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User Request Evaluation Tool (URET) Benefits During Free Flight Phase 1

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Abstract

In the Free Flight Phase 1 (FFP1) Implementation Program a limited deployment of the core capabilities of several decision support systems will be evaluated at a number of operational sites. One component is the User Request Evaluation Tool (URET). URET will be implemented at seven Air Route Traffic Control Centers (ARTCCs) as part of FFP1. This document presents a detailed description of the URET benefits. Summaries of studies show the benefits in each of three areas: safety, FAA productivity, and airspace user cost savings. The plan for benefits measurement during FFP1 is also discussed.

A URET prototype is currently being used daily at the Indianapolis and Memphis ARTCCs. Much of what is described in this report comes from the operational use of the prototype at these centers.

Acknowledgments

The authors wish to acknowledge all of the work done in the URET benefits area by many analysts. Our extensive reference list is an indication of how much we have depended on the work already accomplished. The authors also thank Lynn McDonald and Trish Palmer for their careful preparation of the document for publication.

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Executive Summary

Free Flight Phase 1 (FFP1) is the limited deployment of the core capabilities of several decision support systems. The intent is to deploy these capabilities, currently in development status or in limited operational use at some FAA facilities, to other facilities or locations. The goal of FFP1 is to provide near-term air traffic management capabilities that can provide early benefits to service providers and NAS users, leveraging proven technologies with needed procedural enhancements and appropriate standards.

The User Request Evaluation Tool (URET) is one of the FFP1 capabilities anticipated to provide benefits to the ATC system. URET is expected to provide benefits in the areas of safety, FAA productivity, and user cost savings. Much of the data presented in this report comes from analyses of the URET prototype that is in daily use at the Indianapolis (ZID) and Memphis (ZME) Air Route Traffic Control Centers (ARTCCs). URET field trials began in 1996, starting as a controller initiated conflict probe and quickly progressing to one which continuously checks for conflicts. Several major system upgrades have been evaluated and implemented to incorporate controller feedback since 1996.

Controllers started using URET operationally on a regularly scheduled basis beginning in 1997. Currently, there are approximately 800 operational personnel (controllers, supervisors, traffic management specialists, etc.) trained in the use of URET at the Indianapolis and Memphis ARTCCs. Both facilities extended their available hours of URET operation to 22 hours a day, 7 days a week early in 2000.

Safety

Several studies conducted for the FAA in recent years have identified the causes of most operational errors. These studies indicate that the controller was not aware of the operational error in a significant number of cases. URET has been shown to provide substantial warning time in these situations. In an analysis of operational errors from ZID and ZME, URET provided an average warning time of 7 minutes for the 21 cases where Host provided reliable data. With a consistent pattern of scanning for alerts by the controllers, these cases of not knowing that an operational error was imminent should not occur.

Operational errors also occurred when the controller gave an ill-advised clearance that put an aircraft into an immediate conflict. By using the URET trial planning function, the controller will be warned of this possibility.

In all cases, the quality of URET results are not affected by aircraft density, the workload level of the controller, or whether the aircraft are flying on structured or unstructured routes. URET will accurately and reliably detect that conflict situations exist. With training and consistent use of the conflict information, the potential for operational errors should be reduced even with the forecasted increase in traffic levels.

FAA Productivity

The productivity gains and reduction in sector workload are critical for the effective use of URET. Relief from routine tasks and more efficient management of sector workload are essential aspects of URET that create the opportunity to carry out the strategic planning tasks that will achieve user benefits.

URET will be the primary source of flight data for the sector. The flight trajectory is a more accurate model of an aircraft s predicted flight path than what is presented on a paper strip. The trajectory is continually adjusted using Host track information, wind and temperature. These changes are automatically made to the displayed information. Conflict probe and trial plan results generated by URET provide new, accurate, continuously updated future situation awareness data. This relieves the controller from performing routine, recurring and often time-consuming manual calculations to predict and compare future positions of aircraft.

The conflicts detected by URET and displayed to controllers have proven to be accurate during the use of the URET prototype in ZID and ZME. Controllers are encouraged to provide Discrepancy Reports (DRs) when they believe the system is not performing properly based on their training or when they have improvements to increase usability. Each DR that describes a possible false alert or missed alert is analyzed in detail for its probable cause.

"False alerts" occur when the conflict probe warns a controller of a potential conflict unnecessarily. Operational experience at ZID and ZME has demonstrated that very few "false alert" DRs have been reported (less than 1% of the total DRs) and are not a primary concern of controllers.

"Missed alerts" occur when the conflict probe fails to warn a controller of a potential conflict. Over 80 missed alert DRs have been written by ZID and ZME controllers (about 10% of the total DRs). When these missed alert reports were analyzed, in most instances URET identified the conflict appropriately. However, URET notified a controller in another sector than was expected, or the displayed information was later than expected. In part, the issue of "missed alerts" is a training issue in the use of the tool, which is a continuing process. However, each DR continues to be tracked and analyzed when reported.

User Cost Savings

In order to discuss the benefits to users from URET, it is necessary to describe the restrictions to flight in today s ATC system. The major restrictions are:

- Preferred IFR High and Low Altitude Routes that must be flown by users flying between certain airports or flying through certain airspaces.
- Standard Terminal Arrival Routes (STARs) and Standard Instrument Departures (SIDs) that specify the route to be flown for arriving at or departing from major airports.
- Altitude restrictions for aircraft arriving or departing specific airports.
- One-way airways in congested traffic areas.
- Altitude-for-direction rules in determining allowed cruising altitudes.
- Dynamic restrictions that are applied by traffic management when conditions exist preventing a normal flow of traffic in an airspace such as miles-in-trail, ground delays, and ground holds.
- Lower cruise altitudes than that requested by flights to prevent flights from climbing and descending through the most beneficial cruise altitudes.

Several simulations have been performed to estimate the potential monetary benefits of relaxing these restrictions. These simulations have used different underlying assumptions and different base data to calculate their estimates. Three recent studies have all estimated the potential benefits at several hundred million dollars per year for air carrier operations. These simulations generally eliminate the route and altitude restrictions that are currently imposed on flights. One simulation used flights from 3 May 1995 as a baseline. Then flew the same flights on wind optimal routes with all route and altitude restrictions removed from 20 miles outside of the departure airport to 20 miles from the arrival airport. The difference between the baseline and the optimal scenarios extrapolated to a $620 million savings over a year period.

The experience with the URET prototype at Indianapolis and Memphis, and opinions expressed by controllers participating in the enroute conflict probe program, have shown that about 30 to 50 percent of the maximum benefit can be obtained in practice using full conflict probe and resolution capability. During FFP1, with only seven of twenty centers implementing URET, some smaller percentage of the benefits will be realized.

Another approach to estimating the airline economic benefits of URET during FFP1 is to determine how many restrictions can be eliminated, estimating the cost due to those restrictions for each flight, and multiplying that cost by the number of flights affected by the restriction. For route and altitude restrictions in and around Indianapolis, a quick analysis was done that shows a 1% to 2% savings in fuel for each restriction removed for each flight. On-going operational evaluations show a potential for fuel savings of several million gallons annually by removing altitude restrictions just at ZID.

