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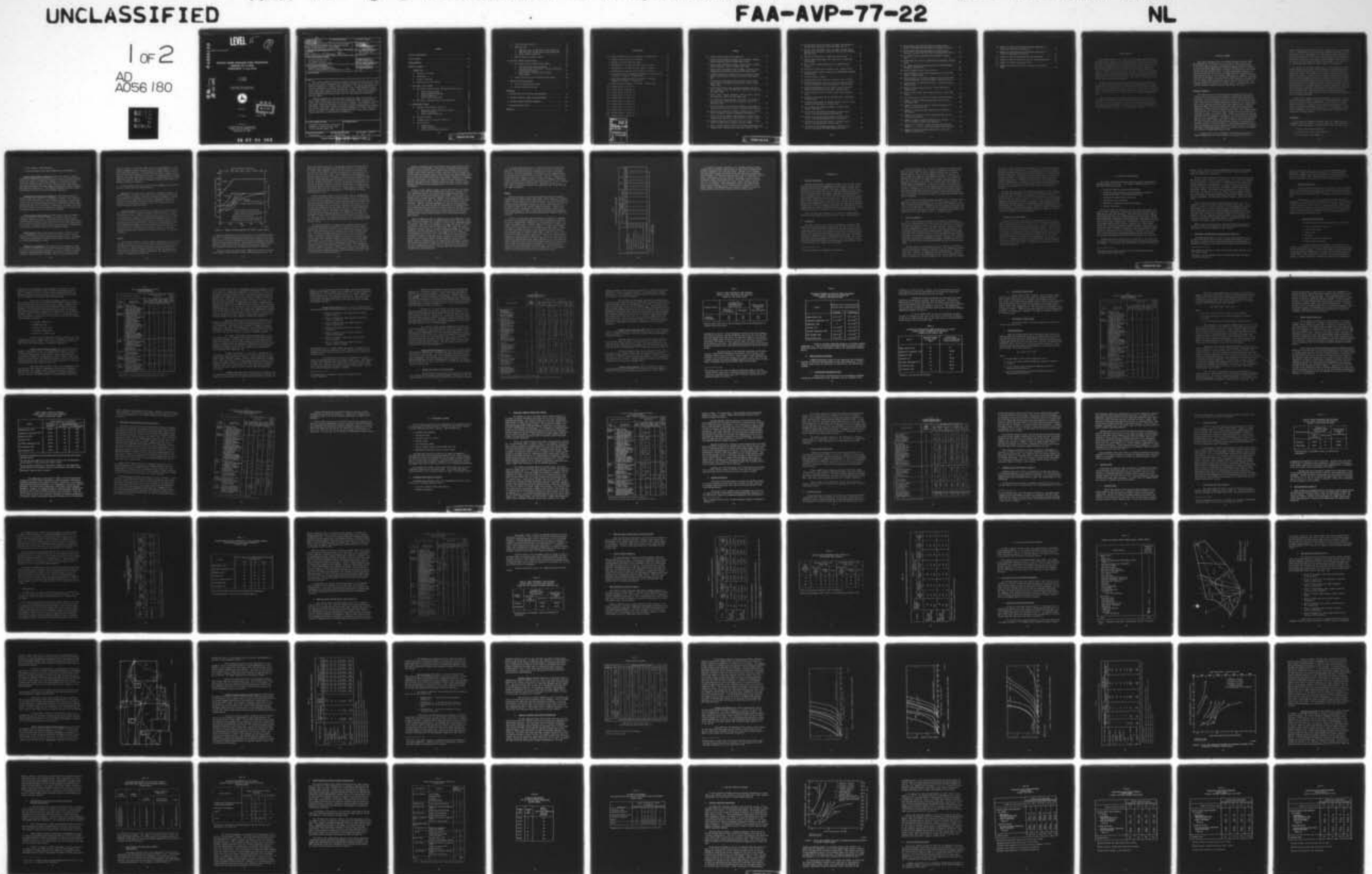

