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FAA/NASA R&D FOR FUTURE AIRPORT AND TERMINAL-AREA OPERATIONS

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INTRODUCTION

I would like to talk today to just one of the elements of our R&D program in the FAA's Advanced Concepts Division of which I am a part. This is a topic we call terminal area ATC automation in the Agency's R,E&D Plan.

Mr. Cirino mentioned at the outset that the NAS plan is the document to which they turn to find out what the FAA is doing. What I am about to talk about is not a part of the NAS plan but is described in the FAA R,E&D Plan which picks up where the NAS plan leaves off. To pick up on Dr. Gosling's last point, there is a need for sustained activity in both research and development of concepts to improve capacity and efficiency of operations of our nation's terminal areas. I would like to go back to an earlier point he made in his presentation, however, and say that we need to make a distinction between development, where we know what it is we are trying to develop, and research where we are trying to figure out what it is we need to develop. Our terminal automation program encompasses both activities.

Briefly, I will outline some of the National Airspace System (NAS) inefficiencies we perceive it is possible to substantially reduce with further automation and communication improvements. I will talk about the objectives and scope of our proposed program and about some of the activities that are already going on.

It is important to say that at the moment for we are still putting the program together and that this is an opportunity for you to provide inputs. We expect to seek management approval of our proposed program and for the necessary resources in a few months, so where you feel our priorities should be either changed or reinforced, I urge you in the workshop sessions that are to follow to think those through and provide us with your insight.

This program is a research effort to develop automation aids to:

- Reduce Air Traffic Control (ATC) induced delays from the top of descent (cruise altitudes) to the runway.

- Increase throughput and improve the controllers' productivity and effectiveness in handling high volumes of traffic during visual and instrument meteorological conditions

- Accommodate user-preferred trajectories (i.e., allow aircraft to fly direct and fuel efficient routes when entering or departing terminal areas)

- Facilitate the adoption of new procedures that increase airport capacity

The automation concepts will include aids to the controllers to handle arriving and departing traffic, and to facilitate coordination between controller positions. For each concept, the research will include emphasis on human-machine interactions.

The program builds upon the successes of and lessons learned from previous terminal automation efforts, and capitalizes on the ongoing modernization of NAS technology and automation functions supporting ATC and aircraft operations. The program includes initial and long-term research efforts. The initial research is aimed at providing system improvements in the current environment, where the controller remains responsible for the separation of traffic and aircraft requests are accommodated, workload permitting. Specific initial research will define controller aids for approach sequence order and efficient path definition and execution, including descent profile and optimal turn to final advisory functions.

Automation aids developed as part of the initial research are intended to provide advisories to the controllers for efficient control of traffic. The longer term research is aimed at providing system improvements in a future ATC environment where the controllers become more of a manager of the ATC process, and the aircraft assumes responsibility for meeting the flight plan negotiated with the ATC system. The research will explore and define the division of automated functions between airborne and ATC automation. ATC automation will provide planning and control commands for paths that are checked and found to be problem free for flow of traffic, and will recommend the necessary tactical control solutions for separation assurance, while the controllers remain responsible for maintaining the required separations. In the longer term research, it is assumed that the NAS plan projects (i.e., AERA, Traffic Management System, Mode S, MLS, and AAS*) have been implemented and that a majority of aircraft have area navigation capability enabling them to accurately navigate along the negotiated routes.

BACKGROUND

Today when weather permits, an aircraft generally adheres to IFR procedures to a fix after which the pilot is advised to expect vectors to the runway. When the aircrew has established visual contact with runway and with potentially conflicting traffic, the controller clears the aircraft to proceed to landing with visual separation from preceding traffic. These operations permit higher runway throughput than could be achieved by maintaining IFR separations all the way to touchdown. In the past, some efforts (3, 4) were made to automate the terminal planning and control functions with the primary objective of increasing airport capacity under IFR conditions during peak traffic periods. The automation designs from those efforts were considered to have operational limitations, as explained below. The most serious constraint was that the designs were considered to provide "inadequate controller interface with automation" (4) to be operationally acceptable.

The Computer Aided Approach System (CAAS) work in the 1960s was designed to achieve final spacings accurately and to improve landing rates. The system generated speed advisories and times to turn on the final approach. During the evaluation in a simulated environment at the FAA Technical Center, an improvement in runway throughput was demonstrated, but the system was not accepted by controllers.

In other terminal automation related studies at the FAA Technical Center, a delay fan approach concept called Transition, Approach, Local and Landing (TALL) was developed to accurately achieve final spacings between aircraft. The concept employed a variable heading command process (i.e., the computer-generated unique heading commands for the controller to give to the pilot) instead of the trombone approach (i.e., an aircraft flies a downwind path parallel to the final approach). The objective was to prevent the aircraft from flying extended downwind paths which are considered inefficient. However, the controllers were unable to predict and assess the computer generated solutions and found them unacceptable as long as they were responsible for separating aircraft. Some of the features and algorithms from above efforts were used in developing the Metering and Spacing (M&S) system design.

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* AERA - Automated En-Route ATC
MLS - Microwave Landing System
AAS - Advanced Automation System

The FAA worked on a Metering and Spacing program from the mid 1970s to early 1980s to develop and implement terminal automation at high density airports. The program was designed to automate planning and control of arrivals for a single runway operation. The traffic planning function in the M&S design was based on flight profiles that assumed separations only on the final approach. There were no conflict-free checks provided at path merge points. The control (advisory) solutions were based on procedures that generated diverse and complex advisories without conflict-free assurance. The controllers were expected to follow the system generated advisories without fully comprehending the computer generated paths, while the controllers remained responsible for assuring separation between aircraft. This raised several human/machine interaction issues, and the program was discontinued.