Plan for Measurement and Accrual

As part of the FFP1 program, benefits for each of the FFP1 capabilities will be measured. In addition to measuring the benefits, a program to actively pursue the accrual of benefits will take place. A restriction analysis will be done for all of the URET sites to determine which altitude restrictions have the greatest impact on flights and which of those the facility feels could be removed from an operational viewpoint. These analyses will initially be done at Indianapolis and Memphis in 1999 and 2000 using the capabilities of the URET prototype. These analyses will be expanded to include all of the FFP1 sites during 2000 and 2001 so that recommendations for operational changes can be made prior to full deployment and training at the FFP1 sites.

Section 1

Introduction

Free Flight Phase 1 (FFP1) is the limited deployment of core capabilities of several decision support systems. A complete definition of FFP1 can be found in [RTCA, 1998]. The 5 core technologies that have been identified as components of FFP1 are:

- Surface Movement Advisor (SMA)
- Collaborative Decision-Making (CDM)
- Traffic Management Advisor (TMA)
- Passive Final Approach Spacing Tool (pFAST)
- User Request Evaluation Tool (URET)

The intent is to deploy these capabilities, currently in development status or in limited operational use at some FAA facilities, to other facilities or locations through a process called Core Capability Limited Deployment (CCLD). The goal of FFP1 is to provide near-term air traffic management capabilities that can provide early benefits to service providers and NAS users, leveraging proven technologies with needed procedural enhancements and appropriate standards.

This report summarizes the benefits expected to be realized in the use of URET capabilities during FFP1. The benefits are categorized broadly in three areas: safety, FAA productivity, and user cost savings. This report presents the results of many analyses completed to date that bear on the URET benefits outlook. There is an extensive reference list for those who would like further details of the analyses. A significant amount of what is reported herein comes from the operational use of a URET prototype over the past two years at the Indianapolis and Memphis Air Route Traffic Control Centers (ARTCCs). The prototype experience is invaluable in attempting to explain how URET provides benefits and to what degree.

URET Functionality

The key capabilities of URET for FFP1 are:

- Trajectory modeling
- Track Management
- Automated Problem Detection
- Trial Planning

- Automated Coordination
- The Computer Human Interface (CHI)

URET processes real-time flight plan and track data from the Host computer system. These data are combined with site adaptation, aircraft performance characteristics, and winds and temperatures from the National Weather Service in order to build four-dimensional flight profiles, or trajectories, for all flights within or inbound to the facility. The reconformance function adapts each trajectory to the observed speed, climb rate, and descent rate of the modeled flight. For each flight, incoming track data are continually monitored and compared to the trajectory in order to keep it within acceptable tolerances. Neighboring URET systems will exchange flight data, position and reconformance data, and status information in order to model accurate trajectories for all flights up to 20 minutes in the future.

URET maintains current plan trajectories, i.e., those that represent the current set of flight plans in the system, and uses them to continuously check for aircraft and airspace conflicts. When a conflict is detected, URET determines which sector to notify and displays an alert to that sector up to 20 minutes prior to the start of that conflict. Trial planning allows a controller to check a desired flight plan amendment for potential conflicts before a clearance is issued. The controller can then send the Trial Plan to the Host as a flight plan amendment. Coordination of Trial Plans between sectors, which might include those of neighboring centers, may be achieved non-verbally using Automated Coordination capabilities.

These capabilities are packaged within a CHI that includes text and graphic information. The text-based Aircraft List and Plans Display manage the presentation of current plans, trial plans, and conflict probe results for each sector. The Graphic Plan Display provides a graphical capability to view aircraft routes and altitudes, predicted conflicts, and trial plan results. In addition, the point-and-click interface enables quick entry and evaluation of trial plan route, altitude, or speed changes and sending the flight plan amendment to the Host.

URET capabilities will be deployed to seven sites by the end of 2002. Figure 1-1 shows the seven centers and their geographical extent where URET CCLD will be deployed. The URET functionality will be delivered in two builds. Build 1, which includes the basic functions in the URET prototype and the enhancements planned during the next year, is scheduled for 2001. Build 2, which is scheduled for 2002, includes additional functionality that will increase the operational acceptability and utility of URET in all seven sites.

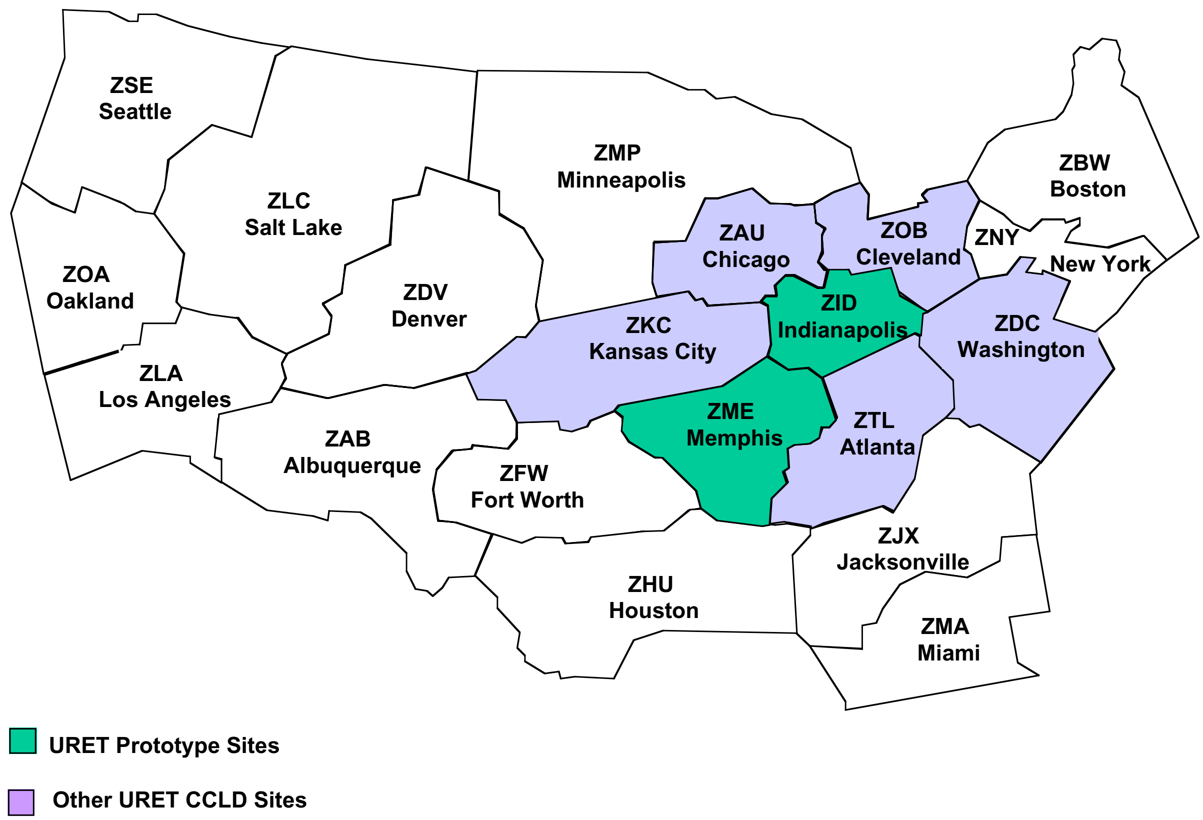


Figure 1-1. URET FFP1 Implementation Sites

URET Prototype

URET capabilities are currently undergoing field trials at the Indianapolis (ZID) and Memphis (ZME) Air Route Traffic Control Centers (ARTCCs) in the form of the URET prototype. These field trials are being carried out:

- To evaluate the URET capabilities for operational acceptability and utility
- To reduce the risk for FFP1 and future national deployment
- To begin achieving near-term benefits

URET field trials began in 1996, starting as a controller initiated conflict probe and quickly progressing to one which continuously checks for conflicts. Several major system upgrades have been evaluated and implemented to incorporate controller feedback. The report on the latest URET evaluation concerning the two-way Host interface can be found in [Bowen, 1999].

