# Conflict Probe Operational Evaluation and Benefits Assessment

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## Abstract

Air traffic controllers currently rely on structured routes and traffic organization for managing separation problems. However, even in today's structured air traffic control environment, human limitations in the rate and accuracy with which they can extrapolate aircraft positions can result in late or unnecessary ATC interventions to resolve conflicts. To meet the additional demands that will be placed on controllers operating in the unstructured routing environment introduced as part of Free Flight, the FAA and the MITRE Center for Advanced Aviation System Development (CAASD) have been researching and developing a strategic conflict probe capability for the en route controller team called the User Request Evaluation Tool (URET).

This paper presents results from (a) recent field evaluations of URET, (b) analysis activities using real traffic scenarios from Indianapolis Center, and (c) a controller-in-the-loop simulation study of the URET being used in a traffic environment with reduced structure relative to current practice. The paper analyzes these results to describe how Conflict Probe can help reduce the restrictions that are imposed on flights.


## Introduction

URET is a set of decision support tools designed to help controllers detect and resolve conflicts. URET uses data from the en route Host computer system (HCS) to model 4-D trajectories for all aircraft with flight plans. Trajectories are updated from radar position reports and flight plan amendments. A conflict probe function carries out continuous, automatic conflict detection and alerts the appropriate controller when a conflict is found. URET also provides a trial planning capability which allows the controller to specify a trial flight plan modification and determine whether the trial plan creates another conflict. URET has a number of other features that are described at the Uniform Resource Locator (URL): http://www.caasd.org.

The URET prototype was deployed to the Indianapolis Air Route Traffic Control Center for field trials in January 1996. Since then, several versions of the URET software have been delivered to the Indianapolis and Memphis centers and tested in live operations at selected sectors. The purpose of these field evaluations is to (1) validate the operational concept for use of the tools in a real world context, and (2) define the initial set of acceptable and beneficial decision support tools for implementation. A previous paper (Brudnicki and McFarland, 1997) discussed results of the first set of Indianapolis field evaluations. This paper presents highlights of recent field developments at Indianapolis and Memphis centers, including results of controller evaluations that contributed to the definition and enhancement of new URET capabilities.

Field evaluations and daily use of the URET prototype have made invaluable contributions to the successful introduction of conflict detection and trial planning resolution tools into the current operational environment. In the past year, complementary research strategies have been applied to extend these results and investigate potential benefits of conflict detection and resolution tools in the evolving Free Flight environment. The Free Flight Concept of NAS operations bases future system improvements on the removal of procedural restrictions enabled by implementation of new air traffic control and flight technologies (RTCA, 1995). In the Free Flight Phase 1 (FFP1) Implementation Program (RTCA,1998) a limited deployment of the core capabilities of several decision support systems (including URET) will be evaluated at a number of operational sites. The FAA and CAASD plan to upgrade the daily use URET prototype to the FFP1 level of capability by early 1999. The FFP1 version of URET is expected to be in place and provide measurable benefits by the end of 2002. This paper presents two studies that address the relationship between URET capabilities, current system restrictions, and operational benefits.

The paper begins with a review of the operational field evaluations and the status of the URET system. Next, a prospective analysis of URET benefits derrived from characteristics of current real traffic situations is presented. This is followed by a discussion of a controller-in-the-loop simulation study. The study provides empirical evidence of benefits associated with the use of URET capabilities in the current and emerging unstructured traffic environments.

## URET Field Evaluation

URET capabilities are being developed and deployed through a collaborative effort between operational personnel and a development team that includes human factors and software specialists. Two separate URET systems are in place at each of the two centers. The evaluation system is used to support URET controller training and the field evalutions. The daily use system is used solely to support daily use of URET at operational sectors. After a new version of URET has undergone one or two field evaluations, and any revisions found to be needed have been incorporated, the new delivery is placed in daily use. Daily use operation of URET began in October, 1997 at Indianapolis Center and in November, 1997 at Memphis Center. As of 2 October 1998, a total of 477 controllers have received URET training and the system has accumulated 17,207 hours of daily use operation at the Indianapolis and Memphis centers.

Structured field evaluations are conducted to assess new capabilities. The field evaluations typically consist of a short briefing to controllers describing the new features in the latest delivery; an opportunity for controllers to exercise the features in an off-line session; use of the new software at operational sectors; and discussion leading to consensus answers to prepared questions.

In addition to structured evaluations, CAASD conducts performance analyses of URET and a discrepancy reporting system tracks operational concerns submitted by controllers in response to daily use of the tools in live operations.

## *New Capabilities*

Over the past year, two major additional URET capabilities have been evaluated: (1) coordination of trial plans between sectors and (2) interfacility capabilities.

### Trial Plan Sector-to-Sector Coordination

URET alerts controllers to conflicts earlier than controllers typically take action to solve conflicts today. This provides an opportunity for controllers to take action earlier and operate their sectors in a more strategic way. A consequence is that a controller may be notified of a conflict that will occur in his sector at a future time, but his sector does not currently control one or both of the aircraft. The sector-to-sector coordination capability allows the controller to generate a trial plan with the desired resolution, and with one click of the mouse send that trial plan to the sector currently controlling the aircraft. The receiving sector can graphically display the trial plan and respond with an approval or a rejection. If the response is approval, the receiving sector is then responsible for voicing the conflict resolution clearance to the aircraft.

Controller feedback collected in the field evaluation indicates that the user interface functions for the sector-to-sector coordination capability were acceptable and that this capability was operationally beneficial. In later evaluations with interfacility capability, the ability to use sector-to-sector coordination with a sector in another center was especially beneficial. Today there is only one direct voice line between Indianapolis and Memphis centers and controllers will sometimes find the line in use when they need to coordinate. With URET coordination, there is no delay. However, the evaluations also highlighted procedural questions associated with the use of sector-to-sector URET coordination. As a result, operational use of this tool has been temporarily suspended pending definition of appropriate procedures and more widespread and regular use of URET.