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ATLANTA CENTER UPGRADED THIRD GENERATION ENROUTE ATC SYSTEM OPERATIONS: A Case Study

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16. Abstract

This report documents the work performed by Stanford Research Institute (SRI) to assess the impact of Upgraded Third Generation Enroute Air Traffic Control (ATC) System alternatives on control facility operations. The various enhancement features are considered to be added incrementally to the current National Airspace System (NAS) Stage A enroute ATC operation and include: automatic data handling, enroute metering, automated local flow control, conflict probe, area navigation, Discrete Address Beacon System (DABS) data link, and DABS-based intermittent positive control.

Staffing estimates for each enhancement system are made for the Atlanta Air Route Traffic Control Center for the years 1980 through 2000, and include Air Traffic Service and Airway Facilities Service personnel. The estimation procedure uses models previously developed by SRI based on extensive observations of ATC operations. These models include the Relative Capacity Estimating Process (RECEP), which relates ATC sector controller workload requirements to traffic capacities, and the Air Traffic Flow (ATF) network simulation model, which assesses traffic capacity and delay in a multisector environment.

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SRI personnel worked at the Federal Aviation Administration's Atlanta Air Route Traffic Control Center collecting operational data and interviewing controllers and support and supervisory staff. This effort could not have been accomplished without the full cooperation and assistance of the center's Air Traffic Service and Airway Facilities Service personnel. We especially appreciate the contributions of the Atlanta Center's air traffic controllers who participated in our data collection and interview sessions, as well as the contributions of the data systems and maintenance support personnel and supervisory staff members who provided additional descriptions of the center's operations. The number of people participating precludes personal acknowledgment.

We wish to thank the project technical monitor, Mr. Walter Faison, of the FAA's Office of Aviation Policy for his foresight in organizing and specifying clearly the overall objectives of this research. Acknowledgment is due to Mr. Nathan Aronson and Mr. Joseph Asin, both of the FAA's Office of Aviation Policy, for their assistance, respectively, in arranging the data collection site and schedule and in obtaining supplementary data.

This work was performed in SRI's Transportation Center under the direction of Dr. George J. Couluris and the supervision of the center's director, Dr. Robert S. Ratner. Mr. Jerome M. Johnson applied the potential conflict processing models, and Mr. H. Steven Procter implemented the network simulation model. Ms. Marika Garskis contributed significantly to data collection, reduction, and interpretation efforts.

EXECUTIVE SUMMARY

This report documents work that Stanford Research Institute (SRI) has performed for the Office of Aviation Policy, Federal Aviation Administration (FAA), Department of Transportation, to assess the impact of certain proposed Upgraded Third Generation (UG3RD) Enroute Air Traffic Control (ATC) System enhancements on enroute ATC operations at the Atlanta Air Route Traffic Control Center. To compare enhancement systems, we estimate the Atlanta Center annual staffing requirements associated with each enhancement for the years 1980 to 2000 based on: models of controller task activity workload, a network computer simulation model that evaluates aircraft traffic capacity and delay, and traffic forecasts provided by the FAA. The models were developed in previous contract work for FAA. The staffing estimates include the Air Traffic Service and Airway Facilities Service personnel required to operate and maintain the center.

Method of Approach

We collected data at the Atlanta Center describing the ATC sector control team task activities and procedures required under NAS Stage A operations. We used these data to adjust our previously developed workload models so that the models describe the sector team routine, surveillance, and conflict processing requirements observed at the Atlanta Center. Routine work includes air/ground (A/G) voice communications, flight data processing (FDP) and radar processing (RDP) manual data entry/display operations, flight strip data processing, intersector interphone voice communications, and intrasector direct (face-to-face) voice communications. Surveillance work is visual observation of radar-derived aircraft situation data on a plan view display (PVD). Conflict processing work includes potential conflict recognition, assessment, and resolution decision making and A/G voice communications. The models, which we previously calibrated against known sector traffic capacities at another center (Los Angeles), are used to quantify workload limit/traffic capacity relationships for selected sectors of the Atlanta Center. These workload models and capacity relationships describe the operational characteristics of the current NAS Stage A Enroute ATC system, which is the base from which we postulate the evolution of UG3RD enhancement systems.

