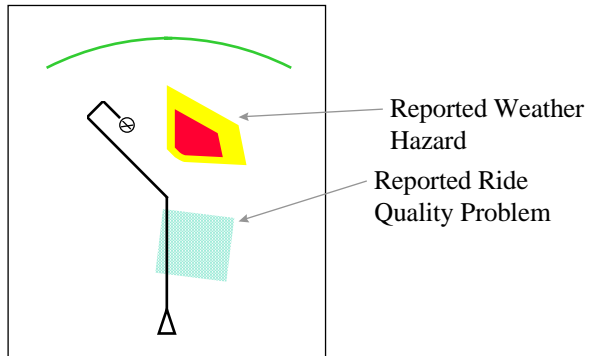


Figure 5. Nominal Weather Information: Weather Radar Data and Weather Reports Depicted

However, the aircrew would also like to be able to evaluate flight profiles (including go/no-go and divert decisions) based on weather forecasts. The preview concept can potentially be used to seamlessly switch between reports and forecasts. This is illustrated in Figure 6. Here, the display preview time has been moved into the future, and weather forecasts are depicted on the displays.

As discussed earlier, the flight crew might also like to see recorded weather information over the last few hours to see trends. This is recognized as a good reason to allow the predictive situation display to also be a recorded situation display depending on the look-ahead/look-behind time selected.

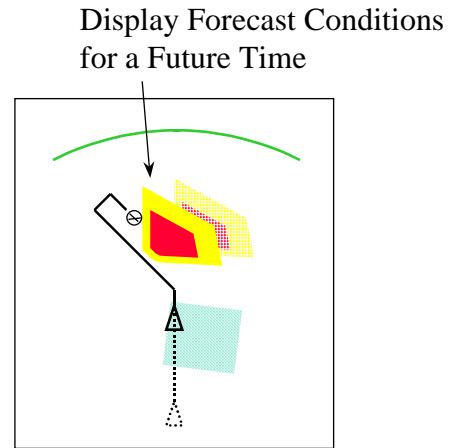


Figure 6. Weather Forecast Information: When Displaying Situation for a Future Time, Weather is Based on Forecasts Rather Than Weather Radar or Weather Reports

Airspace Status

The depiction of airspace status, both in terms of geometry and in terms of schedule, is similar to the problem of depicting certain types of weather information. Effectively, an area of known thunderstorms is a moving/evolving restricted airspace.

For example, a Military Operations Area could be shown as active for the scheduled time interval. A conflict alert similar to that used for aircraft traffic conflicts might also be depicted if the predicted aircraft path will conflict with the restricted airspace during a scheduled time.

It is worth noting that this concept might be expanded into a practical way to do air traffic control, where aircraft are assigned time-dependant airspace.

Terrain Clearance

A terrain database is recognized as an effective information source for evaluating flight plans with regard to terrain clearance. Automatically generated flight profiles can be generated with terrain clearance. Aircrew modified flight plans can be evaluated with regard to terrain clearance by automation. In

any case, the final active flight plan can be depicted against the terrain database to the aircrew so that they might alter it based on more or less conservative criteria as appropriate.

Altitude vs. Time Display Format Concept

In order to visualize future traffic conflicts and hazards in three dimensions, some method of depicting four-dimensional data on two-dimensional displays needs to be employed. Perspective displays conformal to the external view from the aircraft may have an advantage during a very-near-term tactical situation, but some other vantage-point is required for mid- or long-term situations.

One concept that lends itself to this function is to complement conventional horizontal situation displays with an altitude vs. time display. This is similar to a profile display (showing altitude vs. down-range distance, or altitude vs. distance ahead of the aircraft along its heading or track). Figure 7 shows a notional version of such a display on the right, along with a notional horizontal situation display on the left. Common symbology can be used between the displays.

