FACET: Future ATM Concepts Evaluation Tool

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**FACET (Future Air Traffic Management Concepts Evaluation Tool) is a
simulation and analysis tool developed at the NASA Ames Research Center.
This paper introduces the design, architecture, functionalities and appli-
cations of FACET. The purpose of FACET is to provide a simulation envi-
ronment for exploration, development and evaluation of advanced Air
Traffic Management concepts. FACET models system-wide airspace opera-
tions over the contiguous United States. The architecture of FACET strikes
an appropriate balance between flexibility and fidelity, enabling it to
model the trajectories of over 5,000 aircraft on a single desktop computer
running on any of a wide variety of operating systems. FACET has proto-
types of several advanced Air Traffic Management concepts: airborne self-
separation; a decision support tool for direct routing; advanced traffic flow
management techniques; and the integration of space launch vehicle op-
erations into the U.S. National Airspace System.**

INTRODUCTION

The global Air Traffic Management (ATM) system faces the challenge
of increasing system capacity and flexibility to accommodate traffic
growth and user preferences, while maintaining or improving the
current level of safety. In order to achieve these goals, new ATM
concepts must be explored and evaluated prior to field-testing and

eventual deployment. Therefore, an ATM system model is necessary for simulation evaluations of new ATM concepts.

A variety of ATM system models have been developed by various organizations, many of them tailored to a specific set of applications. For example, [Andreatta et al., 1999] presents a set of models for airport planning. A NASA-sponsored comprehensive study on existing and required modeling capabilities for evaluating ATM systems and concepts is reported in [MIT, 1997]. It includes functional descriptions of numerous existing models, such as RAMS (Reorganised ATC Mathematical Simulator), SIMMOD (Simulation Model), and TAAM (Total Airspace and Airport Modeler).

FACET (Future ATM Concepts Evaluation Tool) was developed to meet anticipated requirements for advanced ATM concept development and evaluation activities under NASA's Advanced Air Transportation Technologies (AATT) Project. Based on these requirements, it was determined that there was a need for a flexible modeling environment that would facilitate: (1) Rapid prototyping of diverse ATM concepts; (2) Modeling of new vehicle classes such as space launch vehicles; and (3) Collaborative research and development efforts with other organizations. It is believed that existing ATM models cannot provide the high level of flexibility necessary for realizing all of the above three capabilities.

This paper provides an introduction to FACET. It begins with an overview, and then presents details about the architecture and capabilities of FACET. Finally, the paper presents a description of several advanced ATM concepts that are currently at various stages of evaluation in FACET.

OVERVIEW OF FACET

FACET was designed to provide a flexible simulation environment for the exploration, development and evaluation of advanced ATM concepts. Evaluations of concept feasibility do not generally require a high level of simulation detail. Therefore, FACET's architecture strikes an appropriate balance between flexibility and fidelity, enabling it to model airspace operations at the U.S. national level, and process over 5,000 aircraft on a single desktop computer (e.g., Sun Ultra1, Pentium based PC, Macintosh G3) for a wide variety of operating systems. The core of FACET was designed to provide initially only those modeling features (e.g., airspace and trajectory models) that would be required for the evaluation of virtually any ATM concept application. Other modeling features are added as required by individual ATM concept applications.

FACET models system-wide airspace over the entire contiguous

United States. The airspace model includes geometric descriptions of Air Route Traffic Control Centers (ARTCCs or "Centers"), their sectors (low, high and super-high), Victor Airways, Jet Routes, Standard Instrument Departures (SIDs) and Standard Terminal Arrival Routes (STARs), as well as the locations of airports and fixes (navigation aids and airway intersections). FACET is hierarchically compatible with the Center-TRACON Automation System (CTAS) [Erzberger et al., 1993] in terms of scope and fidelity. The national-level flexible modeling capabilities of FACET will complement the Center-level high-fidelity modeling capabilities of CTAS. In addition to exploring future ATM concepts, FACET will also support the future development of CTAS by providing a simulation environment for preliminary testing and evaluation of new controller Decision Support Tools.

FACET models four-dimensional (4D) aircraft trajectories in the presence of winds using round-earth kinematic equations. Aircraft can be flown along flight plan routes or direct (great circle) routes as they climb, cruise and descend according to their individual aircraft-type performance models. Performance parameters (e.g., climb/descent rates and speeds, cruise speeds) are obtained from data table lookups. Heading and airspeed dynamics are also modeled. FACET can predict the future locations of aircraft; these data can be supplied to application modules implementing advanced traffic flow management concepts. It also has graphic capabilities for data analysis and visualization.

FACET utilizes oblique stereographic projection (and its inverse) for displaying airspace features and air traffic movement on a menu-driven Graphical User Interface (GUI). It can be operated in real-time, fast-time, or slow-time, with various options described later in the following sections.

FACET ARCHITECTURE AND FUNCTIONALITIES

This section first describes the system architecture of FACET, and then details its various functionalities, including trajectory, weather and airspace modeling, system operating modes, and Graphical User Interface.

System Architecture

The FACET software integrates two distinct components: (1) Data computation using the "C" programming language; and (2) Display of information through a GUI written in the "Java" programming language. This feature has enabled the portability of FACET software to computers running on several operating systems: Unix, Windows NT, MacOS, and Linux.