To analyze ATC evolution through successive automation levels, we adjust parameters of the workload models to represent the effects of various enhancement systems on the sector teams' capability for handling traffic. The parametric values encode the assumptions we made as to how each system would be implemented in an operational enroute environment, and how each system would impact the task activities and workload characteristics of individual sector teams. The modeling approach, which we call the Relative Capacity Estimating Process (RECEP), estimates the sector traffic capacity associated with an enhancement system relative to the performance requirements of current enroute ATC operations.

We use the sector traffic capacities in our Air Traffic Flow (ATF) network simulation, also previously developed, to determine the multisector traffic handling and delay characteristics associated with each enhancement system. ATF enables us to examine alternative sector configuration strategies (based strictly on sector splits) and alternative sector manning strategies (based on increasing or decreasing the number of sector team positions when feasible) in order to estimate the number of day-shift controllers needed in a selected multisector region of the Atlanta Center by each enhancement system. We then expand the day-shift manning estimate to an annual controller staffing requirement (which is compatible with current FAA staffing standard calculations) and estimate the corresponding operations and maintenance support and supervisory annual staffing needs. This process yields our estimate of the Air Traffic Service and Airways Facilities Service annual staffing associated with each UG3RD enhancement.

Sector traffic capacities for the enhancement systems are derived using the workload models, from which we determine multisector manning and facility annual staffing requirements. Therefore, the resulting staffing estimates are sensitive to the subjective judgments we have made in structuring the workload models so that they describe an evolutionary implementation of UG3RD enhancements. In the remainder of this Executive Summary, we briefly review the operational assumptions and present the staffing estimates.

Assumptions

The systems are examined in sequence under the assumption that each enhancement feature is added to the previous system. The enhancement features, added consecutively to the NAS Stage A Base (System 1), are:

- Automated data handling (System 2)
- Automated local flow control (System 3)
- Sector conflict probe (System 4)

- Area navigation, RNAV (System 5)
- Discrete Address Beacon System (DABS) data link (System 6).

Automated Data Handling (System 2)--This first add-on to System 1 includes the implementation at sector positions of an electronic tabular flight data display, and RDP/FDP refinements. The tabular display is an electronic flight data presentation designed to replace paper flight strips and attendant manual activities, and would effectively automate some controller manual and verbal tasks associated with control procedures and flight data distribution. The RDP/FDP refinements are minor system modifications that would facilitate equipment operation.

Automated Local Flow Control (System 3)--This feature, which we assume is added on to System 2, is designed to maximize sector capacity utilization by smoothing out traffic peaking situations. It would govern traffic flow on routes by means of an on-line computerized traffic planning process that regulates workload surges in accordance with the traffic handling capabilities of a multisector environment. We assess its impact on enroute traffic capacity by modeling the distribution of traffic peaks and workload surges on the air traffic route network.

Sector Conflict Probe (System 4)--This feature, which we assume is added on to System 3, alerts controllers of potential conflicts and recommends resolution actions. To provide an operationally realistic time prediction horizon at a low false-alarm rate, we assume this feature will be used when aircraft first enter a sector. Since A/G communications are required to transmit conflict resolution instructions, workload reductions affect only conflict detection and assessment tasks.

RNAV (System 5)--This feature, which we assume is added on to System 4, incorporates navigation avionics that could be used in enroute operations to achieve close-spaced multilane traffic routes. Overtaking conflict processing would be eliminated by placing successive aircraft on closely spaced parallel routes.