### Interfacility Capability

A conflict probe system must contain an interfacility coordination capability to be viable as a deployed, nationwide system. To gather knowledge to support the development of such a deployed system, CAASD developed an interfacility coordination capability and incorporated it into the URET field evaluation systems at Indianapolis and Memphis centers. Several field evaluations were conducted to confirm the technical and operational suitability of the design.

In the URET interfacility design, an outer boundary is drawn a sufficient distance outside the actual center boundary to ensure that all aircraft-to-aircraft conflicts will be detected. (In the URET design, this distance is 200 nmi and the outer boundary is called the Automated Problem Detection (APD) boundary.) When the Indianapolis URET adaptation data is prepared, it is augmented with all of the Memphis adaptation data that falls within the Indianapolis APD boundary. The same is done when the Memphis adaptation data is prepared.

The URET systems at Indianapolis and Memphis centers have been provided with direct two-way digital communications using the FAA’s operational National Airspace Data Interchange Network (NADIN II). During operation with the interfacility capability, the two URET systems exchange data routinely to ensure that each system has the same trajectory for each aircraft within the area covered by their APD boundaries. URET logic is provided to ensure that any conflict detected near the center boundary will always be notified to at least one sector in one of the centers. The goal of the URET interfacility design was to provide a seamless operation at the center boundary that allows the controller to observe traffic and operate across center boundaries in the same way as across internal sector boundaries. Thus, the controller can carry out sector-to-sector coordination with a sector in an adjacent center.

Field evaluations showed the interfacility design to be technically satisfactory. Communications delivery times were short, the interfacility communications were dependable, interfacility data traffic loads were modest, and the additional loads placed on the URET computers by processing additional traffic from the adjacent center were minor.

Operational evaluations with controllers confirmed that the interfacility design is operationally acceptable and that the operation across center boundaries is seamless. Controllers indicated that their awareness of traffic in the other center's airspace was much improved. They particularly appreciated the fact that they received earlier notice of inbound traffic and had earlier awareness of problems it might create in their sectors.

Based on the success of the field evaluations, and the value provided by the interfacility capability, the center staff chose to activate this capability in the URET daily use systems, and it is now used on a daily basis.

## *Additional Analyses*

Over the past year, two notable analyses have been conducted: (1) an analysis of probable effect of URET on past operational errors, and (2) an analysis of data collected on cases of potential missed conflict detections.

### Analysis of Probable Effect of URET on Past Operational Errors

Managers at the two centers were interested in assessing the impact that URET could have on some of their operational errors. An operational error is an event where two aircraft under positive control come closer together than the required separation standard (5 nmi and 1,000 or 2,000 ft for en route radar control) because of an error on the part of the ATC system. The managers provided data about eight recent operational errors and CAASD staff replayed URET on those scenarios and analyzed the results. The way in which the operational errors developed fell into two categories. In the first, the two aircraft were on conflicting flight paths for some time before the separation standard was violated. There were five errors in the category, and in all five cases, URET generated alerts with more than adequate time for controllers to take action to avoid the operational error. In the other three cases, the operational errors came about as an immediate consequence of an ill-advised clearance to an aircraft. In these cases, the URET conflict probe did not and could not generate an alert in time to prevent the operational error. However, if the controller had executed a URET trial plan on each of these three clearances before issuing them to the pilot, the trial plan results would have shown the conflicts. This analysis is ongoing, but the results to date provide a strong indication that URET could help avoid many of the operational errors that occur today.

### Missed Detection Analysis

CAASD analysts built several computer programs to help assess the likelihood that URET would fail to detect real aircraft-to-aircraft conflicts. The programs work on recordings of live traffic made simultaneously at Indianapolis and Memphis Centers. They identify a small number of potential missed detections that are then analyzed by hand. Missed detections occurring internal to a center, as well as those occurring at center boundaries because of erroneous coordination between the two URET systems, are detected. So far, the analysis has been carried out on 19 hours of interfacility operation (equivalent to 38 center hours) and continues to be conducted on new scenarios as part of URET testing. This analysis found several missed detections that were caused by a software error in the URET interfacility coordination logic. That error was corrected and no further evidence of missed detections was found in the 38 center hours of operation.

Controllers are encouraged to submit discrepancy reports (DRs) documenting any problems noted with URET during daily use. Some of these DRs indicate that the controllers did not receive an alert from URET when expected. Each DR of this type is investigated to determine if URET missed detecting a conflict. Results indicate that the most common explanation for these DRs is that URET did in fact detect the conflict, but notified a sector other than the one at which the controller who wrote the DR was working. So far, none of the missed detection DRs represented an actual URET missed detection.

## Insights into URET Benefits from Current Real Traffic Situations

Several real Indianapolis center traffic situations are presented to illustrate how URET can help controllers deal with current challenging situations. The discussion is made with reference to the various types of restrictions that are used to help controllers handle today's traffic.