URET daily use began in 1997 in the Indianapolis and Memphis ARTCCs. Daily use is defined as controllers using URET operationally on a regularly scheduled basis. Interfacility URET began daily use operations in May 1998. In June 1999, the two-way communication with the Host was approved. This allows flight plan amendments to be sent to the Host from the URET controller workstation.

Currently, there are approximately 800 operational personnel (controllers, supervisors, traffic management specialists, etc.) trained in the use of URET at the Indianapolis and Memphis ARTCCs. Both facilities extended their available hours of URET operation to 22 hours 7 days a week early in 2000. The prototype was never built to run continuously and requires several hours each day to reinitialize, run off-line analysis tools, and capture the previous day s data for off-line processing. On weekends when the Host is off-line for preventative maintenance and software testing, URET is also unavailable.

Section 2

Benefits Overview

The objectives of Free Flight are to provide greater flexibility and cost savings to the users without compromising safety. The following benefits are expected from URET.

The safety benefit is achieved by reducing the risk of midair collision because of a controller error. This can also be translated into a reduction of operational errors and operational deviations. URET increases safety by:

1. Increased situational awareness
2. Timely and continuous notice of emerging problems
3. Avoidance of time-critical, high stress traffic situations
4. Sector team collaboration
5. Consistently longer problem-identification lead times
6. Less uncertainty about potential conflict situations, and more confidence in long term effects of flight plan amendments

FAA productivity is accomplished by being able to safely handle increasing numbers of annual aircraft operations without a proportional increase in staffing or operating cost. URET provides FAA productivity by:

1. Increased en route sector productivity
2. More effective utilization of sector team resources
3. Enhanced productivity from the D controller (with a potential for less workload given reduced requirements for flight strip manipulation and elimination of the need to scan strips for potential conflicts) with respect to planning, strategic problem detection, and problem resolution
4. Improved quality of flight plan and strategic problem information to the sector as a whole
5. Potential for reduced coordination between sectors when plans are known to be problem-free
6. Better team relationship between the D- and R-side
7. Capabilities that do not degrade as traffic complexity and volume increase

User cost savings are increased by the accommodation of user preferences (route/altitude/speed profiles) and more flexible and deterministic schedules. URET allows:

1. User-friendly maneuvers for conflict resolution
2. Potential for longer direct or wind-optimal routings
3. Reducing the restrictions to flight, both altitude and route restrictions
4. Use of more efficient cruise altitudes
5. Fewer dynamic restrictions based on miles-in-trail and ground delays

In Sections 3, 4, and 5, each of the benefits areas is expanded. Each area is presented somewhat independent of each other as if it was the most important benefits producing aspect of URET. These areas do interact. One obvious example is the discussion in Section 5 about relaxing or removing various ATC restrictions. The restrictions are imposed to help separate flows of aircraft and so the conflict points between aircraft are more predictable. Thereby making the traffic less complex and more manageable for controllers. Removing a restriction will have some affect on controller workload and possibly the number and complexity of conflict situations. These interactions will be an on-going area of study and discussion with ATC operational personnel.

Section 3

Improved Safety

This section summarizes several studies that suggest the widespread use of URET may produce significant improvements in safety of the National Airspace System. The element of safety that may be impacted is the risk of collision between two aircraft under radar control by en route controllers.

Number of Operational Errors as an Indicator of Safety

The risk of collision between two aircraft under radar control cannot be measured in the United States by the number of such collisions because none have occurred during the past 35 years that were caused by a failure of the ATC system or a mistake by radar controllers. This favorable safety record notwithstanding, the risk of collision between two aircraft under radar control is not zero. En route controllers are required to keep aircraft under radar control separated by specified standards (5 nmi lateral or 1,000 or 2,000 feet vertical). On occasion controllers allow aircraft under radar control to come closer together than these standards. If the cause of violating these standards was a mistake on the part of the radar controller, this event is called an operational error. Some operational errors are ones in which the controller was aware of the conflict between two aircraft, but the actions he took were not sufficient to prevent a slight violation of the separation standards. In others the controller was not aware of the developing conflict and the separation achieved was due totally to chance.

The FAA treats all operational errors as serious events and thoroughly investigates each. A report is filed for each occurrence and the data from these reports is collected and tracked as a major indicator of safety of the NAS. Figure 3-1 shows the number of operational errors per year occurring at all U.S. Air Route Traffic Control Centers [FAA]. The operational error rate, computed as number of operational errors per 100,000 Instrument Flight Rules (IFR) aircraft handled, is also shown. During the 10 years covered in this figure, FAA managers at all levels have continuously monitored these statistics and undertaken a number of activities to control the growth in number of errors and reduce the numbers where possible. Adjustments are often made to sector boundaries, to standard operating procedures, or to ATC restrictions and preferred routes in order to maintain a manageable workload for controllers that will minimize the opportunities for operational errors to occur. In recent years these efforts have served to maintain the operational error rate at a steady level, but they have not been able to reduce the rate significantly.