FACET was designed with a modular architecture to facilitate rapid prototyping of advanced ATM concepts. Each ATM concept application is implemented as an individual module linked to the core structure of FACET. This core provides modeling features (e.g., airspace and 4D trajectories) required for the evaluation of almost any ATM concept.

A conceptual representation of FACET's architecture is presented in Figure 1. Details of the various databases and modules are provided in the following three subsections on Trajectory Modeling, Weather Modeling, and Airspace Modeling. Data inputs to FACET include an airspace database, an aircraft performance database, air traffic data (track, flight plan and schedule) from an appropriate source such as the Enhanced Traffic Management System (ETMS), and weather data.

FACET can be run either in playback mode or simulation mode. In the playback mode, track data are sent to the GUI for display. In the simulation mode, a 4D trajectory is synthesized from a set of initial conditions (that may either be derived from real track data or custom designed for a specific application) using various routing and navigation options, as described below.

Trajectory Modeling

In the simulation mode, 4D aircraft trajectories are determined from a set of initial states, using either the Direct (great circle) Routing
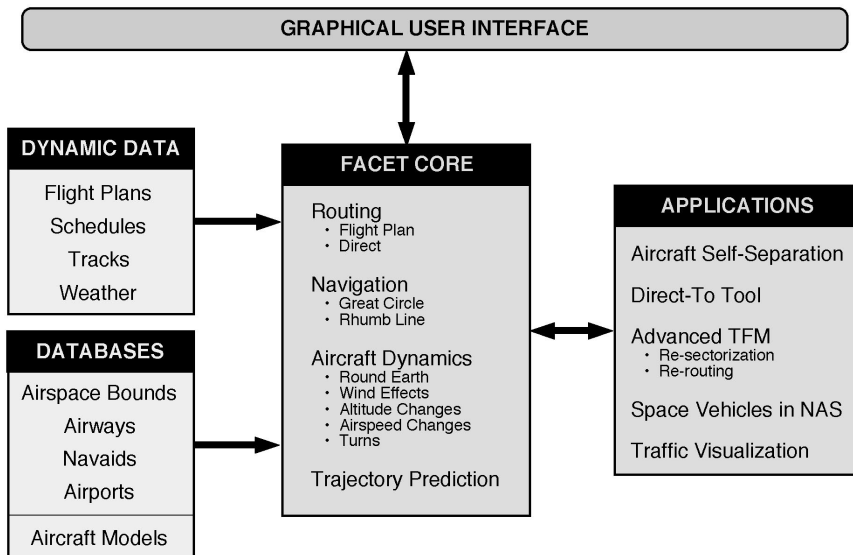
Figure 1. Conceptual Representation of FACET Architecture

option or the Flight Plan Routing option, as specified by the user. The Direct Routing module extracts the destination airport identifier from the flight plan and then determines the latitude and longitude of the destination point from the Airspace Database. The Flight Plan Routing module ingests the entire flight plan, which contains route information expressed in terms of the names of fixes (navigation aids and airway intersections), Fix Radial Distance, and special waypoint coordinates. The names of fixes are converted into positions using the Airspace Database. The Fix Radial Distance specifies a location in terms of distance and bearing from a fix. Thus, using the coordinates of the fix from the Airspace Database, the location specified by the Fix Radial Distance is obtained. Finally, the Flight Plan Routing module employs a flight plan parsing algorithm that reads the flight plan information and creates an ordered sequence of coordinates (latitudes and longitudes) that specify the locations of all waypoints defining the route of flight.

Based on the user-selected routing option, the coordinates of either the destination point (airport) or the next waypoint on the flight plan route are computed by the appropriate routing module (Direct Routing or Flight Plan Routing). These coordinates are then sent to the Route Navigation module, which uses great circle navigation to determine the course angle to the next navigation point. An option for rhumb line navigation (constant course angle) is also available. It is noted that a direct route is flown as a single great circle, while a flight plan route is flown as a series of individual great circles (or, optionally, rhumb lines) connecting the waypoints. Using the current latitude-longitude coordinates (λ, τ) of the aircraft and the latitude-longitude coordinates (λ^*, τ^*) of the appropriate navigation point (destination point for Direct Routing option, or next waypoint for Flight Plan Routing option), the course angle χ_{GC} for great circle navigation (or χ_{RL} for rhumb line navigation) can be calculated. For example, the great circle navigation law [Chatterji et al., 1996] is given by

$$\chi_{GC} = \tan^{-1} \left\{ \frac{\sin(\tau^* - \tau)\cos\lambda^*}{\sin\lambda^* \cos\lambda - \sin\lambda \cos\lambda^* \cos(\tau^* - \tau)} \right\} \qquad (1)$$

The Route Navigation module finally computes the heading angle command, χ_{com}, by adding a wind correction angle to the great circle (or rhumb line) course angle. The aircraft heading angle, χ, is then obtained from the Heading Dynamics module as the response of a first-order system with proportional feedback, subject to bank angle limits.

FACET's Performance Database contains performance models for

66 different aircraft types; it also contains an equivalence list that maps over 500 aircraft types recognized by the Federal Aviation Administration (FAA) to these 66 performance models. For climbs/descents, the airspeed and altitude-rate are derived from the calibrated airspeed (CAS) and Mach schedules for the particular aircraft type. For cruise flight, the airspeed is derived from cruise schedules for the particular aircraft type.

The pressure altitude h resulting from an altitude command, h_{com} (e.g., cruise altitude), is obtained from the Altitude Kinematics module as the response of a first-order system with proportional feedback, subject to altitude-rate limits obtained from the Performance Database.