DABS Data Link (System 6)--This feature, which we assume is added on to System 5, transmits to pilots digital data including routine clearances and conflict avoidance directives. It is not intended to transmit extensive nonstandard-format messages. The data link, integrated with extensive computerization, is the basis for the "control-by-exception" concept in which the controller would become a system manager who is not routinely engaged in minute-by-minute tactical decision making. He would have to maintain cognizance of the computerized sector control operation and intervene when necessary to adjust procedural rules, respond to pilot requests, and resolve nonstandard situations. In modeling workload changes associated with this enhancement, we account for the automation of certain routine and conflict tasks while allowing for controller work required to maintain operational cognizance.

We also assess, but do not explicitly model, DABS-based intermittent positive control (IPC) and enroute metering.

DABS IPC--IPC provides traffic advisories and threat avoidance commands to pilots, as needed. Since this service could operate in the enroute environment on imminent conflict situations that might be "missed" by controllers, we assume IPC to be a safety enhancement device that would not directly impact routine staffing requirements. IPC may be necessary to provide fault tolerance in the event of failures in the other enhancement system operations.

Enroute Metering--This feature is an extension of terminal metering and spacing, a device to maximize airport runway utilization. Enroute metering would require enroute controllers to set up aircraft spacings in accordance with time-varying terminal metering specifications. (Without more advanced automation, such as data link communication, precise time-over-fix aircraft sequencing would not be possible because of the excessive controller work required.) Based on our observations of analogous (though less dynamic) procedures currently used as guidelines for controlling the movement rate of aircraft from the enroute into the terminal airspace, we conclude that significant impact on controller workload will not occur and impact on the level of enroute staffing will be minimal.

Results

We determine day-shift controller manning requirements for a selected multisector study area of the Atlanta Center, from which we develop Air Traffic Service and Airway Facilities Service staff estimates for the entire facility. These estimates include the controller, maintenance, supervisory, and support personnel needed to operate the facility, but do not include controller trainee requirements. The results of these analyses are summarized in Figure S-1.