With the rising fuel costs in the early 1970s, the FAA developed profile descent procedures to permit aircraft to fly uninterrupted descents from cruise altitudes into the terminal areas and to avoid low-altitude level flying near the final approach. In order to absorb gross delays economically at high altitudes, En-Route Metering (ERM) was introduced in some ARTCC's to regulate the flow of traffic into terminal areas. According to the NAS Plan, the ERM functions will be integrated into automation aids that will assist the Traffic Management Unit (TMU) in managing sector loading, and routing traffic into terminal areas at a rate consistent with the airport acceptance rate. As a part of ERM, the Arrival Sequencing Program (ASP) will plan traffic by establishing sequencies and schedules based on aircraft filed flight paths and true airspeeds to a transition fix (typically a point along the cruise segment of flight before the aircraft initiates the descent). The primary objective of the ASP function is to match demand to manually provided airport acceptance rates so that gross delays could be identified and absorbed in the en-route airspace at cruise altitudes. ASP assumes that aircraft would fly the same nominal descent profiles from the top of descent point to the runway regardless of aircraft performance characteristics. The program is not aimed at improving operational efficiency for aircraft in transition/terminal areas.

High performance aircraft are now being increasingly equipped with area navigation and Flight Management Systems (FMS) which provide the aircraft with optimized flight guidance and thrust management. The aircraft industry is making efforts to develop onboard guidance systems, which can predict and precisely control times at points along the flight paths (5). Preliminary time-based control concepts using the capabilities of these aircraft have been defined by the NASA Ames Research Center (6). The impact of using time-based concepts for 4D-equipped aircraft in mixed aircraft environment was evaluated under simulated conditions. The results showed potential benefits to 4D aircraft in terms of fuel savings, and to the ATC in terms of reduced airspace requirements (less vectoring) and reduced controller workload (fewer commands). Additionally, there are indications that delay/throughput improvement may be achieved. Much work remains, however, to resolve the many human/machine interface issues.

The DFVLR of the Federal Republic of Germany has developed aircraft metering time-sequenced displays (7) as a part of the Computer Oriented Metering Planning and Advisory System (COMPAS). Basic advisory information to the controllers in terms of expediting, slowing, or holding aircraft is also provided.

The past and ongoing transition/terminal automation efforts discussed above have focused primarily on the development of algorithms that direct aircraft movements for achieving efficient final spacings. The results have often been successful from the aircraft perspective. However, most of the early efforts did not consider the controller needs. On one hand the controllers were expected to follow computer-provided commands, on the other hand they were assumed to be responsible for providing separation. This resulted in human/machine interface problems that severely restricted the use of various concepts in the field.

The basic lesson learned from the previous efforts are to pay early attention to the human. Three of the human/machine interface concepts that will be explored include the following: providing separate display and I/O systems that continuously show the controller aircraft progress with respect to time; providing enhancements to planned ATC displays that indicate the computer's decision process; and providing conflict-free criteria in the computer decision process to assure separation between aircraft along the entire flight path. Each concept will show how changes to the initial conditions are handled.

PROGRAM SCOPE

The scope of the program is limited to research of alternative concepts and to provide smooth transition from research to implementation by considering development, implementation and human=factor related issues early in the program. The program is a combined FAA/NASA research effort. The results of successful research will be used to establish functional and operational requirements for implementable systems and their interfaces with other NAS elements.

PROGRAM APPROACH

This research and development program is a part of the standard system engineering approach shown in Figure 1. The research will consist of analyzing requirements, establishing alternative concepts, conducting benefit analyses based on these concepts, defining human/machine requirements for concepts showing potential benefits, evaluating alternative concepts in real-time simulation environment, conducting cost/benefit analyses, and establishing the operational and functional requirements for successful research.

The planned sequence of activities in this program are listed below:

1. Obtain and analyze operational data from today's environment to establish fundamental requirements.

2. Characterize and quantify inefficiencies of operations in today's NAS, and establish preliminary requirements for automation in pre- and post-NAS Plan airspace.

3. Define operational concepts and overall performance criteria of supporting system elements required to facilitate reduction of delays and provide more efficient operations.

4. Form an advisory team (to the FAA program manager) to refine the concepts and assess the proposed research. The team will consist of controllers, pilots, and researchers.