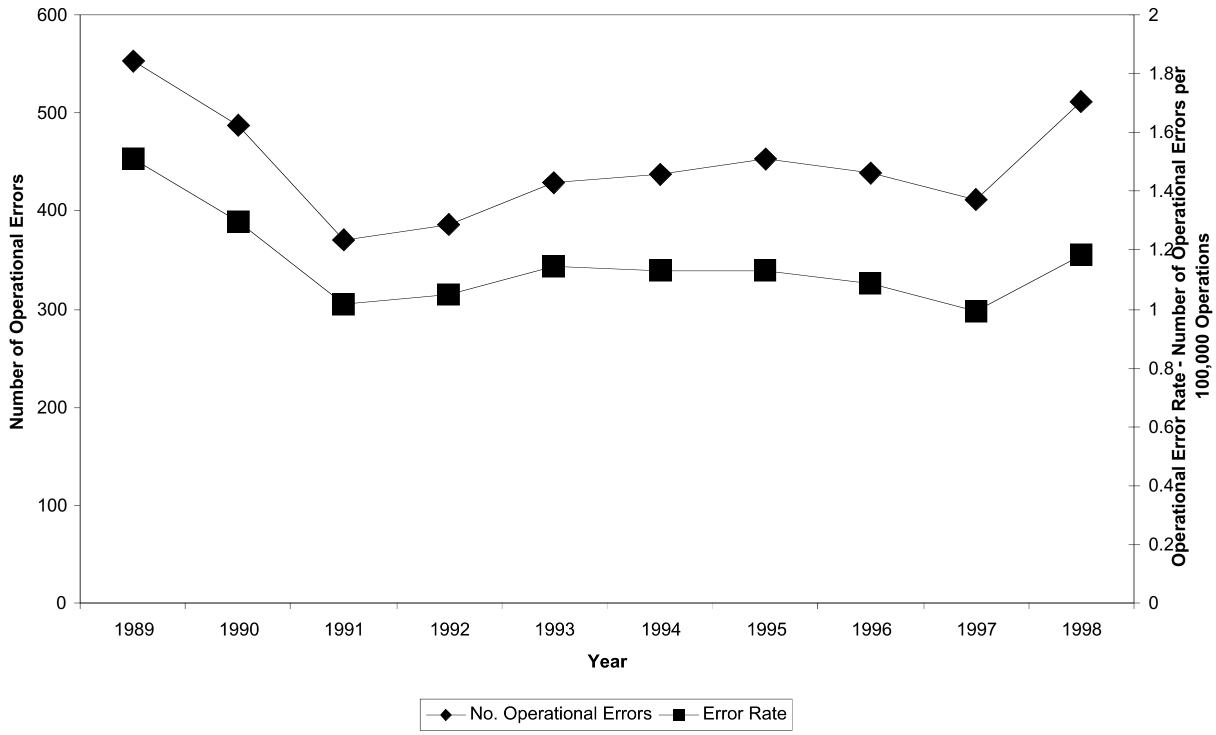


Figure 3-1. Number of Operational Errors and Operational Error Rate for all U.S.˚Air Route Traffic Control Centers

Analysis of 85 Operational Errors at Atlanta Center

One of the activities undertaken often to control the rate of operational errors has been to study the causes of operational errors searching for patterns that might suggest corrective measures. [Rodgers, 1998] carried out an in-depth analysis of 85 operational errors that occurred between June 1992 and June 1995 at Atlanta Center. The focus of their study was to explore the relationship of sector and traffic characteristics to operational errors. Their study showed a clearer indication, than earlier studies, that operational errors were more likely to occur in sectors and during periods when the air traffic being handled is heavier and more complex.

The following is a quote from the conclusions of this report.

> To summarize, this research has shown that high-OE sectors are characterized by problematic weather, radio frequency congestion, high total complexity, high annual review average complexity, and small size. There is also evidence that these sectors tend to have more climbing/descending traffic, a uniform aircraft mix, frequent required procedures, and higher traffic volume.

The form that the center s Quality Assurance staff fill out after investigating an operational error contains a field to indicate whether the controller responsible for the operational error was aware in advance that an operational error was about to occur. [Rodgers, 1998] used the phrase the controller had situational awareness to indicate that the controller was aware in advance of the developing operational error.

Conclusions from the report related to situational awareness follow.

> The separate analysis of controller situational awareness (SA) during the development of OEs is important in that, in these data, 73% of the controllers were not aware of the developing error. Presumably, awareness would have prevented many of these errors from occurring
>
> It was found that high-error sectors tended to have more no-SA errors. It may be that the presence of awareness of a developing error is a mediating factor controlling the frequency and severity of errors in a given sector. If sector or traffic characteristics tend to somehow interfere with general controller SA, it can be expected that more errors will occur, and they will often be rated as no-SA OEs. Thus, higher ATC complexity may result in the kind of high cognitive loading that contributes to a reduction in SA and leads to an elevated probability of error.

Analysis of 35 Small-Separation Operational Errors from 1986

In [Butcher, 1987], the authors investigated 35 small-separation operational errors that occurred in Air Route Traffic Control Centers across the U.S in 1986. The causes of these operational errors and their frequency of occurrence are listed in Table 3-1. Multiple causes were listed for some operational errors.

Table 3-1. Causes of 35 Small-Separation Operational Errors Occurring at ARTCCs in 1986

Cause of Operational Error	Number of Errors With This Cause
Judgment/Inattentiveness	12
Distraction	11
Coordination	10
Air-Ground Communications	9
Flight Progress Strip Errors	9
Misunderstanding/Misreading of Data	5
Traffic Complexity	4
Overlapping Data Blocks	4
Stuck Mike	3
Position Relief	3

This study did not directly determine how many of these operational errors occurred when the controller was not aware of the developing operational error. However, it is likely that the controller was not aware of the developing error in a substantial number of the cases where Judgment/Inattentiveness, Distraction, Flight Progress Strip Errors, Misunderstanding/Misreading of Data, Traffic Complexity, and Overlapping Data Blocks were listed as causes.

URET Makes Controllers Aware of Developing Errors

Both studies discussed above indicate that the controller was not aware of the developing operational error in a significant number of cases. In many of these cases, the conflict was present in the cleared flight paths of the aircraft for a considerable time (5 minutes or more) before the violation of separation standards, but the controller did not recognize the conflict. Study of URET alerting for scenarios containing recent operational errors from Indianapolis and Memphis Centers shows that URET dependably provides alerts with substantial warning times. In an analysis of operational errors from ZID and ZME, URET provided an average warning time of 7 minutes for the 21 cases where Host provided reliable data.

If the controller team monitors the URET display for alerts there should be very little likelihood of an operational error occurring when the controller is not aware of the developing operational error, in cases where the cleared flight paths of the aircraft are stable prior to the loss of separation.

The controller may inspect the path of an aircraft when it first appears on his display, notice that the aircraft will pass near another aircraft or determine that the aircraft will pass with adequate separation, and take no action. At the time, the flight paths may be such that there is no conflict and no action is appropriate. URET may also determine that there is initially no conflict. But a change to the flight paths of the aircraft, because of a change in climb rate for instance or an action on the part of another sector, may cause a conflict to arise after the initial assessment. A number of operational errors occurred in cases where the controller was not aware of the change in status. Through its reconformance logic, URET responds to changes in the aircraft s flight paths and can recognize a newly-created conflict. This capability should help prevent a number of the operational errors of this kind, especially those that occur when the controller is dealing with heavy or complex traffic and is not able to monitor individual aircraft closely for changes that might lead to newly-created conflicts.

URET Informs a Controller that an Action May Create an Error

Some operational errors come about when the controller gives an ill-advised clearance to an aircraft which converts a conflict-free situation into an immediate conflict situation. Or it may be that the controller recognizes a conflict between two aircraft and issues a clearance to solve that conflict, but doesn t recognize that the clearance creates an immediate conflict with a third aircraft. The Automated Problem Detection capability of URET may provide little or no warning time in these cases. However, URET has a separate capability called Trial Planning that can help avoid operational errors in these situations. The controller can quickly and easily create a trial plan for a proposed clearance and submit it to URET for conflict checking, without changing the baseline trajectory for a flight. The significant point is that the URET conflict checking determines not only whether the proposed clearance solves any existing conflict, but also whether it creates any new conflict.