Those restrictions are described in Brudnicki and McFarland (1997) and are listed below:

- Preferred Instrument Flight Rules (IFR) High and Low Altitude Routes
- Standard Instrument Departures, Standard Arrival Routes, Preferred Departure Routes (PDRs), and Preferred Arrival Routes (PARs)
- Miles-in-Trail (MIT) Restrictions
- Altitude Restrictions
- Altitude for Direction Rules

Figure 1 shows a snapshot of Indianapolis center traffic at the time of a busy Cincinnati arrival rush. Individual aircraft are indicated by a heavy dot, and each of the 50 aircraft shown is landing at Cincinnati. All but two of the aircraft are either Delta or Comair flights. There are many more flights being handled by Indianapolis center at this time, but those not landing at Cincinnati are not shown. The trajectory that URET has for each aircraft is displayed. Since URET models aircraft flying the PARs, this figure essentially shows a map of all of the PARs to Cincinnati. Note how these arrival routes form a tree structure that produces successive merging of flows of aircraft. Sector boundaries are drawn with respect to these routes. Individual sectors have specific tasks to merge certain of these flows. Many of the altitude restrictions in Indianapolis center are in place to ensure that aircraft are down into the appropriate altitude stratum for the sector that will have to merge these aircraft into a single stream. During busy arrival periods, miles-in-trail restrictions for successive flights in the output stream will be imposed on many of these sectors. In general, the number of miles separation required is smaller for sectors closer to the airport. Preferred IFR High and Low Altitude routes are applied to cause aircraft to arrive at designated transition fixes so as to disperse the traffic across a number of PARs.

Air traffic managers use these types of restrictions (Preferred IFR High and Low altitude routes, PARs, PDRs, altitude restrictions, and MIT restrictions) to pre-plan how the controllers will handle a busy arrival rush, and to distribute the workload of merging these aircraft into two streams for landing on the two runways. The FAA conducts occasional reviews of these restrictions in an effort to eliminate unnecessary ones, but without the help of automation aids, it has proven difficult to substantially reduce them. Note in Figure 1 that much of the activity in beginning to merge and space the Cincinnati arrivals takes place in other centers, especially Cleveland Center to the north.

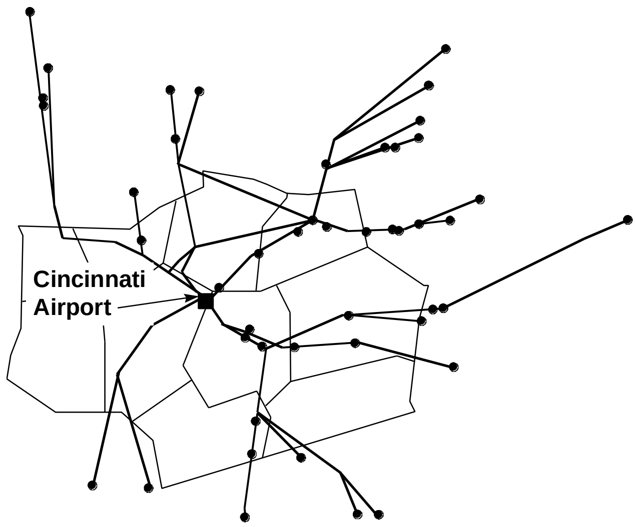


**Figure 1. Snapshot of Cincinnati Arrivals**

Figure 2 shows actions the sector controller in Indianapolis Sector 87 took to merge and space two aircraft that entered his sector in different streams during a heavy Cincinnati arrival period. Other traffic being handled by the sector at this time is not shown. It was apparent to the controller that the two aircraft were going to reach the BOWRR merge point at nearly the same time and then follow the same route to the airport. So he provided altitude separation temporarily and issued a 90-degree left turn and a subsequent turn back to DAL573. The in-trail separation that would have existed without this maneuver was estimated to be 3 nm; after the maneuver the aircraft were 13 nmi in trail. Carrying out this maneuver can be challenging when the controller has a number of other conflicts to tend to. It is compounded by the fact that he needs to return his attention to this aircraft and issue the turn-back instruction at the appropriate time, or he will have achieved too much or too little separation. Observe that the controller in this sector has a relatively small amount of airspace in which to carry out such maneuvers.

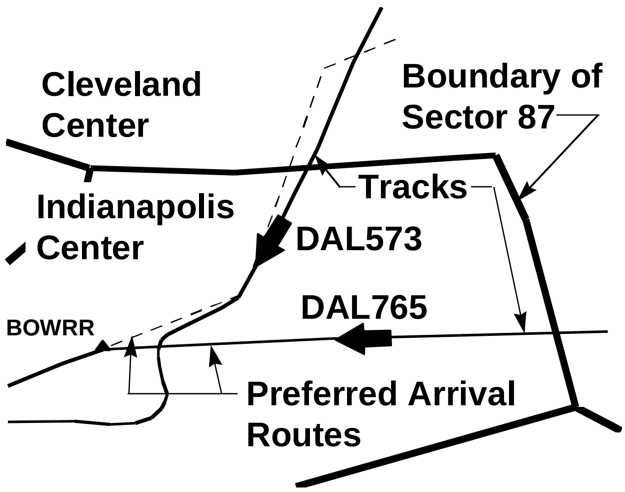


**Figure 2. A 90 Degree Turn for Spacing**

These aircraft have been handed off to Sector 87 from two different sectors in Cleveland Center. Typically, MIT restrictions are in effect for each of these sectors. Even if those two sectors achieve their individual in-trail separations there is no guarantee that the two aircraft will not arrive at BOWRR at nearly the same time. This is characteristic of the miles-in-trail approach to handling spacing during heavy arrival periods - actions are taken independently within each sector. There is little coordination across sectors that might permit spacing with less extreme maneuvers than the 90-degree turn used here. These two aircraft will be descended from cruise altitude (both of the Cleveland sectors have altitude restrictions for Cincinnati arrivals at the center boundary) and maneuvered to achieve the arrival merging and spacing by a total of 5 different sectors - one in Cleveland center, Sector 87, Indianapolis low Sector 23, and two sectors in the Terminal Radar Approach Control. Each of these sectors has a rather small amount of airspace in which controllers can carry out their maneuvers.