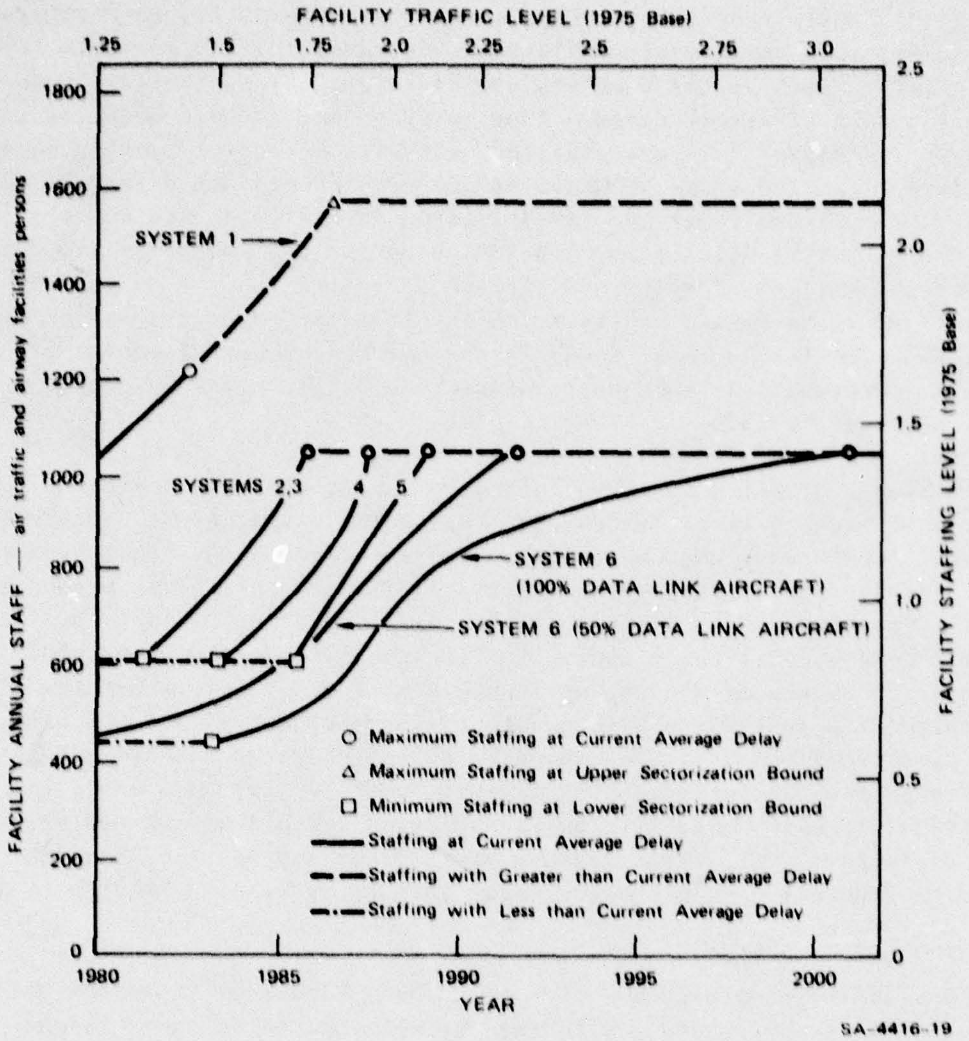

FIGURE S-1 ANNUAL STAFFING FORECASTS, BY SYSTEM: ATLANTA CENTER

Based on available data, the Atlanta Center's 1975 staffing requirement under the NAS Stage A Base was 744 persons, of which 476 were controllers. To allow for handling additional traffic demand at the current level of delay, we model alternative sectorization strategies and alternative sector manning strategies. These controller deployment strategies account in large part for the staffing increases shown in Figure S-1. Also included are appropriate increases in noncontroller personnel.

Figure S-1 shows that under System 1 (NAS Stage A Base) the current level of delay could be maintained until 1983 by increasing staff. We assume the staffing increase is accomplished by resectorization (sector splitting), while individual sector manning is held at 2.5 controllers per sector; this complement consists of one radar (R) and one data (D) controller in each sector team and one assistant (A) controller in support of a pair of sector teams. (Our workload and network modeling analysis indicates that sectorization, rather than sector manning changes, is a more effective means of handling the traffic projected for the early 1980s.) During 1983, maximum sectorization is achieved, and no more sectors can be split efficiently. (Based on operational considerations and a review of Atlanta airspace and current sectorization, we judge that an upper bound on sectorization is twice the Atlanta Center's current number of sectors, while the lower bound is the current number of sectors.) The maximum sectorization limit corresponds to a 65% increase in facility staff relative to 1975.

System 1 staffing could be increased, after 1983, by implementing a 3.5 sector manning level, which requires adding a tracker (T) controller to each sector team. However, our analysis indicates that this strategy could not increase facilitywide traffic handling capabilities beyond 1983 and simultaneously maintain the current level of delay. Since the T controller does support the R controllers, especially during heavy traffic activity and workload stress, we assume that the 3.5 sector manning will be implemented in 1983 to help handle the projected traffic, but with increased traffic delays. As shown by the dashed line in Figure S-1, we extrapolate the corresponding facility staffing increase until the mid-1980s, at which time all the reconfigured sectors are manned at the 3.5 controller level. This maximum staff level may be maintained through the year 2000 only by increasing delay further or by constraining traffic demand or both.

Our analysis of System 2 (automated data handling) indicates that its automation components (including the elimination of paper flight strips) will obviate the need for A and T controllers and that the two-man (R and D controllers) sector team will be the most efficient operation. Therefore, we assume sectorization will be the only effective means of increasing staff to maintain the current level of delay as traffic increases. As shown in Figure S-1, this level of delay could be maintained until 1986 when maximum sectorization is achieved, which corresponds to a 42% increase in facility staff relative to the 1975 base. This staff level could be maintained beyond 1986, but with increased delay or constrained traffic demand or both. The staffing advantages of System 2 relative to System 1 are due in part to reductions in sector manning requirements and increases in sector team traffic handling capacities (resulting from the reduced workload per aircraft associated with data handling automation).