When considering each of the individual items that were shown to be correlated with, or the cause of, operational errors in the two studies described above, it is apparent that URET is not as susceptible as the unaided controller to many of these factors. The quality of the URET trajectories and the ability to dependably detect conflicts is nearly the same whether there are a large or small number of aircraft, whether the aircraft density is high or low, and whether the controller is distracted or dealing with multiple tasks or not. The only reason that the technical performance may not be the same is that the trajectory accuracy and alert times are affected by clearances voiced to aircraft (usually temporary heading vectors) that are not entered into Host as amendments. It may be that the number of voiced clearances without amendment messages is somewhat higher when controller workload is higher, producing a second order effect that may result in somewhat shorter warning times than normal.

Section 4

FAA Productivity Gains

The productivity gains and reduction in sector workload that URET will provide sector control teams are critical for the effective use of the tool. Relief from routine tasks and more efficient management of sector workload are essential aspects of URET that create the opportunity to carry out the strategic planning tasks that will achieve user benefits.

Flight Data Management

Although it does not eliminate paper strips, URET is intended to be used as the sector team s primary source of flight data. URET s flight trajectory is a more accurate model of an aircraft s predicted flight path than what is presented on a paper strip. The trajectory automatically and continuously adjusts the planned route of flight with Host track information, wind and temperature, aircraft type, letters of agreement, restrictions, SUA status, and local SOPs. These changes then automatically update the displayed information.

Operational experience at ZID and ZME has demonstrated it is not viable to use URET while maintaining full strip management functions; to do so increases workload [FAA, 1999a]. Attempts to use two sources of flight data information creates additional sector team workload and potential for error and confusion within the sector team since the state of the data can easily be different (URET flight information is automatically updated, and therefore often more accurate than the paper information).

The FAA has identified several initiatives aimed at reducing, and eventually eliminating the use of paper flight strips. (Examples include reduced strip marking and posting procedures, use of the 4th line of the data block for speed and heading, national use of destination in the data block, and a conflict probe capability available at every R and D console.) As such, URET implementation can be viewed as one step towards the eventual elimination of paper strips. A successful strip reduction effort will facilitate a site s operational transition to URET operations [FAA, 1998].

URET operations will nominally run around the clock, 24 hours per day, 7 days per week. However, since URET will not become a critical ATC system until after FFP1, URET must allow transition to a strip environment in the event of URET planned or unplanned outages [FAA, 1998]. Therefore, all strips will be printed and the sector will determine those to be posted.

Studies on various aspects of the use of paper flight progress strips have been carried out for more than a decade, producing an extensive bibliography of publications. Findings indicate that controllers experimentally deprived of access to strips compensate for the loss of this presumed memory aid and actually tend to perform at a higher level on a number of important measures [FAA, 1999a].

- Controllers severely restricted in their use of strips (which also carried reduced amounts of information) performed as well as controllers working under normal conditions in one simulation study.
- The restricted controllers "were able to focus on the most relevant information, thus more than compensating for the lost memory aids .
- When denied access to strips, controllers compensated by requesting four times more FPSs than did controllers with normal access, allowing them to spend more time watching the PVD. The decrease in workload that resulted from the elimination of the strips (and strip marking) appears to outweigh any detrimental effects caused by their removal [Albright et al, 1994]."

The National Research Council (NRC) panel on human factors in air traffic control automation concluded that the results . . . generally supported the reduced-workload hypothesis. Their aggregate observations suggest that an interactive integrated display or interface that provides more direct access to both flight and radar data could enhance controllers performance without a reduction in situation awareness. [NRC, 1998]

Conflict Probe and Trial Planning

To smooth sector workload and improve coordination, as well as respond to user preferences and improve the level of safety, timely conflict information is required. URET functions determine a desired warning time that is between 10 and 20 minutes. (Warning time is defined as the interval between predicted conflict start time and time at which controller is notified of conflict). In URET, highest likelihood conflicts (red alerts) are set to 20 minute warning time; near-zero likelihood conflict notification is close to a 10 minute warning time.

The conflict probe and trial plan results generated by URET provide new, accurate, continuously updated future situation awareness data. When notification of a predicted conflict is received, the controller may elect to trial plan potential solutions. The controller will be able to see the impact of potential solutions in terms of creating other conflicts. Although the sector planning decision process with URET remains a mental assessment and judgment by controllers, URET relieves controllers from performing routine, recurring and often time-consuming manual calculations to predict and compare future positions of aircraft [FAA, 1998].

The URET conflict probe warns controllers of potential conflicts. If URET provides inaccurate information or information that does not accord with a controller s understanding and experience, the controller will not trust the displayed conflicts and the probe s utility will be diminished. The conflicts detected by URET and displayed to controllers have proven to be accurate during the use of the URET prototype in ZID and ZME. Controllers are encouraged to provide Discrepancy Reports (DRs) when they believe the system is not performing properly based on their training or when they have improvements to increase usability. Each DR that describes a possible false alert or missed alert is analyzed in detail for its probable cause.

False alerts occur when the conflict probe displays a potential conflict unnecessarily. There are instances in which the controller has better information than the URET trajectory modeler; e.g., he may have better information of the pilot s intent than URET does. Operational experience at ZID and ZME has demonstrated that very few false alert DRs have been reported (less than 1% of the total DRs) and they are not a primary concern of controllers.

Missed alerts occur when the conflict probe fails to warn a controller of a potential conflict. Over 80 missed alert DRs have been written by ZID and ZME controllers (about 10% of the total DRs). When these missed alert reports were analyzed, in most instances URET identified the conflict appropriately. However, URET notified a controller in another sector than was expected, or the information was displayed later than expected. In part, the issue of missed alerts is a training issue in the use of the tool, which is a continuing process. However, each DR continues to be tracked and analyzed when reported. Based on the experience with the operational use of the prototype at ZID and ZME, controllers have not found either missed or false alerts a deterrent to their use of URET.

Interfacility Data Exchange

The URET systems at Indianapolis and Memphis center have an interfacility capability. Using the FAA's operational National Airspace Data Interchange Network (NADIN II), they exchange data routinely. Controllers indicated that their awareness of traffic in the other center's airspace was much improved. They particularly appreciate the fact that they received earlier notice of inbound traffic and had earlier awareness of problems it might create in their sectors. The center staff chose to activate this capability in the URET daily use systems, and it is now used on a daily basis [Kerns, 1998].

Automated Coordination

The automated coordination feature of URET permits a controller to electronically forward to a designated sector an aircraft s current plan or a trial plan for that aircraft, annotated with a menu-selectable reason code. Because the controller receiving an automated coordination will be able to view the same graphic and textual data associated with an aircraft as the initiator and respond electronically, use of automated coordination is expected to reduce the need for associated verbal coordination. The receiving controller can respond electronically to the request [FAA, 1998].

Advance planning and automated coordination can resolve a prospective conflict by amending the aircraft s route, altitude, or speed prior to entry in the sector. The problem is resolved earlier and the workload is balanced across the center.

Amendment Generation

URET will be used to enter flight data amendments and flight plans into the Host. The graphic display of an aircraft s trajectory and the point and click capabilities of the URET CHI provide a significant time savings for controllers using URET to generate a route amendment. When a controller decides to implement the Host flight plan amendment associated with a trial plan or an automated coordination request, URET automatically generates the associated Host flight plan amendment. The controller may then submit the amendment to Host with a single action [FAA, 1998]. The ease with which route amendments can be generated and submitted to Host is expected to result in flight plans that better reflect the intent of the aircraft.