The controllers' work in Sector 87 would be simplified if they could deal just with merging and spacing the Cincinnati arrivals. However, this sector has no airspace that is dedicated to handling only arrivals. Figure 3 shows the traffic in Sector 87 from a URET display during a moderately busy Cincinnati arrival period. Sector 87 is handling traffic for Detroit, Washington, Chicago, and Philadelphia, as well as the US Airways departures from Pittsburgh bound for airports to the west. These flights are at the same altitudes as the Cincinnati arrivals and cause frequent conflicts with each other and the Cincinnati arrivals. Each aircraft is shown with the destination airport and the number of red and yellow conflicts that aircraft has with other aircraft. There are times when Sector 87 must handle simultaneous hub arrivals at Cincinnati and at Pittsburgh, and it is possible that the sector may need to meet MIT restrictions for westbound traffic to Cincinnati at the same time as applying MIT restrictions for eastbound traffic to Pittsburgh. A very high proportion of the traffic in this sector is climbing or descending.

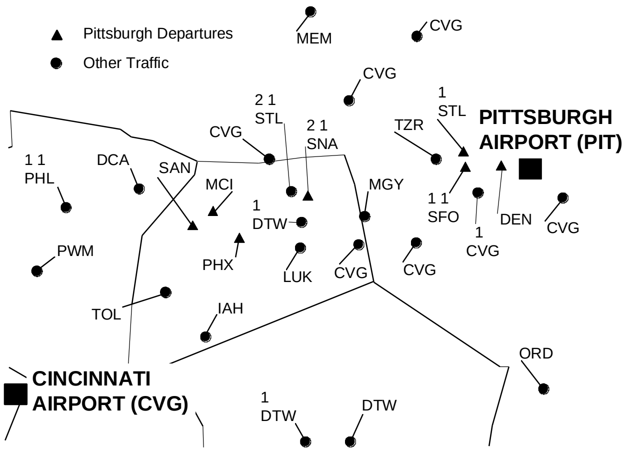


**Figure 3. Sector 87 Traffic from CVG and PIT**

Figure 4 shows the actual path of DAL1616, a flight arriving at Cincinnati from the south during a busy arrival period. Until the turn to an eastbound heading the flight was at FL 240. The PAR is also shown. Note that the PAR, itself, causes the aircraft to fly a longer path to the airport than if it were allowed to proceed direct. But the actual path of the aircraft is longer yet because of the vectoring to achieve merging and spacing. This is a general observation. URET, in conjunction with other automation, can help controllers provide more direct routes to the airport for users and reduce the amount of additional path stretching needed for merging and spacing. Strategic conflict detection and automated coordination provide advance notice of conflicts and allow the merging and spacing operation to be distributed across sector boundaries. Observe in Figure 4 that the controller used the entire airspace in his sector to achieve merging of this aircraft.

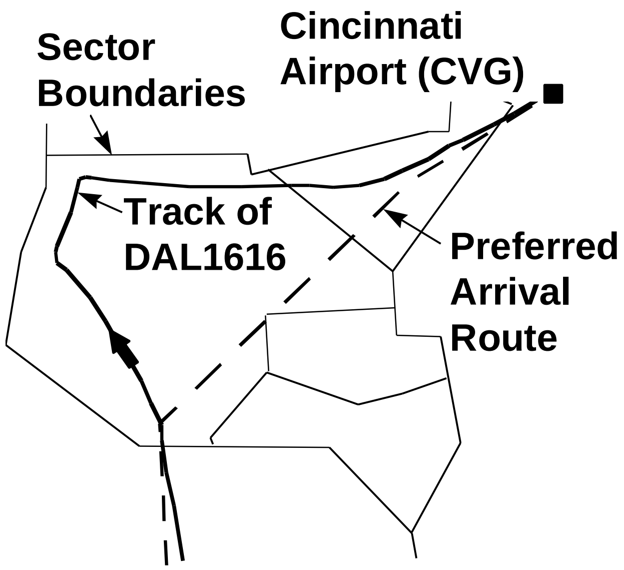


**Figure 4. Extensive Vectoring for Merging**

Figure 5 shows the arrival traffic the controllers were handling at the time they were working DAL1616. The controller eventually placed DAL1616 in the eastbound arrival stream behind COM817. Other non-arrival traffic in this sector at the time is not shown.

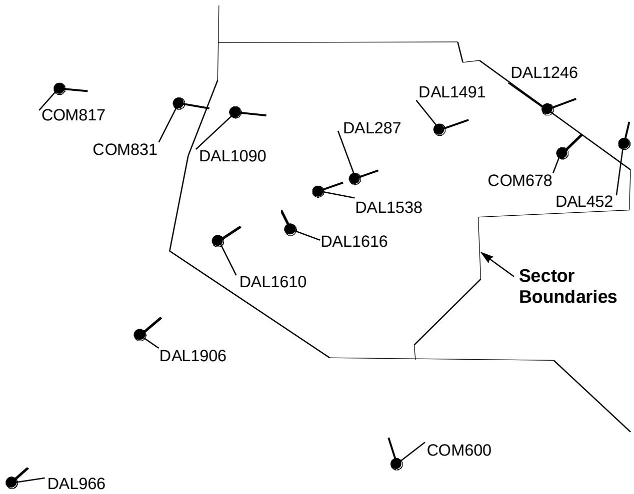


**Figure 5. Conflicting Arrival Traffic**

The preceding figures show how tactical the current control of traffic is and the degree to which merging and spacing is accomplished independently within each of the sectors that handle aircraft on arrival. Another indication of the workload of controllers and the degree to which operations are tactical is the number of times the controller asks pilots for specified performance in their clearance. Although these types of clearances are not used routinely, an analysis of controller communications in Sector 87 during a busy arrival period uncovered the following five such requests within a 30-minute interval:

- USA183, climb and maintain FL330, no delay through FL290
- USA800, descend and maintain FL240, maintain at least 2000 fpm or greater through FL280 for traffic
- USA96, descend and maintain FL190, maintain max descent rate to FL190
- DAL1415, expedite descent through FL290 for traffic
- DAL1521, decrease speed by 70 knots