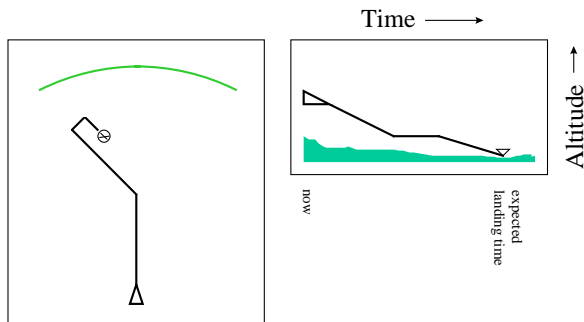


Figure 7. Altitude vs. Time Display Complementing a Notional Horizontal Situation Display

The altitude vs. time display can be used to depict terrain in much the same way as a profile display; that is, the terrain height of the area that the ownship is predicted to be over at a

future time can be shown on the display. A required time of arrival, an element of a 4-D clearance that some have proposed, or a runway-use time slot can potentially be easily visualized since time is an axis on the display.

The use of these displays as predictive situation displays is shown in Figure 8. Here, the look-ahead time is shown graphically on the altitude vs. time display.

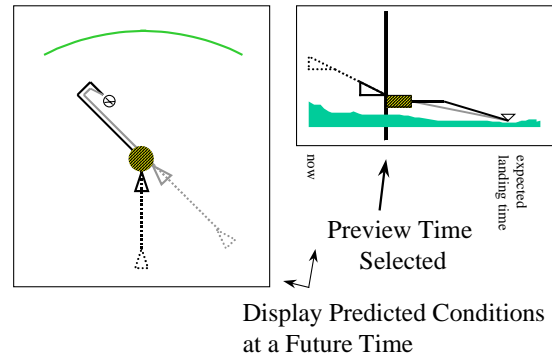


Figure 8. Notional Horizontal and Altitude vs. Time Predictive Situation Displays

In a conventional profile display where down-range distance is shown on the horizontal axis rather than time, angles of the flight path on the display are proportional to predicted aircraft flight path angle. In this altitude vs. time display, angles of the flight path on the display are proportional to predicted aircraft vertical speed.

Relationship to Farther-Term Advanced Interface Technologies

The concepts presented in this paper coupled with some more imaginative interface technologies being explored by researchers, yields some exciting potential applications. One approach would be to apply Three Dimensional (3D) display techniques. The hardware requirements of such a system could be limited to a head tracker, which would be used in conjunction with a conventional display to provide feedback on the viewpoint of the observer. The system would maintain the

image in an apparent fixed location in space and movement of the head would create a parallax shift between objects in the display.

Juxtaposition, or the eclipsing of one object by another, is a powerful visual cue in developing a perception of depth. The parallax feature would allow the operator to selectively optimize his vantage to observe either juxtaposition or relative distance. Stereo optic cues could be added to complement the parallax by use of shutter glasses that switch in phase with the display to ensure that each eye sees the displayed scene from its own perspective.

Another means by which a pilot could develop a future path for the aircraft would be to allow him to fly the aircraft in the future (predicted) world. In this scenario the pilot would require not only a 3D strategic display, as was described previously, but he would also require a tactical display with sufficient field of view to allow navigation of hazards. The Head Mounted Display (HMD) is an example of such a display since it has both the excellent field of view and the capability of full or partial stereo field overlap. To generate a path with this system, the pilot could actually fly in a future world in standard, accelerated, or decelerated time depending on the complexity of the task and the time available to develop the new path. There would be advantages of such a system for a stealthy aircraft negotiating rough terrain in hostile territory while avoiding fixed and moving threats and remaining cognizant of ownship radar vulnerabilities. In a commercial application, free flight may include similarly complex tasks that might benefit from such an approach.

Summary and Future Work

A concept for expanding upon the notion of a situation display to seamlessly include recorded past and predicted future situation information was presented. It was motivated by advances in airborne processing capabilities and datalink communications. It was arrived at as a

way to apply these technologies to improve the ability of flight crews to evaluate decisions and manage workload. Several design issues associated with such a concept were discussed, including:

- Methods for Dealing with the accuracy and uncertainty of predicted information
- Selection and control of look-ahead/look-behind times
- Ways of depicting several specific types of information.

A low-fidelity simulator is planned to be utilized to accomplish an initial evaluation of this concept. Ongoing work includes a prototype of the predictive situation display with traffic and weather information. Techniques for look-ahead time control and handling large changes to predicted data are among the first to be examined. In addition, the implications of giving flight crews access to predicted data will be examined. Among these, better workload management, reduced error rate, and improved response to alerting systems are hypothesized.