Using information on altitude and altitude-rate, the Aircraft Performance module determines the airspeed command, V_{com}, from a performance table lookup for the appropriate aircraft type. The airspeed, V, is then obtained from the Airspeed Dynamics module as the response of a first-order system with proportional feedback, subject to acceleration limits derived from the Performance Database.

The Latitude and Longitude Kinematics module integrates the round-earth equations of motion given by

$$\dot{\lambda} = \frac{1}{R}\,(V\cos\gamma\,\cos\chi + W_N) \tag{2}$$

$$\dot{\tau} = \frac{1}{R\cos\lambda}\,(V\cos\gamma\,\sin\chi + W_E) \tag{3}$$

where the flight-path angle, γ, is approximated by

$$\gamma \approx \sin^{-1}(\dot{h}/V) \tag{4}$$

In Eqs. (2) and (3) above, W_N and W_E are the north and east components of the wind speed, and $R = R_e + h_g$, where R_e is the mean radius of the earth and h_g is the geometric altitude. However, since $h_g \ll R_e$ for atmospheric flight, the approximation $R \approx R_e + h$ is used, where h is the pressure altitude.

Weather Modeling

FACET utilizes weather data generated by the Rapid Update Cycle version 2 (RUC-2), available on an hourly basis from the National Center for Environmental Prediction [Benjamin et al., 1998]. RUC-2 provides short-term forecasts of wind and temperature profiles

(along with other atmospheric and surface parameters) over various time intervals ranging from 1 hr to 12 hrs. The horizontal resolution of the RUC-2 grid is 40 km, and the vertical resolution includes 37 isobaric levels corresponding to pressure altitudes ranging approximately from sea level to 53,000 ft.

Airspace Modeling

A general description of airspace features can be found in [Nolan, 1994]. FACET contains a comprehensive Airspace Database that represents the geometry and structure of the airspace in the 20 ARTCCs covering the contiguous United States. It defines the horizontal boundaries of all 20 ARTCCs as well as the horizontal and vertical boundaries of all sectors (low altitude, high altitude, and super-high altitude) within each ARTCC.

Representations of airways (both Victor Airways and Jet Routes) are available in terms of the fixes (navigation aids and airway intersections) that define them. Position data for each fix are available within the Airspace Database. SIDs and STARs are defined as sequences of waypoints specified as latitude-longitude pairs. The locations of over 13,000 U.S. airports are also available.

System Operating Modes

FACET can operate in either simulation mode or playback mode, as selected by the user. In simulation mode, FACET generates trajectories using initial conditions obtained from track and flight plan data. This mode is appropriate for the testing and evaluation of new ATM concepts implemented in FACET. In playback mode, FACET replays track data from a recorded data file. This mode is appropriate for data visualization applications.

Both of the above modes can be operated in a synchronous or asynchronous manner. Synchronous operation is recommended if the user wishes to maintain a fixed correlation (in fast-time, real-time, or slow-time) between trajectory update display and clock time; this is accomplished by introducing an appropriate time delay between computation and display of results. During synchronous operation, there is a linear proportional relationship between trajectory time stamps and clock time (the constant of proportionality is called the time-scale factor), and the display is updated at regular time intervals. This is the default operational state for both simulation and playback modes.

Asynchronous operation is recommended if the user wishes to move through the simulation/playback as quickly as possible; this is accomplished by displaying results as soon as computations are com-

pleted. During asynchronous operation, there is a nonlinear monotonic relationship between trajectory time stamps and clock time, and the display is updated at irregular time intervals.

Graphical User Interface

The control and display of all information in FACET is achieved through a Graphical User Interface (GUI). The GUI is written using "Swing" and the Abstract Window Toolkit, which is available with the Java Development Kit. The motivation for developing the GUI in "Java" was to facilitate the transfer of FACET software to various computer platforms. Architecturally, FACET has been designed so that all of the data computations are performed in the "C" programming language, and the information display graphics are done in the "Java" programming language. The integration of the Java-based GUI with the underlying C-code data computation is accomplished through the use of the Java Native Interface.

Figure 2 shows an example Graphical User Interface, which consists of a display canvas, a menu bar, and a status bar. The canvas is primarily used to display the selected airspace boundaries, aircraft locations, flight plans, track histories, and aircraft Flight Data Blocks. FACET is menu-driven, and the main menu bar contains the following options: Animation, Simulation, Airspace, Aircraft, and Applications (see Figure 2). From the Animation Menu, the user can pause, resume, restart, or terminate the current operational mode.

The Simulation Menu is used for selecting an input file to run FACET in Playback Mode, or Simulation Mode with either Direct (great circle) Routing or Flight Plan Routing. This menu also provides the option to run FACET in either synchronous or asynchronous operation mode. Additionally, the Simulation menu provides the capabilities for manually adding aircraft to a simulation and for recording aircraft track data (actual or predicted) over a user-selected ARTCC.