It is believed that URET, operating in conjunction with other automation support can help convert air traffic control operation from the current highly tactical operation with little cross-sector coordination for merging and spacing, to one where conflicts are detected and resolved earlier with the help of sector-to-sector coordination aids, and merging and spacing is done in a coordinated way across sectors. Eliminating some altitude restrictions is one way in which such aids could help provide user benefits. Many of those altitude restrictions, in place to ensure that flights are down into the altitude stratum for a sector that needs to merge two streams, would no longer be needed. With the coordination aids, the controller could effect the necessary maneuvers to space aircraft or solve future conflicts in his sector without having the aircraft on his frequency and in his sector. Brudnicki and McFarland (1997) provide more rationale for how the automation tools can help reduce restrictions and achieve benefits.

## Controller-in-the-Loop Experiment

Although the URET results to date indicate that the conflict probe will benefit current controller operations, less is known about the benefits of strategic conflict advisories and conflict resolution tools in the context of an unstructured, free routing traffic environment. Years of earlier research conducted under the Automated En Route ATC (AERA) program indicated that conflict detection and trial planning tools would allow controllers to accommodate more user preferred routes but the earlier research was not designed to measure and quantify benefits associated with the specific capabilities embodied in the URET. In contrast to the AERA research which assumed equivalent decision support capabilities at the R and D controller positions, the URET capabilities have been adapted for use primarily by the D controller.

In January of 1998, a study was conducted in the dynamic simulation (DYSIM) facility at Indianapolis Center and using the URET capability. The primary objectives of this study were to (1) determine whether a conflict probe capability can yield more efficient flight paths within acceptable safety and workload limits and (2) determine whether these effects generalize across current traffic and emerging free flight conditions. Since the URET capability also reflects important concepts about how to manage traffic complexity and controller workload, a third objective of the study was to analyze controller performance impacts of the conflict probe capability.

Two important conflict probe functions, which are planned for the URET FFP1 implementation, were not available in the URET at the time of this study. These were (1) a two-way interface to the HCS that will allow the controller to transfer a trial plan to the HCS without reentering the data and (2) an automated coordination capability that will allow the controller to transfer trial plans to surrounding sectors for approval and implementation without voice communication.

## Approach

The controller-in-the-loop simulation study used an experimental design to control for the effects of as many extraneous variables as was possible and isolate the effects of two independent variables, the conflict probe capability and traffic conditions, on flight efficiency and controller performance. Structured traffic scenarios were built from samples of recorded traffic in the Indianapolis airspace with matched samples of unstructured traffic created by assigning the same flights to direct routes. High volume unstructured scenarios were created by adding flights to the direct route samples in order to examine performance with greater levels of air traffic. Data were collected under high fidelity simulation conditions with URET-trained, airspace-qualified controllers and comparing performance with and without the conflict probe. Multiple dependent measures, shown in previous research to be sensitive to changes in ATC automation and the traffic environment, were used to assess the effects of the independent variables.

The equipment and configuration at the experimental sector in the DYSIM laboratory was identical to the operational en route control area and included a URET workstation which was slid back into the console when it was not in use. In the DYSIM mode, the HCS read data from a scenario tape to generate simulated radar targets and to allow the simulator operator position to fly the aircraft using keyboard entries to input instructions received via voice communications. Three former controllers staffed the simulator operator position. The HCS was used to collect data on aircraft position, time, and event variables. On all test runs, the URET system was used to collect data on predicted aircraft conflicts, distance and time flown, and controller interactions with the conflict probe capabilities.

Twelve full performance level controllers participated in six teams. Participation was limited to controllers who were qualified to work the simulated airspace, Indianapolis Falmouth High Sector 83, and trained in the use of the URET capabilities. Participants' URET experience was lower than expected but representative of a facility where the capability had just been implemented.

The experiment used a within subjects design. Both independent variables—automated conflict probe and traffic condition—were manipulated within subjects. The conflict probe variable was defined by two levels—on or off. Traffic condition was defined by three levels—baseline structured traffic, unstructured traffic, and high volume unstructured traffic. Combining these two independent variables resulted in six test conditions.

An operational expert from the facility accompanied each of the teams and served as a supervisor. Participants were asked to think aloud while working the test scenarios and report any conflict situations that would require control actions, as soon as they recognized them. After each 30-minute traffic simulation run, controllers rated the perceived workload and operational acceptability of the run. Supervisors rated the controller team's performance and assessed the overall safety of the run. Two observers recorded the R and D controller conflict reports.

## Results and Discussion

Inferential statistical procedures were used to analyze the study data. The discussion of the results in this section uses the term significant to refer to the results of formal tests of statistical significance.

## Safety and Acceptability

It can be argued that any improvements in flight efficiency as a result of new procedures or decision aids have the possibility of being safety compromising. This study found no evidence of safety problems under any of the test conditions. No separation violations occurred under any of the test conditions. Supervisors' operational safety assessments indicated that ATC performance was typical and acceptable or higher than normal for the sector on all simulation runs. Although not significant, conflict probe tended to be associated with higher safety ratings under all traffic conditions.

Operational acceptability was assessed to determine how well the joint controller-automation system performed in the context of the traffic conditions. The Controller Acceptability Rating Scale (CARS) was used as an overall measure of the joint controller-automation system performance (Lee & Davis, 1995). Using CARS, the controller assigns a numeric rating indicating the degree of problems or deficiencies experienced in the simulation. The results indicated that conflict probe significantly improved the operational acceptability of the unstructured traffic conditions. However, this effect was observed only for the D controller, the primary URET user (see Figure 6). As shown in Figure 7, the R controller ratings revealed that conflict probe reduced operational acceptability under structured traffic conditions. Comparing the trendlines for R controllers across traffic conditions indicates that the gap between the acceptability ratings with and without conflict probe under the structured condition was reduced and then eliminated in the unstructured and high volume unstructured conditions, respectively. Observations and controller feedback during the simulation suggest that this pattern of results may reflect a problem of reduced R controller access to flight data when the conflict probe was in use.