Section 5

Benefits to Airspace Users

In order to discuss the benefits to users from Conflict Probe, it is necessary to describe the restrictions to flight in today s ATC system. The FAA publishes a set of Preferred IFR High and Low Altitude Routes that must be flown by users flying between certain airports or flying through certain airspaces. These are referred to as ATC preferred routes. Many of these routes specify the entire route of flight, including departure and arrival routing. Most of the ATC preferred routes are associated with the major airports in the eastern U. S. There are very few for western airports. Some of these ATC preferred routes are rather close to direct routes between the associated airports, while others incorporate some degree of indirect routing in order to segregate major departure and arrival flows. However, the major effect of these routes is to force the users to fly the specified route every day, even though the wind-optimal route would vary from day to day and on occasion could differ substantially from the ATC preferred route.

The FAA also publishes Standard Terminal Arrival Routes (STARs) and Standard Instrument Departures (SIDs) that specify the route to be flown for arriving at or departing from major airports. These specify the routes to be flown within about 100 nmi of the airports, and they apply to all aircraft, not just those subject to ATC preferred routes.

In addition, FAA establishes a number of altitude and routing restrictions. Typically these specify that a controller must direct an aircraft arriving at a certain airport over a specified fix, or must clear that aircraft to a specified altitude when it crosses a particular sector or ARTCC boundary. These restrictions are established through Letters of Agreement between different ATC facilities or are reflected in the Standard Operating Procedures written for each sector. The altitude restrictions usually require an aircraft to descend to one or more lower altitudes than the desired cruise altitude and to spend some time in level flight at those lower altitudes.

FAA establishes one-way airways in congested traffic areas. These routes segregate major flows of traffic (often separating departure flows from arrival flows). These routes are prevalent in the airspace between Atlanta, Washington D.C., Cleveland, and Boston.

FAA applies altitude-for-direction rules in determining allowed cruising altitudes. Pilots flying an hour or more in the cruise phase of flight will want to go to higher altitudes as their aircraft burns fuel. With these altitude-for-direction rules in effect they must wait to climb to a higher altitude until they can climb 4,000 feet, if above FL290.

Many restrictions have been applied over the years as a means of providing structure to aid the controllers in manually handling growing levels of air traffic. Taken together, these restrictions have caused users to burn more fuel and to fly longer than if they could fly unrestricted.

In addition to the route and altitude restrictions that are static , that is imposed almost every day between certain hours, there are dynamic restrictions that are applied by traffic management when conditions exist preventing a normal flow of traffic in an airspace. This is primarily because of severe weather conditions, equipment outages, airport runway closures, or other temporary problems. Dynamic restrictions take the form of miles-in-trail to specified airports, a Ground Delay Program where all flights to a specific airport are delayed by an amount of time, or a Ground Stop where all flights destined for an airport are stopped on the ground for a specified time. These dynamic restrictions can be the most detrimental to the airlines when they disrupt the hub and spoke operations at an airport by making passengers miss a connection or flights are canceled because the aircraft has not arrived.

The ATC system also lowers the cruise altitude requested by flights to prevent them from climbing and descending through congested cruise altitudes above FL290. Many short haul, less than 400 mile, flights are capped in altitude, especially in the eastern US between New York, Chicago and Atlanta. This prevents flights from cruising at more fuel-efficient altitudes.

To estimate the benefits to the users, the analysis can begin with an estimate of the overall benefits of Free Flight then attribute a percentage of those benefits to URET based on expert assessments. The other approach is to estimate the benefit of eliminating one restriction then extrapolate to the number of restrictions that may be possible to remove.

Analysis of Potential Free Flight benefits

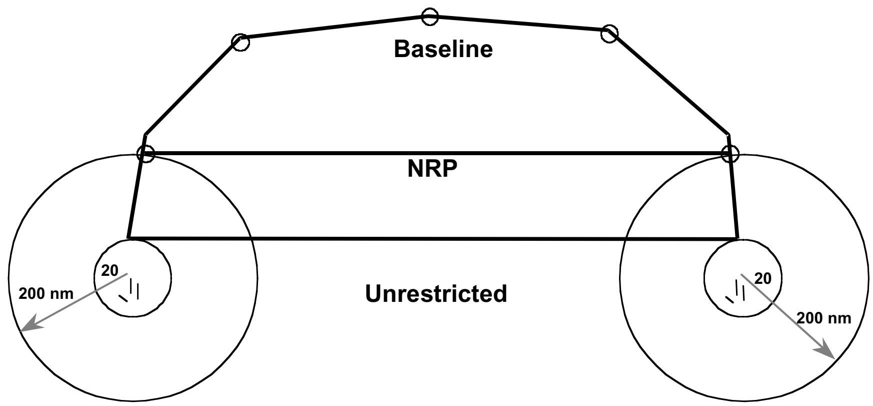
URET will allow controllers to relax many of the restrictions that are presently imposed on airspace users. The National Route Program (NRP) allows some qualifying flights to operate on more direct routes, gaining some benefits [FAA, 1996]. This analysis demonstrates additional benefits over and above those available through NRP, if under URET the qualifying restrictions applied to NRP flights were removed. This result places an upper limit on URET benefits.

An analysis by [White, 2000] is based on the CAASD developed Traffic Management Analysis Capability (TMAC). TMAC is a time step simulation of the NAS. It simulates the movement of aircraft throughout the system, including all major airports, and all sectors of en route airspace. Its outputs include delay, throughput at airports and airspace sectors, and also the time it takes each aircraft to complete its flight. In simulation runs, traffic was limited to commercial air carrier flights; general aviation and military flights were omitted. The simulation runs were based on an actual flying day, 3 May 1995. Real-world data from the Enhanced Traffic Management System (ETMS) was used as input to the TMAC model, providing an as flown baseline, including departure times and routes. Being based on real-world data, there were numerous errors, many brought about by duplication of flight IDs due to code sharing among airlines. These faulty records were manually removed from the analysis, leaving around 31,000 valid flights.

The experimental design consisted of three scenarios. In the baseline, or as flown case, flights were routed as they were on the baseline day. This is represented in Figure 5-1 by the topmost line, schematically showing a circuitous ATC preferred route, although any flights granted direct routes were flown that way. The second scenario was wind optimal routes subject to the rules under which the National Route Program is conducted for all qualifying flights. In order to qualify for a wind optimal NRP route, flights had to be at an altitude of 29,000 feet or higher, and have a stage length of 750˚nautical mile (nm) or greater. Flights were required to fly on ATC preferred route structure until they were 200 nm away from their departure airport, and to rejoin the structured route when they reached 200˚nm from their destination.

In the third scenario, all of these restrictions were removed. All flights were eligible for a wind optimal route regardless of altitude or stage length. The 200 nm exclusion rings were reduced to 20 nm, reflecting only minimal required route structure in the terminal areas.

The TMAC model computed wind optimal routes in the second and third scenarios. Flight time for the best wind route was compared to the original route. In cases where the wind route was no shorter in time, the flight was placed back on its original as flown route. In cases where the wind optimization routine failed to converge, the route defaulted to a direct route, as an approximation of a user preference.