The Airspace Menu controls the display of various airspace features. For example, the 20 ARTCCs over the contiguous United States can be displayed along with their sector (low, high, and super-high) boundaries. Other airspace features include navigation aids / fixes, Jet Routes, and Victor Airways. The user can zoom in and out of the displayed area and translate across the airspace. This menu also provides the user with options for displaying specific waypoints and airways. When the user clicks on any of the displayed waypoints, the name and coordinates of the waypoint appear in the status bar at the bottom of the GUI. The Airspace menu also provides access to the airspace redesign capabilities of FACET (described in the next section). Using this capability, the user can modify sector boundaries or load a previously saved airspace design in real-time.
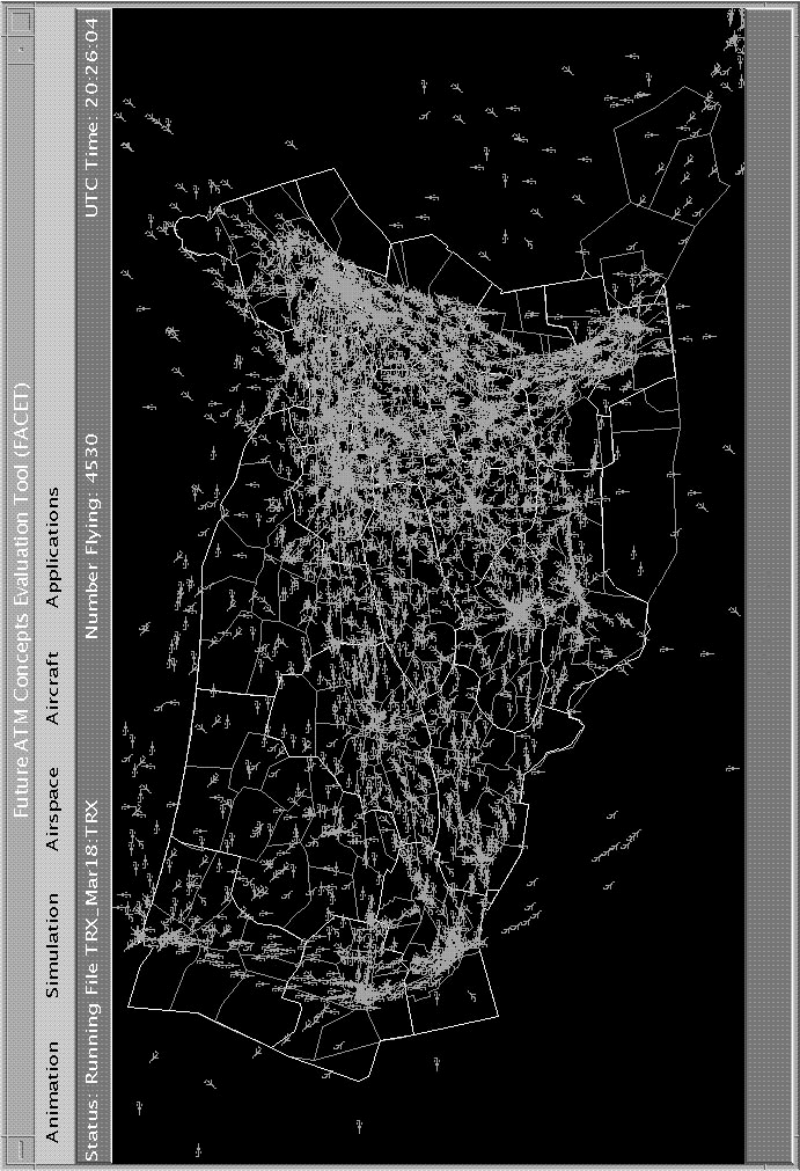
Figure 2. FACET Graphical User Interface

By interacting with the Aircraft Menu, the user controls the amount of information displayed for selected (or all) aircraft in an active simulation. This menu provides options for specifying the contents of the aircraft Flight Data Block, modifying an aircraft's flight plan, toggling the display of both flight plans and track histories, and placing size-selectable range-rings around aircraft. In addition to displaying information for specific aircraft, the user can also filter the displayed aircraft based on user-specified combinations of altitude strata, airline, and aircraft type.

The last element of the menu bar is the Applications Menu. This menu allows the user to access application modules for advanced ATM concepts that are currently being implemented in FACET. Some of them are described in the following section.

ADVANCED ATM CONCEPTS IN FACET

This section describes some advanced ATM concepts that are currently at various stages of implementation and evaluation in FACET. These descriptions are not intended to be comprehensive treatments of the individual ATM concepts; the objective is to highlight some of the possible applications of FACET.

Aircraft Self-Separation

Distributed Air/Ground Traffic Management (DAG-TM) is an advanced ATM concept for mature Free Flight operations [Green et al., 2000]. In the current air traffic control system, the decision-making authority for air traffic separation is centralized, and resides with the ground-based air traffic controllers. DAG-TM corresponds to a decentralized paradigm of air traffic operations, featuring distributed decision-making between three entities: flight deck, air traffic service provider (ATSP), and aeronautical/airline operational control (AOC). In the DAG-TM paradigm, ATSP personnel may delegate separation responsibility to the pilots of appropriately equipped aircraft under certain operational conditions. An airborne conflict detection and resolution (CD&R) capability is a key requirement for this "Free Maneuvering" aspect of DAG-TM.

Two qualitatively different aircraft-centered CD&R algorithms have been implemented in FACET to conduct studies on Free Maneuvering. One CD&R scheme utilizes a modified potential-field approach [Eby, 1994; Eby and Kelly, 1999] to compute conflict avoidance commands that are updated at each cycle, which generally results in continuous path modification. In a multiple conflict situation, each aircraft uses an avoidance command equal to the vector sum of the avoidance commands for all its individual conflicts.