During the conflict probe test conditions, when D controller used the graphic display to analyze conflicts, it covered the aircraft list, concealing the flight data. This caused the R controller to invoke the flight plan readout function in order to obtain the flight data. Because the aircraft routes were more complex and they were expected to use standard procedural routings, R controllers needed to refer to flight plan data more in the structured traffic conditions and this may account for the reduced acceptability. A study is currently being planned to address the integration of the URET display and control capabilities with the new Display System Replacement controller console and allow the R controller unconstrained access flight data in the Free Flight Phase 1 implementation.

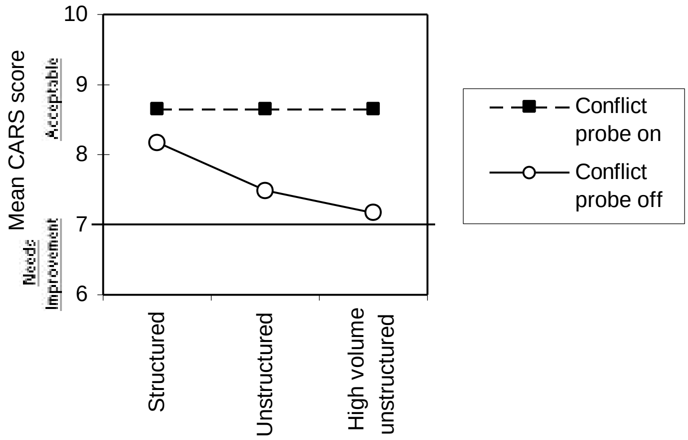


**Figure 6. D Controller CARS Scores**

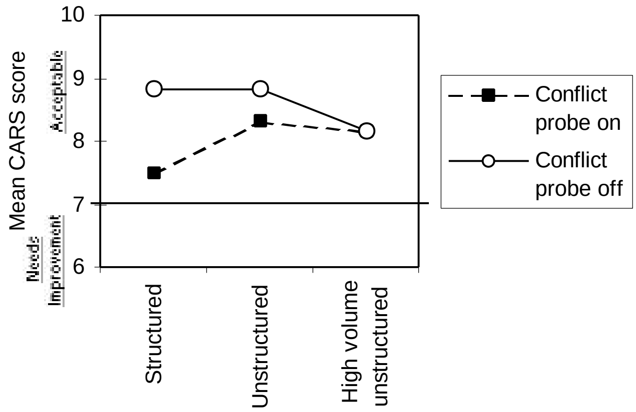


**Figure 7. R Controller CARS Scores**

## Controller Workload

Subjective mental workload was assessed using the NASA Task Load Index (TLX). Delays in handoff acceptance were used as an objective measure of R controller load shedding with longer handoff acceptance latencies indicating higher workload (Tofukuji, 1993).

Overall TLX scores were analyzed separately for R and D controllers (see Figure 8). In general, TLX scores indicate that light to moderates workloads were experienced under all test conditions. The statistical analyses confirmed that traffic conditions had a significant effect on R and D controller mental workload. Although not significant, conflict probe by traffic condition interaction trends suggest that workload decreased under the high volume unstructured traffic condition with conflict probe, particularly for the D controller, whereas under structured traffic conditions, conflict probe was associated with increased workload, particularly for the R controller. This increase in R controller workload ratings under the structured traffic condition with conflict probe may be another indicator of a problem with flight data access in the current URET configuration.

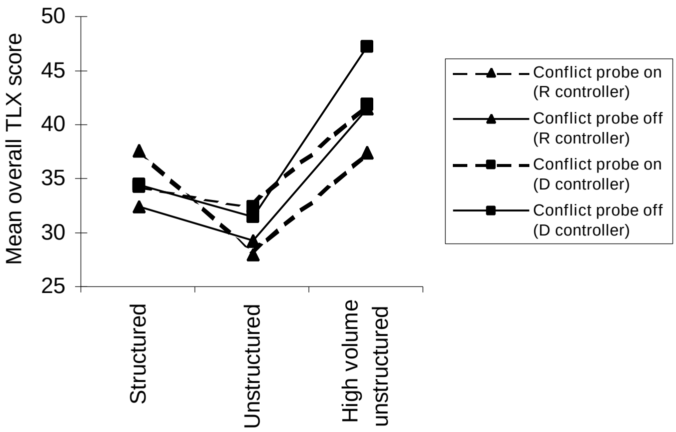


**Figure 8. Mean TLX Subjective Workload for R and D Controllers**

In the unstructured condition, R controllers did not have to issue clearances associated with procedural routings. Clearly, this reduced R controller workload relative to the structured traffic condition. Increasing the traffic load in the high volume unstructured condition tended to offset the workload reduction from eliminating the restrictions and brought the subjective workload level back up to the level in the structured traffic condition. In contrast, D controllers experienced a significantly higher workload in the high volume unstructured condition compared to the structured and unstructured conditions.

The analysis of handoff acceptance latency revealed a marginally significant effect for traffic condition. Handoff latency (and controller workload) increased from the structured condition to the unstructured condition and increased again from the unstructured to the high volume unstructured condition. These data also suggest a conflict probe by traffic condition interaction. Although not significant, the trend indicates that workload decreased with conflict probe in the unstructured and high volume unstructured conditions whereas workload increased with conflict probe in the structured condition. Again, this increase may be indicative of a flight data access problem.