- Baseline: as flown based on ETMS data for 3 May 1995, including NRP flights as flown that day
- NRP:
  - Filed altitude of FL290 or above
  - 200 nm exclusion zones at origin and destination
  - 750 nm minimum stage length
  - Altitude restrictions on descent
  - Wind optimal, routes outside exclusion zones (maintaining baseline altitudes)
- Unrestricted (maximum potential benefits)
  - All restrictions removed
  - Wind optimal routes over entire flight (maintaining baseline altitudes)

Figure 5-1. Experimental Design

TMAC outputs showed the differences between the three scenarios in terms of total and average flight times, separated by airline. These time savings were converted to dollar savings by multiplying time savings by the direct operating costs for air carrier aircraft. These costs include fuel, crew, maintenance, and other costs directly associated with the operation of the aircraft. This analysis did not include any representation of passenger time value; inclusion of this factor would increase benefits greatly.

The maximum potential benefits of free flight are summarized in the accompanying table. The first line of this table, labeled 100 percent , shows the annual benefits in millions sof dollars. The first column, labeled NRP shows the savings that would accrue if all eligible flights got an NRP route. At the time this study was conducted, few eligible flights were taking advantage of NRP. However, there were some NRP flights in the baseline scenario, so this results underestimates the benefit of NRP by those few flights under NRP.

The second column, labeled Descent Fuel Savings shows the savings obtained from removing altitude restrictions on arrival. The next two columns, labeled Fuel Savings and Other Direct Cost Savings show the savings due to optimal routes, over and above NRP. The right column shows the total increment of savings over NRP.

The lines labeled 50 percent, 25 percent, and 10 percent show the savings that would result if that percent of the maximum attainable savings were realized. The values on those lines are simple fractions of the 100 percent line. The results show potential savings of $620 million per year.

Table 5-1. Analysis Results

	(Millions of Dollars Annually)				
	NRP Direct Operating Cost Savings*	Additional Unrestricted Descent Fuel Savings	Additional Unrestricted En Route Fuel Savings	Additional Unrestricted Other Direct Operating Cost Savings	Total Additional Unrestricted Savings
100%	62	105	255	260	620
50%		53	128	130	310
25%		26	64	65	155
10%		11	26	26	62

*Beyond what was already realized in base day (as flown).

[Couluris, 1995] documents a study made by Seagull Technology, Inc, for the National Aeronautics and Space Administration (NASA) Ames Research Center. The study estimates the benefits of various advanced technologies supporting or allowing more efficient flight procedures.

Seagull considered three levels of incremental enhancement over basic NRP: Relaxation of the 200 nmi constraint, granting User Preferred Routing (UPR) to flights not subject to ATC preferred routes, and UPR to all flights. These enhancements generally match those considered in [White, 2000]. Benefits of $326 million for 1995 and $402 million for 2005 were calculated.

In [Hoffman, 2000], an independent analysis of the FAA s ETMS data to determine excess mileage flown on airways as compared to direct routes was constructed. This analysis did not employ any simulation model, but analyzed the ETMS data directly. Data from the ETMS 4.2 feed was used, describing October 23, 1998. This particular source of data excludes VFR flights and military traffic. Weather on that day was generally good across the U.S Great-circle arcs are drawn from the departure point to the acquisition of the aircraft by en route radar, and from the end of en-route control to the destination airport. A total potential benefit of about $757 million per year was calculated.

From these analyses, the potential for airline savings from free flight is in the several hundred million dollar range. The experience with URET at Indianapolis and Memphis, and opinions expressed by controllers participating in the enroute conflict probe program, have shown that about 30 to 50 percent of the maximum benefit can be obtained in practice using full conflict probe and resolution capabilities. During FFP1, with only seven of twenty centers implementing URET, some smaller percentage of the benefits will be realized.

Individual Route and Altitude Restriction Analyses

In [Brudnicki, 1996], a situation observed in an Indianapolis ARTCC traffic sample from 29 March 1995 was described. A cluster of eleven aircraft bound for Dallas/Ft. Worth (DFW), and all on airway J6 were observed in the vicinity of Charleston, WV. This situation is shown in Figure 5-2.

These eleven aircraft took off from eight different airports in the northeast - Boston, Bradley, Laguardia, Newark, Philadelphia, Baltimore/Washington, Washington National, and Dulles. It is surprising to find that these aircraft are essentially sequenced for arrival at DFW over Charleston, which is more than 800 miles from DFW. Each of the eight departure airports had a preferred route specified for DFW, the entire route was spelled out, and the route coincided with J6 through Indianapolis ARTCC. Using a plot of the forecast upper winds for the time of that sample, a route for the flight from Boston to DFW was constructed by hand that appeared to be more efficient than the preferred route. Both the preferred route and the alternative were submitted to the URET system, and the times of arrival compared. Even though the alternative route had a ground track 29 miles longer, it had a flight time 4 minutes and 33 seconds shorter than the preferred route. This represents a 2% savings in flying time. Had a true wind-optimum route been generated, the time savings might have been greater.

The qualification rules for NRP were made less restrictive after 29 March 1995, so other traffic samples from later dates were looked at to determine if NRP were used for these flights at a later time. Five different scenarios all from dates after 29 March 1995 were viewed, and every time there was a cluster of aircraft flying from various airports in the northeast to DFW, all the aircraft in the cluster were on the preferred route. The forecast winds for each of these scenarios had quite different patterns and it was apparent that the wind-optimal routes would have been quite different for each.

Our latest data from the summer of 1999 shows that some of these flights are flying routes other than J6 through ZID. We will be doing additional analysis to determine the current use of NRP for these routes.