The other CD&R scheme resolves conflicts using a geometric optimization approach [Bilimoria, 2000] that attempts to minimize deviations from the nominal path. Although conflict avoidance commands are updated at each cycle, this approach nominally resolves a conflict by commanding a single discrete path change; upon completion of the conflict avoidance maneuver, an additional command returns the aircraft to its preferred path. In a multiple conflict situation, each aircraft sequentially resolves its most immediate conflict until all conflicts are resolved. Figure 3a shows a challenging test scenario featuring an eight-aircraft encounter that results in multiple conflicts (without CD&R). Figure 3b shows the same test scenario with the Geometric Optimization CD&R scheme engaged; all conflicts were resolved.

A realistic free flight traffic scenario has been developed in FACET for the Denver Center airspace, using initial conditions based on a set of real ETMS air traffic data. This scenario was used as a test environment to evaluate the feasibility of airborne separation assurance for Free Flight. It was found that the impact of self-separation on air traffic operations, as measured by the performance metrics of path-length changes, flight-time changes, and system stability was relatively small [Bilimoria et al., 2000].

Benefits Study of the CTAS Direct-To Tool

Several studies have shown that airlines can realize significant time/fuel savings and other benefits by flying user-preferred direct routes instead of the current ATC-preferred routes. The CTAS Direct-To Tool [Erzberger et al., 1999] belongs to the CTAS family of controller Decision Support Tools. It searches through all aircraft within an ARTCC airspace, and identifies aircraft that could save flight time by flying a direct route instead of following the flight plan route. The CTAS Direct-To Tool has been extensively tested using real traffic data from the Fort Worth Center.

A direct-routing algorithm has been implemented in FACET. Air traffic data from the Fort Worth Center were used to calibrate the FACET Direct-To implementation relative to the CTAS Direct-To implementation. The FACET Direct-To simulation was run using ETMS data to estimate benefits for 20 ARTCCs in the U.S. National Airspace System (NAS). Initial results indicate NAS-wide savings of up to $200M per year using the Direct-To Tool [Sridhar et al., 2000]. The impact of Direct-To Tool utilization on traffic patterns in the Fort Worth Center was also studied; preliminary results indicate that the Direct-To Tool's implementation does not significantly change the number or location of conflicts.
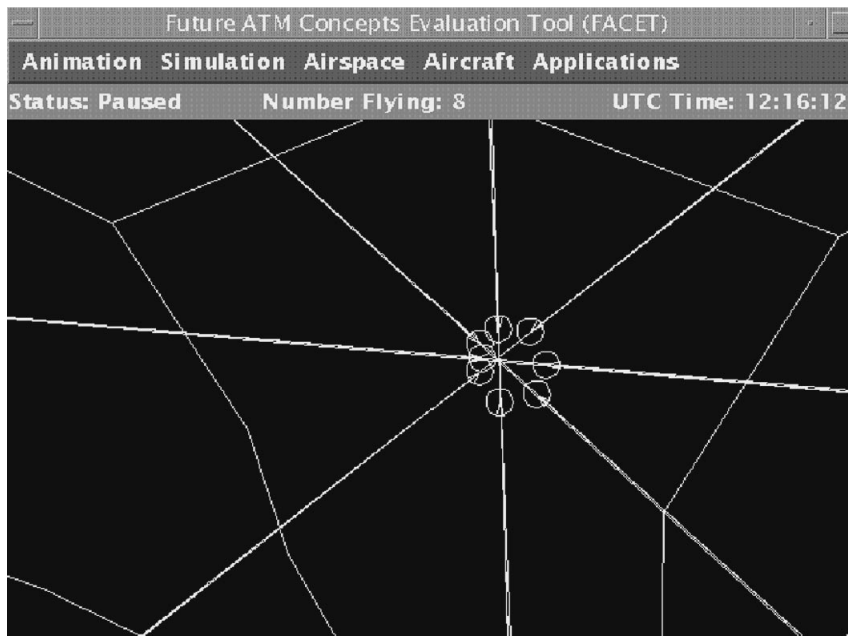
Figure 3a. Test Scenario without CD&R.
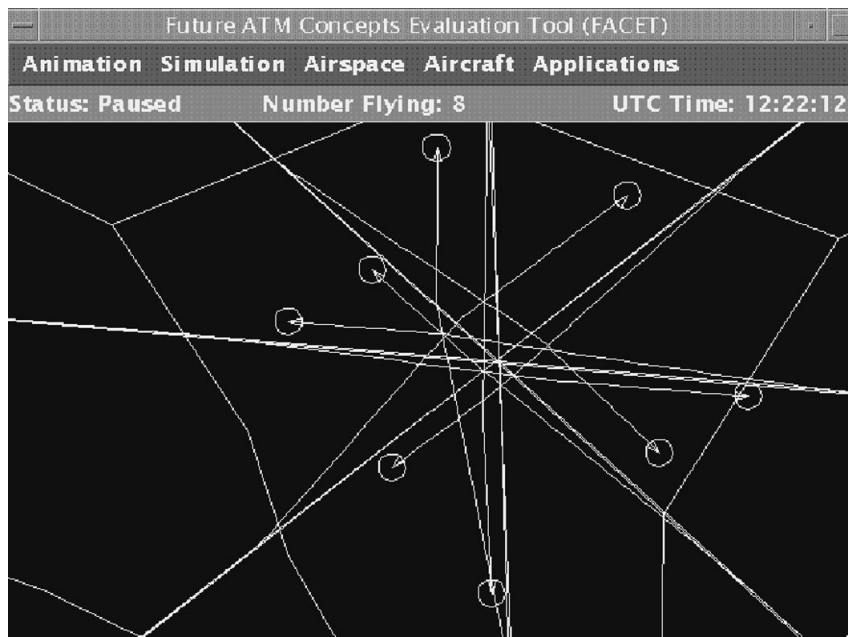
Figure 3b. Test Scenario with CD&R using Geometric Optimization.