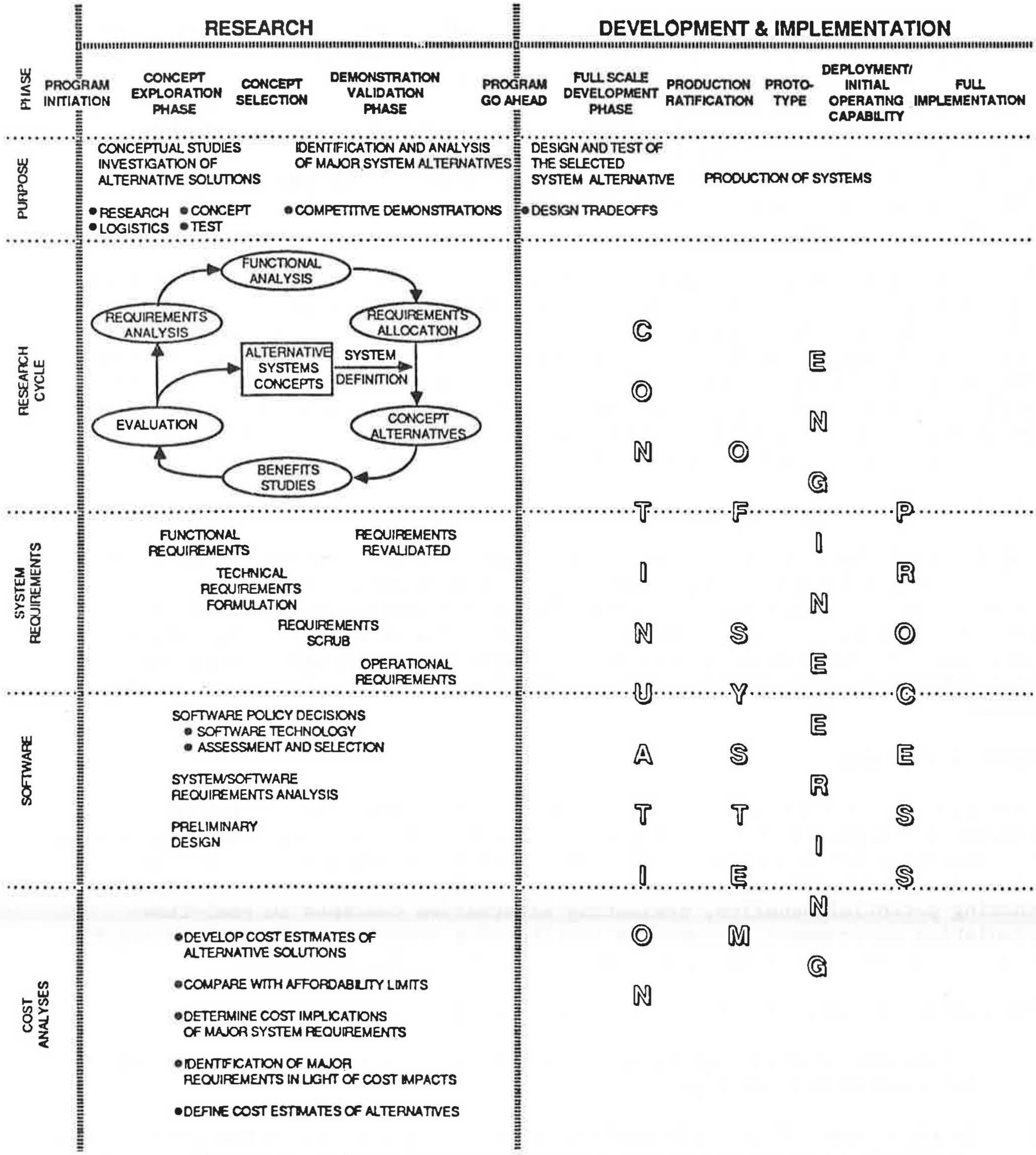

Figure 1 System Research and Development Activities

5. Select airport scenarios that will be used to assess the alternative concepts. The scenarios include a definition of transition/terminal airspace procedures, runway configurations, departure/en-route coordination, aircraft mix, and weather and winds.

6. Develop evaluation criteria and analytical tools to assess the alternative concepts.

7. Establish technical feasibility in a simulated (laboratory) environment and refine the system concept based on comments by the advisory team.

8. In parallel with steps 6 and 7, develop necessary simulation of ATC environment at the FAA Technical Center. This simulation includes models of aircraft performance, aircraft navigation performance, winds, communications, controller response, and pilot response. In addition, analytic tools to apply the evaluation criteria will be developed.

9. Conduct real-time realistic simulation studies and concepts evaluation at FAA Technical Center using controllers.

10. Evaluate concepts feasibility in operational environment, and as appropriate, develop functional requirements for incorporation in evolving NAS System.

11. Hand off program for system development and implementation.

12. Continue concepts development and algorithms refinement to accommodate evolving avionics technology and NAS enhancements.

The approach assumes effective utilization of, and expands upon NASA and other ongoing work accomplished to date, in a comprehensive activity to be conducted in a realistic simulation environment at industry, NASA and FAA facilities. As shown in Figure 2, the concept development, evaluation and validation activites will be conducted in three major phases: in individual laboratories with fast-time simulations, in airborne/ATC concept integration simulation facilities at NASA and in industry, and at the FAA Technical Center with realistic, real=time simulations for a selected site.

If technical feasibility and operational suitability of certain functions or concepts are established, the functional concepts could be separately developed for field implementation. Whenever a system design concept shows promise for field use after human/machine interface requirements are met, and the controllers accept the system in the FAA Technical Center simulation environment, the design will be spun off into a development and implementation program, while the research continues to develop and evaluate future automation concepts.

TRANSITION/TERMINAL AREA REQUIREMENTS

Current System Inefficiencies

In the current ATC system, the controllers have demonstrated capabilities to manage many variables in achieving high throughput during heavy traffic demands. Yet there is clearly a limit to the number of variables human beings can efficiently deal with. The controllers are limited in their ability to precisely predict aircraft performance due to a lack of accurate knowledge of aircraft performance parameters (particularly in maneuvers), imprecise estimate of the impact of winds, and navigation inaccuracies. As a result of these uncertainties, the deviations between the predicted vs. actual aircraft performance grow with flying time/distance. This inhibits the controllers in accurately planning traffic merges from more than two tracks at a time. During

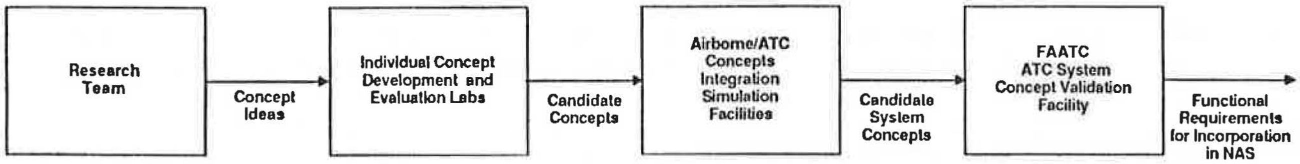

Figure 2 Concept Development, Evaluation and Validation Activities

peak traffic demand at the airport, aircraft are often metered at a rate that slightly exceeds capacity so that the uncertainties do not result in lost landing slots. The inefficient planning and control causes delays and loss of throughput. In addition, it creates heavy workload and stress for the controllers trying to fully utilize the airport capacity. As such, the delays encountered by aircraft depend heavily upon the skills and judgment of the controllers.