System 3 (automated local flow control) does not show further staffing gains relative to System 2. This result is probably because of the intensity of the facility's radial traffic flow (focused on the Atlanta airport), which limits practical traffic rerouting or delay alternatives to the inbound and outbound routes rather than the over and crossing routes. In this case, the automated operation uses traffic distribution strategies that are already part of current local flow control. However, an automated operation will probably be necessary to enable the flow controller to maintain cognizance of the increased traffic projected. System 3 sector manning and traffic handling capabilities are the same as those assumed for System 2.

System 4 (sector conflict probe) could be maintained at the current level of delay until 1988 when maximum sectorization is achieved. System 5 (RNAV with 100% of the aircraft fleet equipped with requisite avionics) could be similarly maintained until 1989. In both cases, the two-man sector manning strategy is assumed, and staffing increases are obtained by sector splitting. The System 4 and 5 maximum facility staff levels are identical to those of System 2 and are 42% greater than the 1975 base. However, staffing advantages are realized by both Systems 4 and 5 in that they delay the need for deployment of the maximum staff. The staffing advantages of System 4 relative to System 2 and those of System 5 relative to System 4 are due to increases in sector team traffic handling capacities (resulting from the reduced workload per aircraft associated with conflict probe automation and closely spaced parallel RNAV routes).

System 6 (DABS data link) is evaluated under two assumptions: first, that 50% of the aircraft fleet is equipped with requisite data link equipment; second, that 100% is so equipped. (In both cases, 100% RNAV avionics is assumed.) Under the first assumption, we judge that System 6 could be maintained at the current level of delay until 1992; under the second assumption, System 6 could be similarly maintained through the year 2000. Progressive staffing increases to 42% are required in both cases. Staffing advantages are realized in the early 1980s by the use of one-man (R controller only) sectors, but, as the traffic level increases in the mid-1980s, transition to two-man sectors is needed. This transition, together with a forecast surge in traffic demand in the mid-to-late 1980s, causes the irregularity in the shape of the two System 6 curves. The staffing gains shown in Figure S-1 for System 6 relative to System 5 are due to significant increases in sector team traffic capacities (resulting from reduced workload per aircraft associated with control-by-exception data link operations).

To provide some insight into the relative efficiencies of the systems, we calculate their productivity gain relationships, as shown in Table S-1. The productivity gain comparisons are based on the staff and traffic levels corresponding to the maximum traffic demand handled at the current level of delay by each system. The 1975 operation of the current NAS Stage A System is used as the base reference. Although no productivity gain is shown for System 3 relative to System 2, the former system is assumed to be integrated along with Systems 2, 4, and 5 (through evolutionary development) into System 6. Therefore, Systems 2, 3, 4, and 5 would be required to achieve the productivity gain (2.28 after the year 2000) of System 6.

Remarks

Staffing estimates are made using previously developed controller workload and air traffic network flow models. These models are reasonably logical representations of ATC systems operation, but, being analytical in nature, they are abstractions of the real world. Therefore, the resulting staffing estimates should be interpreted as first-order indicators of the relative impact of the various automation features. These results should be useful as guidelines for further experimental testing of the various enhancements in order to define their operational and technological design feasibility, and for developing detailed economic feasibility analyses.

Relative to operational and technological feasibility, we emphasize that many of our modeling assumptions are based on judgments concerning the future implementation capabilities of the enhancement features. We assume, for example, that a conflict probe could be used to predict and resolve conflicts within a sector's airspace. It might prove possible to operate a conflict probe as a centerwide flight plan probe, in which case additional workload reduction and concurrent staffing reduction gains (beyond those we estimate) would result. However, there is also the question whether a conflict probe of any type can be integrated with controllers' mental/cognitive capabilities. In fact, the basic issue of productively interfacing man and machine applies to each enhancement and requires considerable additional study, experimentation, and evaluation. This is especially true of the data-link-based control-by-exception operation in which the mental/cognitive processes of the controller must be evolved into system-interactive monitoring mode. Further research is needed to ascertain the degree to which a controller's mental/cognitive capacity would constrain his ability to handle more traffic.