Advanced Traffic Flow Management

Predicted growth in air traffic, and the desire for more user-preferred routes in the NAS, will require advanced techniques and tools to efficiently manage the flow of air traffic. There will be times when the

projected traffic load in a local region of airspace will exceed the abilities of the human controllers to safely and efficiently handle the traffic flow. This load can be balanced by reconfiguring local airspace (sector) boundaries, or by rerouting aircraft to change the pattern of traffic flow.

There is a need to understand the effect of changing airspace configurations and traffic flow patterns on the workload of air traffic controllers. This complex relationship is referred to as "Airspace Complexity." Research indicates that "Dynamic Density" is a good measure of airspace complexity [Chatterji and Sridhar, 1999]. Dynamic Density is a function of the number of aircraft and their changing geometries in a given airspace. In order to utilize Dynamic Density in a Traffic Flow Management (TFM) tool, it is necessary to project its behavior over the planning time horizon.

A Dynamic Density measure that was derived from actual controller workload and air traffic data [Laudeman et al., 1998] has been implemented in FACET. Using the trajectory prediction capabilities of FACET (based on flight plans and aircraft performance models), the aircraft states can be calculated at various times along the planning horizon. These predicted aircraft positions and speeds are then used to calculate the Dynamic Density at the corresponding times, up to 30 minutes in advance. The prediction time horizon is limited primarily by the accuracy of departure time estimates [Sridhar et al., 1998].

An example of Dynamic Density distributions is shown in Figure 4a. In this particular example, a 20-minute prediction of Dynamic Density values for all of the high-altitude sectors in the Denver Center is displayed. It can be seen that the Dynamic Density in the central sector is predicted to reach a value of 130.6 after 20 minutes. For illustrative purposes, the boundaries of this sector were manually reconfigured (as shown by the arrows in Figure 4a) in an attempt to reduce the build-up of Dynamic Density over the next 20 minutes. Figure 4b shows the resulting changes in the distribution of dynamic densities. It can be seen that the 20-minute prediction of Dynamic Density in the central sector has decreased to 84.2, at the expense of increased dynamic density in the neighboring sector to the north. The airspace reconfiguration obtained in this illustrative example may be acceptable if the predicted values of Dynamic Density in the two affected sectors are within acceptable limits.

Tools for automated airspace redesign and aircraft rerouting are under development in FACET. These Traffic Flow Management tools will make it possible to easily modify airspace configurations and traffic flows at the sector (or even ARTCC) level, and evaluate their impact on air traffic operations by utilizing proven guidelines for airspace complexity and controller workload measures.
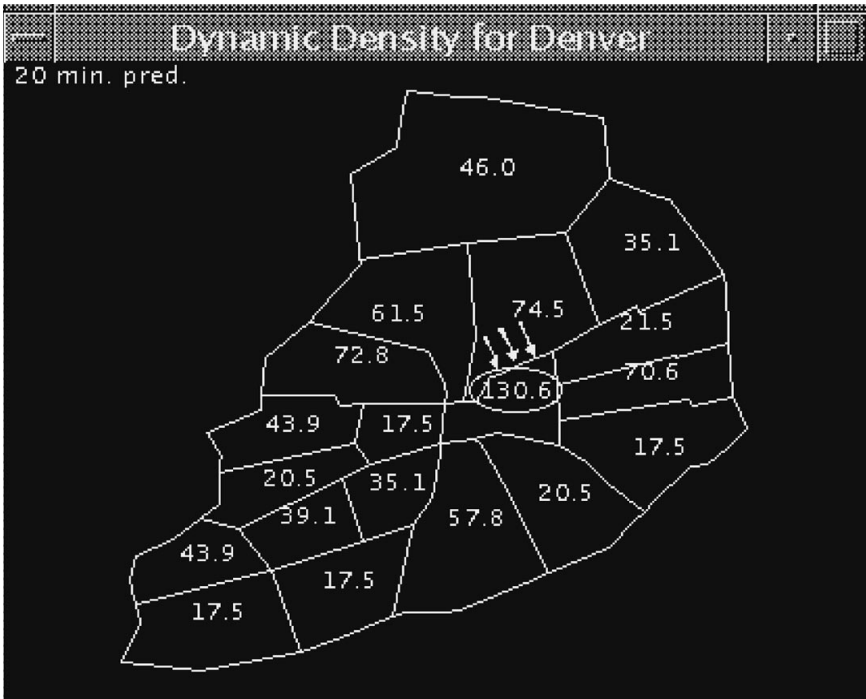
Figure 4a. Dynamic Density Distributions Before Resectorization.
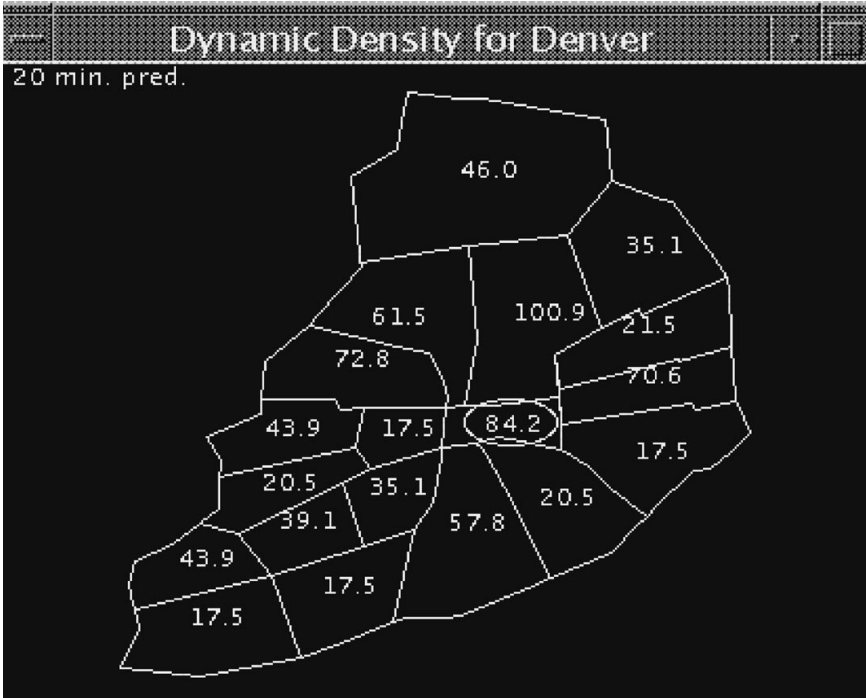