Moreover, the controller's primary tool, the radar display, gives a spatial relationship view of the aircraft which a controller mentally projects into future aircraft interrelationships. As a result, the traffic flows into the TRACON are organized primarily over Standard Arrival Routes (STAR), and the controllers use vectors and airspeed commands to separate aircraft while merging traffic. During heavy traffic, the controllers often convert three-dimensional traffic situations in terminal areas into two dimensional perceptions while merging traffic, by making the aircraft arriving from same sector to fly same airspeeds and altitudes. This practice prevents overtakes, but it may cause the aircraft to fly imprecisely selected airspeeds, altitudes, and headings. This process of controlling aircraft does not account for unique aircraft performance characteristics and makes the flight operations inefficient.

More specifically, when planning traffic flows during heavy demand conditions, the en-route controllers regulate the flow of arrivals over fixes in accordance with rates provided by the TRACON supervisor. Typically, these rates are translated into in-trail spacings. The terminal controllers establish tentative landing sequences for aircraft about 10 minutes before landing, and firm these sequences about 5 minutes before touchdown. Aircraft taking off from shared or intersecting runways are accommodated by manually creating or utilizing ad hoc gaps in the arrival stream. Short lead-time planning constrains a controller's ability to efficiently deal with dynamic variations between manual planning and actual aircraft performace. Additional inefficiencies are necessarily introduced into the system by procedural arrival/departure separations, in which airspace occupied or unoccupied remains separated inhilbiting use of airspace by aircraft even during medium traffic. Manual coordination between control positions is cumbersome, especially during heavy traffic periods.

An initial assessment and quantification of the inefficiencies at three to four airports is planned. The results will be used to illustrate the magnitude of benefits that can be obtained by automation aids.

REQUIREMENTS ANALYSIS

Preliminary requirements can be defined, then, from analysis of the inefficiencies in current operations. From a user (i.e., pilot's and airline's) perspective, the requirements are as follows:

- Reduce ATC-induced delays
- Accommodate user-preferred trajectories
- Improve schedule reliability
- Increase capacity

From a controller's perspective, the automation aid requirements to respond to the user requirements are as follows:

- Provide accurate knowledge of aircraft performance and wind effects so that planning can be more effective.

- Provide an accurate projection of traffic demand

- Provide a recommended sequence of aircraft based on current position and speed, flight plan, aircraft type, and forecast wind effects.

- Help coordination between controller positions allowing more sharing of airspace

- Reduce the need for the repetition of messages to aircraft

- Provide a conflict probe function to allow the controller to assess the future impact of a user-preferred trajectory

- Provide understandable and workable solutions to traffic situations including the turn to final

- Permit the controller to override the automation aid

- Permit the controllers to input special constraints (e.g., demand on fixes, weather avoidance routes)

- Allow all controllers to perform consistently

In addition to the differences in manual coordination between control positions, and in human judgment in planning and controlling traffic, variations in airport geography, weather, traffic mix and demand, and en-route/terminal interface make operations at various high density airports quite different and often distinct. To establish more detailed operational requirements, we plan to collect specific data at some selected airports that represent both the inland and the coastal airports with high density operations. The purpose of the initial data collection and analysis effort is to: 1) provide a measure of the site-specific requirements and site-to-site variations in order to isolate common and unique problems; and 2) provide background data and operational familiarity need to develop strawman concepts. The following data collection and analysis activities will be performed:

a) Examine operational data from coordinated ARTS/SAR/VOICE tapes for at least three airports to quantify the following:

   -- Deviations from aircraft planned flight paths
   -- Distribution of delays and workload (i.e., number of commands)
   -- Accommodation of user preferred trajectories
   -- Deviations in the final approach profile among aircraft type

b) Analyze current system performance in terms of reduction in potentially avoidable delays, controller/pilot communications, and possibilities of increasing throughput.

c) Define minimum level (baseline) operational requirements for transition/terminal automation in today's environment

INITIAL RESEARCH

The initial research encompasses a five-to-seven year effort that culminates in a demonstration at an operational facility. This initial research includes planning and control of arrival operations from the top of descent to the runway and departure traffic through the climb to cruise altitudes. The initial research will emphasize the controller/machine issues in an environment where the controller is responsible for separation assurance, and automation aids are used to provide advisories for efficient control of traffic, while a limited number of aircraft have area navigation, FMS, or data link. The MMI (Man/Machine Interface) issues presume a requirement for dynamically adapting to changing operations through interactive capabilities. The plan assumes that the algorithms and models developed from previous and ongoing government research will be made available to all researchers. This section describes the automation functions that must be developed or refined from previous research alternative man/machine concepts to be evaluated, and FAA Technical Center simulation development required to support the assessment of alternative concepts. The research is to be performed on individual functions in manageable development steps.