## Flight Efficiency

By far, the most important cost savings associated with unstructured routings are realized when the user's preferred route is filed and accepted by the ATC system. However, there is also a collateral in-flight benefit, especially for air carrier aircraft, when ATC interventions are minimized and the predictability of the flight schedule is maintained. Therefore, for this study, efficiency improvements resulting from conflict probe were hypothesized to depend on (1) the ability of the controllers to manage the unstructured traffic, and (2) the efficiency of the resolutions generated by the controllers. The analysis of conflict resolution efficiency further assumed that the aircraft's flight plan reflects the user's preference and that any deviation from that plan reduced the user's operational efficiency.

Study data relative to the first hypothesis were discussed in the previous section and show that controllers were able to manage low to moderate levels of unstructured traffic, even without conflict probe. However, the results are also consistent with an improved margin of safety and acceptability when conflict probe was available in the unstructured traffic environment. The analysis discussed in this section focuses the second hypothesis, the efficiency of conflict resolutions.

This study found limited evidence that conflict resolutions were more efficient with conflict probe. However, because of study limitations, it was not possible to associate quantitative estimates of airspace user benefits with the potentially more efficient resolution strategies. A measurement problem was encountered in the analysis of time flown. A random parameter used in the DYSIM to model flight profiles precluded accurate and repeatable measurements of total (origin/destination) time flown. The analysis of distance flown revealed that the effects of horizontal maneuvers were only evident in the structured traffic condition. Although not significant, the distance data indicate that the magnitude of the deviation due to conflict resolution under structured traffic conditions was slightly smaller with the conflict probe. Study results on the number of maneuvers issued per aircraft suggested a reduced rate of maneuvers with conflict probe, although the effect of conflict probe was not significant.

In sum, the statistical analysis of flight efficiency produced inconclusive results. The study measurement strategy appears sound. Based on previous research (McNally, Bach & Chan, 1998; Whitaker, Marsh & Shroter, 1997) which points out limitations of using a measure of losses or gains in time or distance through a sector to estimate the effects of decision support tools, this study used measures of delta time and distance flown. Delta time and distance reflected the difference between the actual (origin/destination) trajectory time and distance flown in the test scenario and the initial URET trajectory time and distance calculated for the aircraft at the start of the scenario. Delta distance flown captures the effects of horizontal maneuvers while delta time flown captures the effects of all types of maneuvers. Addressing the technical measurement issue associated with delta time should enable a reliable measure of the effect of conflict probe on time flown. However, because the transit of one sector is a small part of the aircraft's journey, it may also be necessary to expand the problem space to allow a sufficiently powerful analysis of the cumulative effect of ATC interventions on overall flight efficiency.

## Conflict Detection and Resolution Task Performance

The analysis of decisions taken with regard to conflict detection and resolution considered the number of conflicts reported and their priority. A marginally significant increase in the number of conflicts reported with conflict probe was consistent with the expected increase in the level of strategic conflict detection by the D controllers. D controllers were significantly more proactive when they operated with the conflict probe, coordinating resolutions with their R controller and the surrounding sectors.

Conflict decision making was further analyzed to identify any differences between test conditions in terms of the priority[1] of the conflicts controllers reported. Results indicated that the proportion of red and yellow conflicts reported by controller was statistically equivalent across all test conditions. Overall, a little over half (.55) of the conflicts reported by the controllers were red and just over a quarter (.28) were yellow. The remaining proportion (.17) of the controller-reported conflicts did not show up as predicted conflicts in the URET conflict data. These might be considered a rough estimate of unnecessary interventions by the controller. However, observations and controller feedback during the simulations revealed that controller s commonly made strategic interventions to manage traffic complexity, moving a single aircraft and thereby anticipating a multi-aircraft conflict situation. Although these interventions were reported by the controller as pairwise conflicts, the specific aircraft pair was not always captured in the URET pairwise accounting of conflicts nor was it necessarily significant from an operational perspective.

Controller teams operated more strategically with conflict probe, detecting and resolving conflicts earlier. Data on conflict detection and resolution lead times, shown in Figure 9, revealed that controllers detected and resolved conflicts about 1 minute earlier with conflict probe. The main effects of conflict probe on conflict detection and resolution lead time were marginally significant.

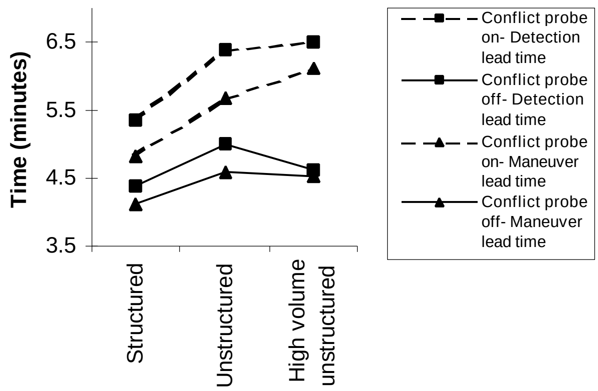


**Figure 9. Conflict Detection and Resolution Lead Times**

[1] Conflicts with a predicted minimal separation less than or equal to 5 nautical miles (nmi) were coded red, and conflicts with a predicted minimum separation distance greater that 5 nmi were coded yellow.

Data on resolution maneuver types indicate that altitude maneuvers were used to resolve fully three fourths of the conflicts. The conflict probe by traffic condition interaction was marginally significant. The interaction was represented by a marked increase in the use of altitude resolutions under the structured traffic conditions with conflict probe. The significant main effect of traffic condition was evident in an increased level of altitude resolution maneuvers in the unstructured and high volume unstructured conditions as compared to the structured conditions. Controller feedback during the simulation suggested that conflict resolution was more difficult in the unstructured conditions. In these conditions, controller decisions on horizontal maneuver options were constrained by the random locations of surrounding traffic and by the obvious negative impact of the maneuvers on the horizontal path of the flight. The larger role played by the D controller in the conflict probe conditions may have also contributed to the shift toward vertical resolutions that reflect standard practice for strategic separation of aircraft.