Figure 4b. Dynamic Density Distributions After Resectorization.

Space Launch Vehicle Operations in the NAS

Due to the increasing emphasis on affordable access to space, the number of space launch vehicle operations is projected to increase significantly over the next decade [FAA, 1998; FAA 1999]. For example, [FAA, 1999] states that market forecasts indicate launch rates in excess of 1 per week by 2005. New spaceports may be built to accommodate this increase, and some of them may be located inland. Space launch vehicles operate within the NAS during a portion of their ascent to orbital (or suborbital) altitude; Reusable Launch Vehicles (RLVs) also operate within the NAS during a portion of their descent and fly-back to a spaceport. The amount of time spent in the NAS during ascent is of the order of 90 seconds; the amount of time spent in the NAS during RLV descent is of the order of 300 seconds.

In order to assure safe separation between all user classes, the ATM system currently treats space launch vehicle operations as special events and reserves large volumes of airspace, referred to as Special Use Airspace (SUA), for these activities by removing them from airspace available for use by commercial and general aviation aircraft. These SUA envelopes are very large because in addition to a safety buffer around the nominal trajectory, they must also include very conservative estimates of airspace allocation for off-nominal operations and emergency situations (e.g., launch abort go-around trajectories for RLVs). Also, SUA regions often remain active for periods of time that are far greater than the actual flight time spent in the NAS. The current mode of operations may be appropriate for infrequent launches that are truly "special" events. However, as the number of space launch vehicle operations increases to a point where they become routine (rather than special) events, the corresponding growth of SUA may have a significant adverse impact on the operations of other airspace users. This provides the motivation to model space launch vehicle operations and study their interaction with other vehicle classes in the NAS to optimize the use of airspace for both conventional and special users.