Automation Functions

Today's controllers perform three major functions: 1) plan the flow of traffic; 2) control the movement of aircraft to assure separation between aircraft; and 3) coordinate with other controllers and pilots for appropriate use of airspace. Automation could efficiently perform several complex computations, and assist controllers in several burdensome tasks of routine planning, control and coordination. The automated planning aid can efficiently schedule and sequence aircraft based on individual aircraft characteristics, weather/wind conditions, aircraft mix, IFR/VFR traffic mix, noise abatement requirements, and arrival/departure mix. The control function can assist in regulating the paths and speeds of aircraft to cause the aircraft to conform to the planned flight profiles while assuring separation between aircraft.

Automated coordination can provide for the necessary information exchange between controllers and with pilots. Figure 3 shows the functional relationships and interfaces between individual functions. The figure shows a basic schematic of functional elements that will need to be developed. The following is a list of functional development efforts that will need to be developed to support a basic automation concept.

a) Aircraft performance models
b) Wind Model
c) Transition/terminal traffic planning (sequencing and scheduling)
d) Interface with ASP to accommodate dynamic transition traffic planning
e) Dynamic traffic planning in TRACON
f) Control advisory generation process

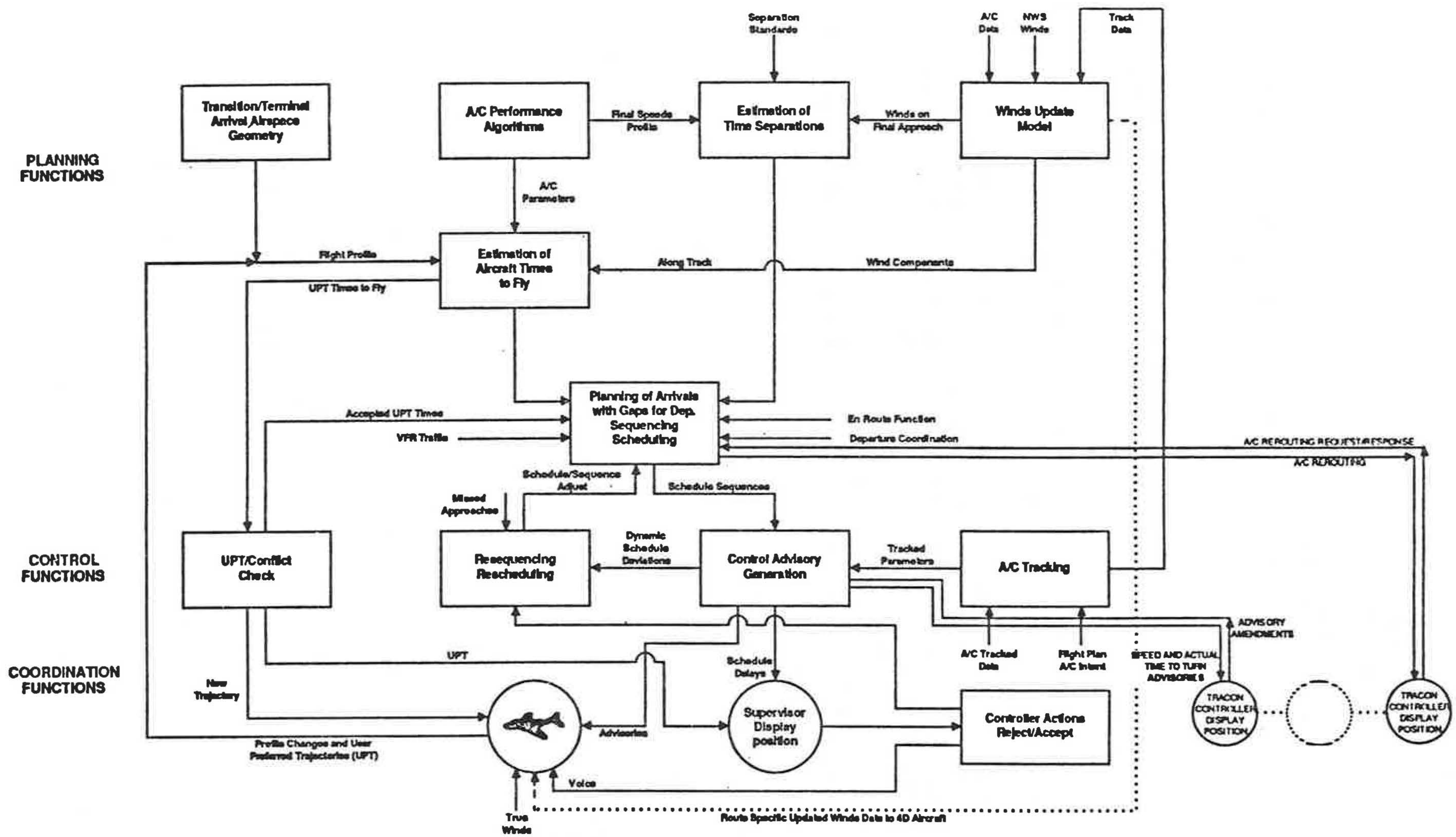

Figure 3 Functional Relationship

g) Coordination function
h) Basic controller information display
i) Interactive display capabilities

Algorithmic and Function Development

Refinements to existing algorithms and models will be based on a data collection and analysis activity at airports and via laboratory simulations. It is planned to:

a) Compare expected (ground computed) aircraft performance with the actual aircraft (cockpit simulator) data to evaluate the accuracy of ground-based aircraft performance algorithms.

b) Compare theoretical capacity with actual throughput to evaluate the level of achieved performance as a function of optimum expected performance.

c) Determine the stability of the ground system generated schedules and sequences in terms of the number and periodicity of changes. It will also be important to determine that the system generates schedules/sequences that are operationally acceptable to the controllers.

d) Determine time tolerances at key points along the flight paths that can be accepted without imposing penalties on aircraft performance or need for large controllabilities.