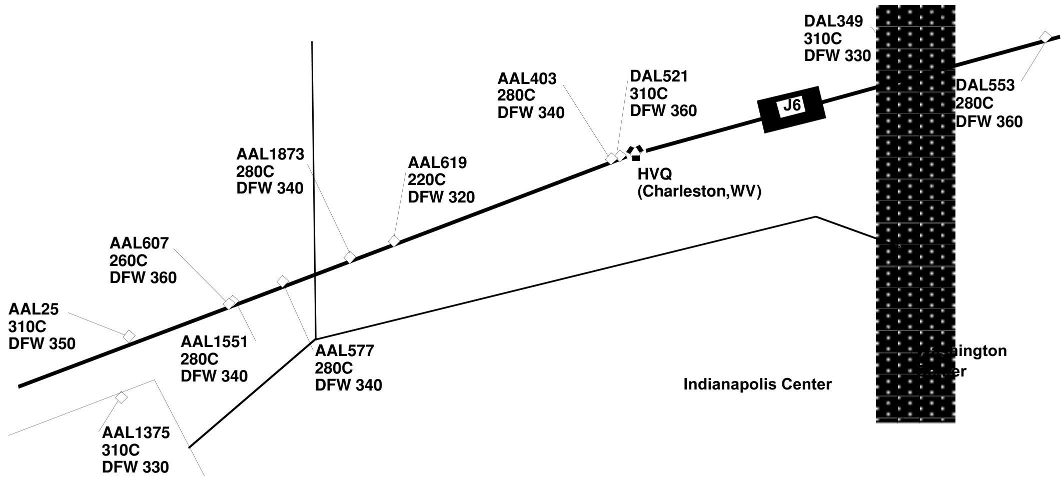


Figure 5-2. Eleven Aircraft Bound for DFW on the Same IFR Preferred Route

Since URET provides an effective conflict probe capability that enables air traffic controllers to anticipate when and where conflicts will occur, the need to restrict traffic to predictable and potentially undesirable patterns by imposing sector boundary restrictions is minimized. In order to quantify the benefits of removing restrictions, an analysis was conducted by [Brudnicki, 1996] using a subset of common altitude restrictions applied to Indianapolis Center arrivals. Flight profiles were constructed for typical routes and aircraft types, once with the appropriate restriction applied and again with the restriction removed. The resultant fuel burns were computed and compared. Since altitude restrictions generally require an aircraft to descend at a point earlier than that desired for optimal fuel usage, this comparison represents the potential savings to the user. For example, a flight from Baltimore to Louisville, a distance of 458 nm., must be at or below 28,000 ft. as it crosses the Charleston/Falmouth sector boundary in Indianapolis Center, roughly 150 nm. from its destination. A DC9 will burn 6,554 lb. of fuel on this trip. If that restriction is removed, the same flight will burn 6,466 lb., a savings of 88 lb. or 1.3%.

The overall results of the analysis are consistent with the example above. A total of 23 cases were examined for a combination of routes (Washington National to Cincinnati, Atlanta to Indianapolis, Baltimore to Louisville, Albuquerque to Cincinnati, and Fort Worth to Cincinnati) and the aircraft types that would typically fly those routes. Fuel savings were shown to fall approximately between 100 and 200 lb., or 0.5 to 1.5%. The average was 130 lb., or 1.1%. Based on inspection, similar benefits could be expected from the removal of additional sector boundary restrictions. These savings are clearly significant, particularly considering the fact that the analysis was limited in scope to internal sector boundary crossing restrictions. An even greater benefit could be accrued by removing restrictions between adjacent centers due to the longer flying times and distances involved.

Operational personnel at ZID and ZME have been conducting evaluations of relaxing altitude restrictions since October 1999. These evaluations are conducted to understand the operational implications of relaxing and possibly removing restrictions. Evaluations in December 1999 and February 2000 at ZID enabled many aircraft to stay higher longer. Table 5-2 is a summary of the evaluations and an estimate of the fuel saved. Extrapolating these results for restrictions that are likely candidates for relaxation at ZID, there is potential for fuel savings of several million gallons annually just for ZID.

Table 5-2. Summary of Restriction Relaxation Evaluations

	Facility		RESTRICTIONS	IMPACT		
Date	**ZID**	**ZME**	**Restriction Description**	**Number of Aircraft**	**Average longer distance at altitude per a/c, miles**	**Average Fuel Saved per aircraft, Gallons**
12/29/99	X		FL310 or below Indianapolis arrivals	4	59	11
12/30/99	X		FL290 or below for Nashville arrivals	1	73	20.4
2/24 — 2/25/00	X		FL310 or below Indianapolis arrivals	18	57	8
2/25/00	X		FL290 or below for Columbus arrivals	10	54	7

Further analysis is required to determine exactly how many restrictions can be relaxed or removed with URET and how many flights are affected by those restrictions in order to determine the total benefit. ZID intends to evaluate additional restrictions during the next several months.

Section 6

Plan for URET Benefits Measurement and Accrual During FFP1

As part of the FFP1 program, benefits for each of the FFP1 capabilities will be measured before the tools are in place then while the tools are being used. In addition to measuring the benefits, a program to actively pursue the accrual of benefits will take place. URET CCLD will be implemented at seven ARTCCs starting in late 2001. Indianapolis and Memphis centers will be fully operational with URET CCLD very quickly since they have been operational with the URET prototype for several years. The other five CCLD sites will require several months of training before the facility is completely operational.

Benefits Measurement

Even before CCLD is implemented, benefits metrics data will be collected. Benefits data will be collected based on Indianapolis and Memphis center s usage of the URET prototype. Also, baseline data will be collected at the other five centers to eventually compare pre- and post-URET usage. The data collected will include observed metrics and daily use metrics.

The observed metrics work is described in [FAA, 1999] Performance Metrics: An Operational Impact Evaluation Plan . The observed metrics include:

- Time and distance at cruise
- Percent of time at cruise altitude
- Aggregate degrees turned
- Air distance

These metrics attempt to measure the overall impact on the ATC system within the area where FFP1 capabilities are implemented.

The daily use metrics attempt to quantify the use of URET by the controllers that would impact safety, productivity, and user benefits. The daily use metrics include:

- Average number of Trial Plans created in the center per hour URET was available
- Number of amendment messages sent to Host
- Number of amendments to the flight plan that shorten the route
- Distance saved from lateral amendments
- Auto Reprobe Count

- Explicit use of Conflict Information (show plan)
- Use of Future Time feature on GPD
- Usage by center area
- Correlation to traffic level

Benefits Accrual

A restriction analysis will be done for all of the CCLD sites to determine which altitude restrictions have the greatest impact on flights and which of those the facility feels could be removed from an operational viewpoint. These analyses will initially be done at Indianapolis and Memphis in 1999 and 2000 using the capabilities of the URET prototype. Evaluations to assess the affect of removing selected restrictions will be carried out during 2000. If these evaluations prove to have a positive affect on ATC operations, then some of the restrictions could be removed permanently. These analyses and evaluations will form the basis for similar analyses of the other five sites. During 2001, the entire restriction analysis process will be conducted for the other five URET CCLD sites. By the time the five new sites approach operational usage, a plan for removing restrictions within those facilities will already be in place.

In addition to altitude restrictions, there are preferred routes that are flown between city pairs and through large blocks of airspace that do not correspond to any single facility boundary. Some of these routes can be circuitous causing additional flying time and distance. An analysis of these routes will also be done to determine if more direct routings or no preferred routing can be given with URET CCLD in operation.

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Glossary

ARTCC	Air Route Traffic Control Center
CCLD	Core Capability Limited Deployment
CDM	Collaborative Decision-Making
CHI	Computer Human Interface
DFW	Dallas/Ft. Worth
DR	Discrepancy Report
ETMS	Enhanced Traffic Management System
FAA	Federal Aviation Administration
FFP1	Free Flight Phase 1
FL	Flight Level
GPD	Graphic Plan Display
IFR	Instrument Flight Rules
NADIN	National Airspace Data Interchange Network
NAS	National Airspace System
NRC	National Research Council
NRP	National Route Program
OE	Operational Error
pFAST	Passive Final Approach Spacing Tool
PVD	Plan View Display
SA	Situational Awareness
SID	Standard Instrument Departure
SMA	Surface Movement Advisor
SOP	Standard Operating Procedure
STAR	Standard Terminal Arrival Route
SUA	Special Use Airspace
TMA	Traffic Management Advisor

TMAC	Traffic Management Analysis Capability
UPR	User Preferred Routing
URET	User Request Evaluation Tool
VFR	Visual Flight Rules
ZID	Indianapolis Air Route Traffic Control Center
ZME	Memphis Air Route Traffic Control Center