Work is underway to model space launch vehicle trajectories in FACET. As an illustrative example of current analysis capabilities, Figure 5a shows a possible airspace corridor for an RLV returning to a spaceport while Figure 5b shows, as a function of time, the instantaneous number of aircraft whose nominal routes pass through this corridor. The total number of aircraft affected by the activation of this RLV airspace corridor depends on the duration of activation; this cumulative value would, of course, be far greater than the instantaneous values shown in Figure 5b. A current research objective is to study the interactions of space launch vehicle traffic with air traffic,
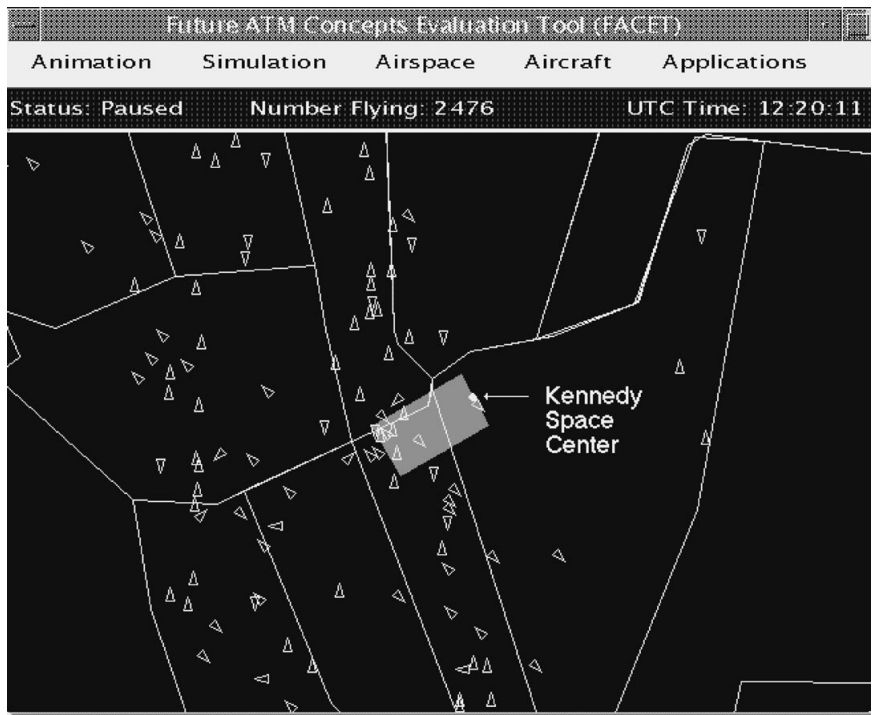
Figure 5a. Example of RLV Airspace Corridor.
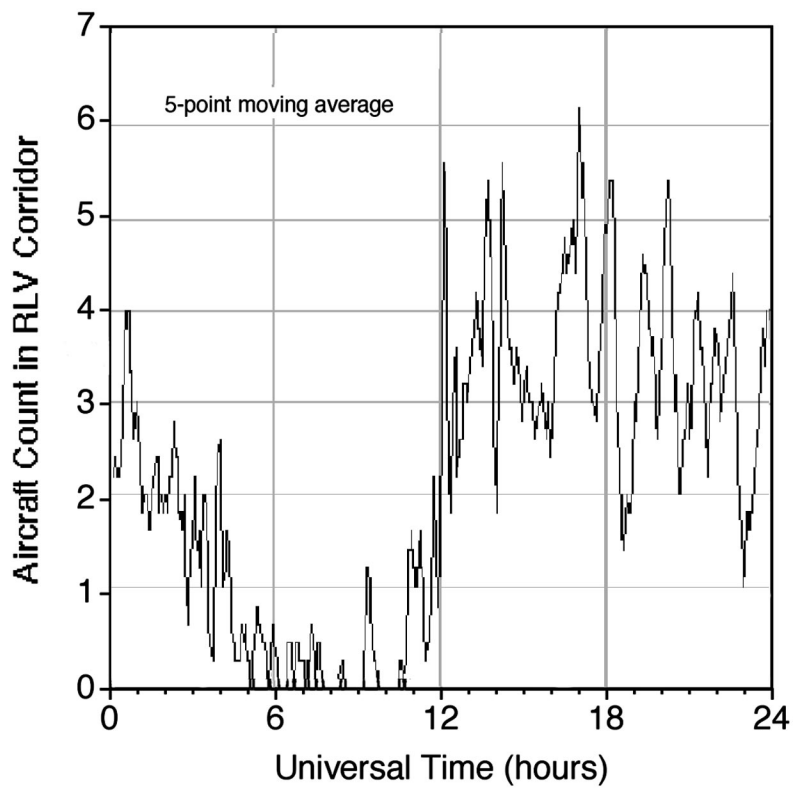
Figure 5b. Instantaneous Count of Aircraft in RLV Corridor.

and to investigate the feasibility of dynamic allocation of space access corridors to optimize airspace usage for both of these user classes.

SUMMARY

The design, architecture, and functionalities of the Future ATM Concepts Evaluation Tool have been presented. FACET's core capabilities include system-wide modeling of airspace and 4D trajectories. Its modular architecture facilitates rapid prototyping and evaluation of advanced ATM concepts. Several of these concepts have been summarized.

FACET's capabilities are being expanded to meet the needs of NASA and the FAA in the area of air and space vehicle operations, in collaboration with industry and universities. Some of these activities will support feasibility evaluations of the Distributed Air/Ground Traffic Management concept of operations. Other activities will focus on the development of advanced techniques and tools for system-level Traffic Flow Management. Applications include decision support for TFM initiatives such as rerouting around airspace regions constrained by workload or weather, miles-in-trail spacing, en route metering, and ground delay.

ACKNOWLEDGMENTS

ACRONYMS

4D	four-dimensional
AATT	NASA's Advanced Air Transportation Technologies program
AOC	aeronautical/airline operational control
ARTCC	Air Route Traffic Control Center
ATM	Air Traffic Management
ATSP	air traffic service provider
CAS	calibrated airspeed
CD&R	conflict detection and resolution
CTAS	Center-TRACON Automation System
DAG-TM	Distributed Air/Ground Traffic Management
ETMS	Enhanced Traffic Management System
FAA	Federal Aviation Administration

FACET $\underline{F}$uture $\underline{A}$ir Traffic Management $\underline{C}$oncepts $\underline{E}$valuation $\underline{T}$ool
GUI   Graphical User Interface
NAS   National Airspace System
RAMS   Reorganised ATC Mathematical Simulator
RLV   Reusable Launch Vehicle
RUC-2   weather data generated by the Rapid Update Cycle, version 2
SID   Standard Instrument Departure
SIMMOD   Simulation Model
STAR   Standard Terminal Arrival Route
SUA   Special Use Airspace
TAAM   Total Airspace and Airport Modeler
TFM   Traffic Flow Management

SYMBOLS

h pressure altitude
h_{com} commanded pressure altitude
h_g geometric altitude
R_e mean radius of the earth
V airspeed
V_{com} commanded airspeed
W_E east component of wind speed
W_N north component of wind speed
χ heading angle
χ_{com} heading angle command
χ_{GC} course angle using great circle navigation
χ_{RL} course angle using rhumb line navigation
γ flight-path angle
λ latitude of aircraft
λ^* latitude of navigation point
τ longitude of aircraft
τ^* longitude of navigation point

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