Human/Machine Interface Research

The functions in figure 3 will be addressed from the perspective of the following controller positions.

- TMS
- En-Route Controller(s)
- TRACON Supervisor
- Arrival Sector Controller(s)
- Final Controller(s)
- Tower Controllers(s)
- Departure Controller(s)

The initial research will examine the alternative means of interfacing with automation and displaying the computer solutions to the above controller/supervisor positions.

- Separate displays and data entry devices
- Integration with existing displays and data entry devices
- Integration with planned AAS displays and data entry devices

The display research will involve an assessment of alternative means to show the controller the plan (i.e., sequence and schedule) being generated in the computer and control advisories to meet the plan. Several research alternatives to show the plan include:

- Enhanced data block
- Future traffic projection (e.g., five minutes ahead)

- o Time progress display
- o Lists

Several research alternatives to provide control advisories include:

- o Profile descent advisory
- o Periodic speed reduction advisories
- o Turn to final advisory
- o Path change advisory
- o Time delay advisory
- o Departure gap advisory

In order to permit controller response to dynamic conditions data entry devices to assess the following conditions will be researched:

- o Pop up and VFR aircraft
- o Rerouting requirements (e.g., due to weather, runway load balancing, etc.)
- o Arrival/departure interaction
- o Controller preferred control actions
- o Missed approaches
- o Impact of controller selected flow strategies
- o Data link communications

a) Assess the impact on controller workload by measuring the number of control actions required to meet schedules while maintaining safety. Evaluate controller productivity by comparing performance without and with the system.

b) Evaluate the impact on crew performance particularly when the user-preferred trajectories are used in high-density traffic.

c) Measure controller response/acceptance from the number of accepted/rejected system advisories by different controllers.

Evaluation Facilities

The transition/terminal automation concepts will require evaluation via fast/real time simulations. Once the functional algorithms meet the expected performance criteria, they will be integrated into a real-time realistic (within man/machine interaction) ATC simulation laboratory. The ATC simulation capabilities will be developed at the FAA Technical Center (FAATC).

LONG-TERM RESEARCH

The long-term research involves improving the functions developed during the initial research (such as a more accurate wind model and more individual aircraft models); using data link to facilitate the negotiation of user preferred trajectories from cruise altitude (top of descent) to the runway, providing automation aids to match the newly defined controller positions in an Area Control Facilities (ACF) post-AAS environment; applying the automation computations to more complex arrival geometries including dependent approaches to parallel and converging runways; and eventually providing conflict-free clearances to the aircraft who are responsible for meeting the agreed-to flight profiles and the controller having the role of manager of the traffic flow.

Some elements of the long=term research, especially the use of data link and application to converging approaches, will be explored in parallel with the continuation of the initial research effort.

Evolution of Automation Role

In the current ATC environment the controllers plan traffic by trying to meet airport acceptance rates and separation requirements at terminal entry fixes, and assure separations between aircraft by manually controlling the speeds and paths of the aircraft. In near term (mid-1990's) automation aids would be available to provide advisories to the controllers in planning the flow of traffic and controlling the aircraft to meet the desired schedules or adjusting the aircraft's schedule. Though automation will provide problem-free advisories, the controllers will be responsible for separation assurance, and would have to deal with gross aircraft deviation tactically.

During the mid term of automation implementation (post year 2000), as NAS Plan enhancements become operational and a large percentage of aircraft acquire avionics with area navigation, FMS, and data link, an ATC computer could provide automated planning based on individual aircraft nominal profiles, or user defined paths that are checked and found to be problem free for regulating the flow of traffic. The ATC computer could also recommend problem-free tactical control solutions necessary for separation assurance. Normally, the controllers would be expected to rely on automation-established problem free profiles and control commands. However, in case of gross aircraft deviations or other anomalous ad hoc situations, the controllers would remain responsible for the required separations and overall safety of aircraft.