The findings on controller task performance and strategies strongly support a shift toward more strategic ATC with conflict probe as well as a significant increase in the contribution of the D controller to critical separation tasks. The study findings on changes in conflict resolution strategies under unstructured traffic conditions are consistent with previous research (Endsley et al., 1997), although the increased use of altitude resolutions, found in the present study is likely the result of an interaction between the unstructured traffic and the strategic conflict probe capability.

# Conclusions

## *Current Traffic Situations*

Based on the real traffic situations analyzed here, it is clear that in busy areas handling a mix of traffic operations, it is not enough to provide only early detection of conflicts or to provide only merging and spacing assistance. What is needed is integrated support tools for the controller that can assist in both functions. Such tools might establish aircraft sequences and scheduled arrival times at defined meter fixes, automatically detect when an aircraft's arrival is predicted to be outside acceptable tolerances of the scheduled time, automatically detect conflicts involving any aircraft in the airspace, permit trial planning of maneuvers that will indicate whether there are any meter fix time violations or aircraft conflicts in the trial plan, and suggest resolution maneuvers that would simultaneously solve any existing meter fix time violations and aircraft conflicts. Such capabilities would need to operate transparently across center boundaries. With such capabilities, operation at the sectors would be less stressful, exposure to operational errors would be reduced, and the users would experience shorter flights more aligned with their desired paths. Work is going on at CAASD and elsewhere to create such integrated tools.

Achieving benefits from automation tools will be a gradual process. Indications are that the current daily use URET should begin to provide benefits by gradually increasing protection against operational errors as more and more sectors use the tool for longer periods each day.

When URET is implemented at the FFP1 sites and there is a sizable block of contiguous airspace with URET coverage, the potential exists to eliminate altitude-for-direction rules at higher altitudes, allowing users on longer flights to achieve fuel benefits on every flight by flying at more efficient altitudes. Modest user benefits may also be achieved during operation of FFP1 by eliminating some altitude restrictions, reducing the extent of some preferred routes, and improving the efficiency of the merging and spacing operation.

To further reduce the impact of restrictions on users will require introduction of integrated and enhanced tools into the operational environment as a follow-on to FFP1.

## *Simulation Study*

Empirical evidence from the controller-in-the-loop simulation study leads to the general conclusion that the conflict probe has favorable impacts in terms of safety and ATC performance, and these impacts are most pronounced in the unstructured, free routing environment. Study constraints prevented a firm conclusion regarding the quantification of the impact of the conflict probe on flight efficiency and user benefits, although there was some limited evidence that conflict resolutions were more efficient with conflict probe.

In addition, the study findings strongly support the conclusion that with the conflict probe capability controllers are changing their operating practices and the distribution of sector tasks in ways that are consistent with strategic conflict resolution. However, the extent to which these changes enable increased flight efficiency could not be determined.

This study was the first conducted to look at the benefits of conflict detection and trial planning resolution aids in the context of unstructured traffic conditions. As such, there were a number of limitations in terms of the conflict probe capabilities and traffic conditions studied as well as technical measurement issues. Notwithstanding these limitations, the findings on operational acceptability and workload impacts indicate that the conflict probe capability may offset increased demands on controllers that will arise from the removal of restrictions in the free flight environment. Further research, combining field and simulation studies, is needed to (1) confirm the beneficial impacts of conflict probe found in this study and investigate the efficiency of strategic conflict resolution under more demanding scenarios and over a larger airspace, and (2) investigate the interaction of other procedural changes, such as removal of procedural altitude restrictions, with the conflict probe capability. Field studies may be most appropriate to assess benefits over larger airspace and under heavy traffic loads. Simulation studies may be most appropriate for preliminary assessments of the effects of new procedures. Changes in the next version of HCS software should resolve the DYSIM measurement issues, allowing reliable measures of flight time over the aircraft's full route.

## References

Brudnicki, D. J. & McFarland, A. L. (1997). User Request Evaluation Tool (URET) Conflict Probe Performance and Benefits Assessment (MP97W112). McLean, VA: The MITRE Corporation.

Endsley, M.R.. Mogford, R., Allendoerfer, K.R., Snyder, M.D. & Stein, E.S. (1997). Effects of Free Flight Conditions on Controller Performance, Workload, and Situation Awareness (DOT/FAA/CT-TN97/12). Springfield, VA: The National Technical Information Service.

Krois, P. & Marsden, A. (1997) FAA ODID IV: En Route Baseline Comparison Simulation Final Report (Crown Doc. No. C012-001-008). Washington, DC: Crown Communications, Inc.

McNally, B.D., Bach, R.E. & Chan, W. (1998, August). Field Test Evaluation of the CTAS Conflict Prediction and Trial Planning Capability. Paper presented at the American Institute of Aeronautics and Astronautic Guidance, Navigation, and Control Conference, Boston, MA.

RTCA. (1995). Final Report of RTCA Task Force 3: Free Flight Implementation. Washington, DC: RTCA, Inc.

RTCA. (1998). Government/Industry Operational Concept for the Evolution of Free Flight: Addendum 1. Free Flight Phase 1 Limited Deployment of Select Capabilities (Draft Report). Washington, DC: RTCA, Inc.

Tofukuji, N. (1993). An En Route ATC Simulation Experiment for Sector Capacity Estimation. IEEE Transactions on Control System Technology, 1(3), 138-143.

Whitaker, R., Marsh, D. & Schroter, H. (1997). PD/1 Final Report (DOC96-70-24). Brussels, Belgium: The EUROCONTROL Agency.