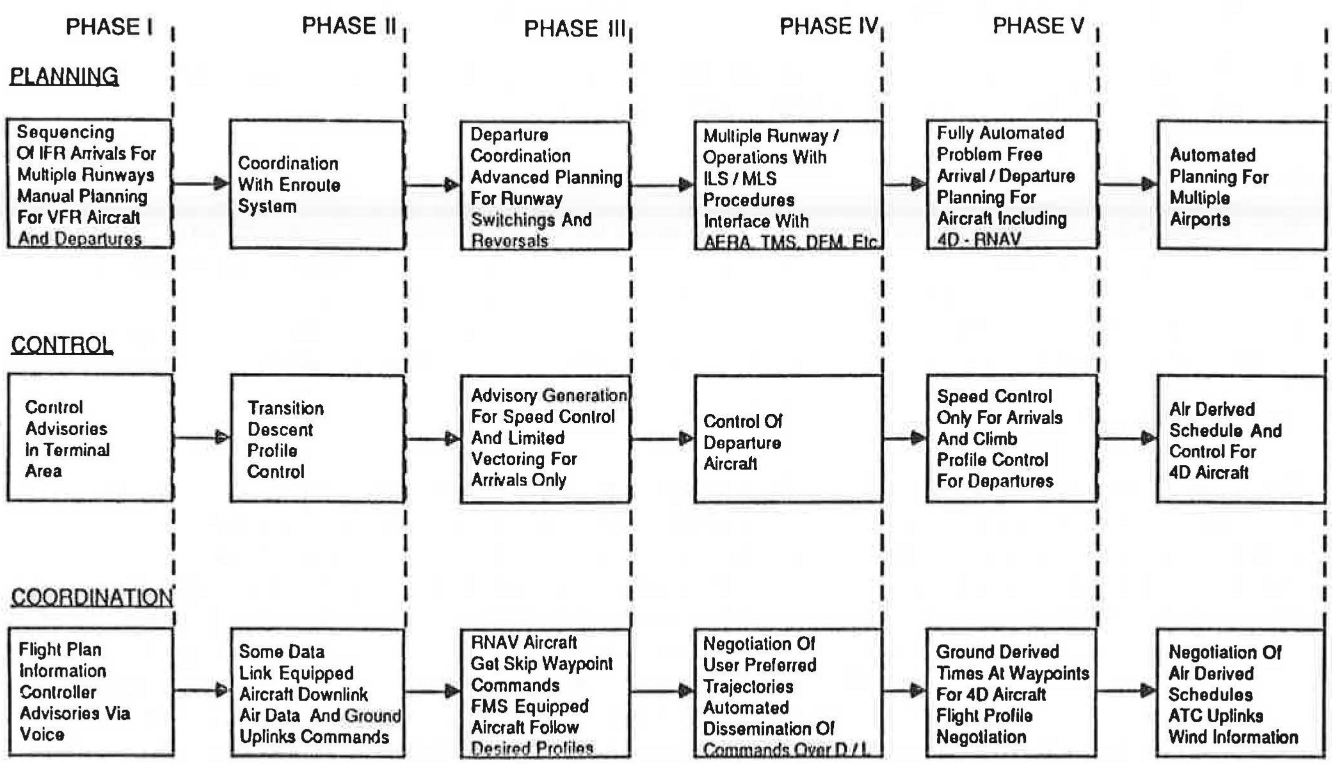

Figure 4 Evolution of Terminal Automation Capabilities

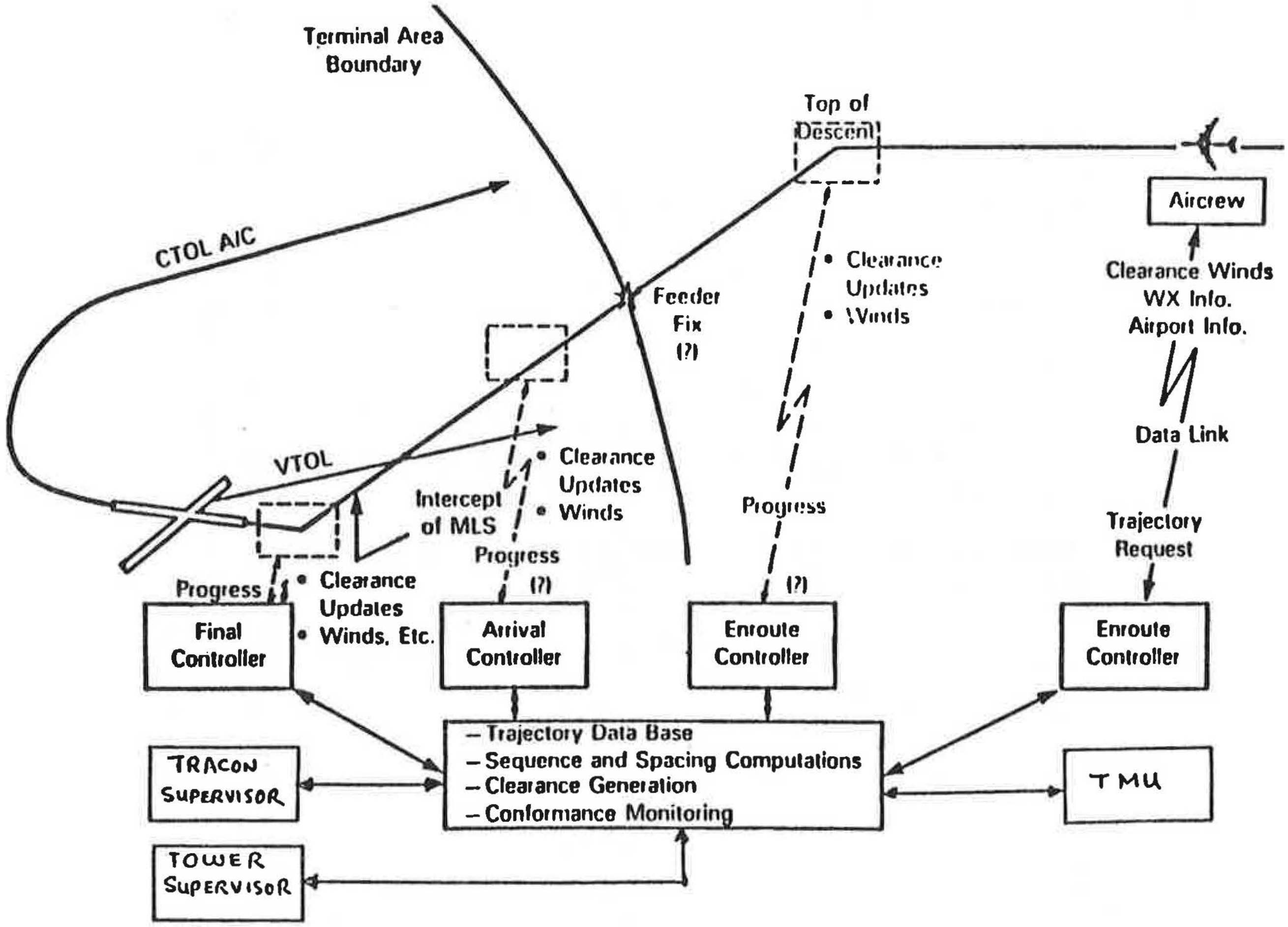

Figure 5 Precise Planning and Control
with Automated Coordination

In far term (year 2010 and beyond), when most aircraft are expected to be able to accurately navigate anywhere and are equipped with a data link, the ATC system is expected to be fully automated. The ATC computer would automatically direct the aircraft over planned flight profiles through a ground/air computer-to-computer interface. In such an environment, the ATC computer would plan traffic on paths desired/negotiated by aircraft, and the aircraft would be responsible for adhering to the agreed plan through air derived control. The automated conflict prediction and resolution system would generate commands for maintaining separations between aircraft. The controllers' role would be to supervise traffic and monitor aircraft performance. The controllers would intervene and interact with automation only under very unusual or life-threatening situations.

Evolution of Functions

This program does not presently contemplate research beyond the mid-term concepts. In order to meet the requirements in the near and mid-terms, the

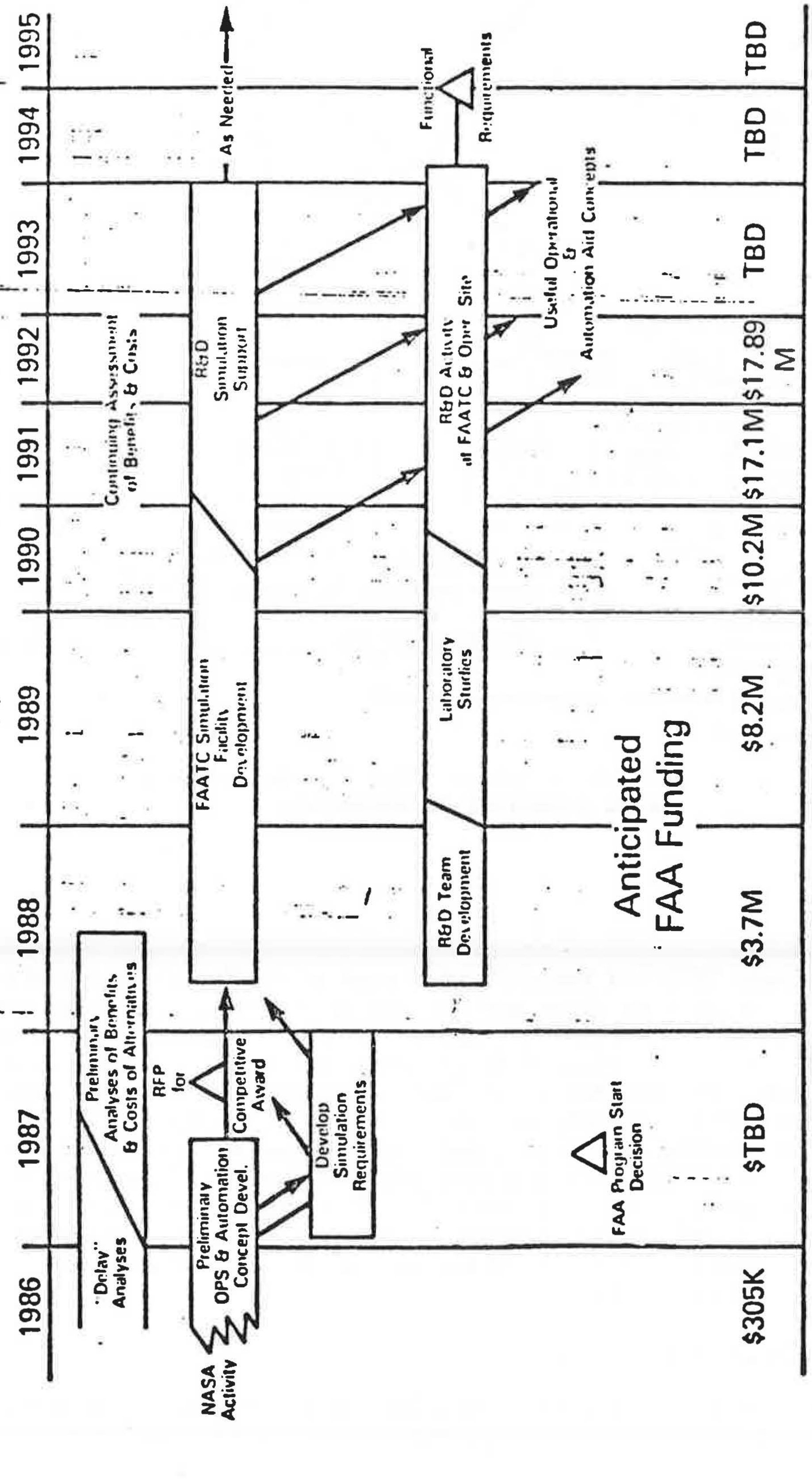

Figure 6 Research and Development Schedule

basic functional capabilities shown in Figure 3 will have to be enhanced in steps to deal with traffic growth complexities and interface with NAS elements. The enhancements needed to upgrade the planning, control and coordination functions is expected to evolve in five phases as shown in Figure 4. These evolutionary automation concepts would provide support to the controllers in ATC environments where the controllers would continue to provide separation assurance. Evolution to a fully automated system operating in an environment in the far term where the controllers operate as supervisors or managers, may require continuation of research in several phases after phase V presented here. Specific details of functional evolution after phase V is beyond the scope of this program at this time.

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