Table S-1

ATLANTA CENTER PRODUCTIVITY COMPARISONS*

System	Year	Facility Annual Staff Estimate (persons)				Staffing Level	Traffic Level	Productivity Gain Factor†
		Controllers	Total Air Traffic Staff	Total Airway Facilities Staff	Total Facility Staff			
1. Current NAS Stage A Base	1975	476	614	130	744	1.0	1.0	1.0
1. NAS Stage A Base	1983	874	1066	160	1226	1.65	1.44	0.87
2. + Automated data handling	1986	699	891	162	1053	1.42	1.71	1.20
3. + Automated local flow control	1986	699	892	162	1054	1.42	1.71	1.20
4. + Sector conflict probe	1988	699	892	162	1054	1.42	1.94	1.37
5. + RNAV (100% avionics)	1989	699	892	162	1054	1.42	2.13	1.50
6. + DABS data link (50% avionics)	1992	699	895	164	1059	1.42	2.34	1.65
or								
6. + DABS data link (100% avionics)	2000	699	895	164	1059	1.42	3.24	2.28

*Productivity comparisons correspond to the maximum traffic demand handled at the current level of delay by each system.

†Productivity gain factor = $\frac{\text{traffic level}}{\text{staffing level}}$.

In regard to economic feasibility, our staffing estimates provide insights into the relative effectiveness of each system in reducing FAA operating (manpower) costs and user delays. However, a full economic analysis should consider trade-offs between FAA operating, engineering and development, and capital investment costs, and user delay and avionics costs. Furthermore, since the scope of this effort is restricted to estimating enroute ATC staffing impacts, enhancement system attributes relative to terminal ATC staffing, safety, airport capacity, and the like are not assessed. Those enhancements that do not significantly impact enroute staffing, such as metering and IPC, should not be dismissed lightly; such enhancements may contribute important system performance qualities other than reduced enroute staffing costs.

I INTRODUCTION

A. Objectives and Scope

The work described here assesses the impact on air traffic control (ATC) operations of various automation systems proposed as part of the Upgraded Third Generation (UG3RD) Enroute ATC program. We make this assessment by relating automation enhancement proposals to current observed control operations in order to judge how automation might successfully be integrated with operational requirements and how controller activities might change. We evaluate the operational potentials of the various UG3RD automation system alternatives by estimating and comparing their effects on staffing at an enroute center. We use the Atlanta Air Route Traffic Control Center as the study site, and the current National Airspace System (NAS) Stage A3d.2 as the base for comparing the staffing requirements. The staff studied includes both Air Traffic Service and Airway Facilities Service personnel who operate and maintain the facility. Staffing estimates are presented for the years 1980 through 2000.

This case study was performed for the Office of Aviation Policy, Federal Aviation Administration (FAA), under Contract DOT-FA75WA-3714.

B. Background

This work is based on ATC analysis capabilities developed by SRI during two projects previously conducted for the FAA. The first project[1-4]* was a multiyear effort performed for the Systems Research and Development Service, FAA, during which we developed various analytical models of ATC operations and furthered a sensitivity to the operational realities of automation and its implementation potentials. The models included the Relative Capacity Estimating Process (RECEP), which relates controller workload requirements to sector traffic capacities, and the Air Traffic Flow (ATF) network simulation model, which assesses traffic capacity and delay in a multisector environment.

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*A list of references is appended to this report.

The second project[5] was a case study of UG3RD ATC staffing requirements for the Los Angeles Center, which we performed for the Office of Aviation Policy, FAA. We used the RECEP and ATF models to estimate staffing impacts of the various automation systems. In doing so, we made a number of assumptions and judgments regarding the feasibility of implementing the postulated enhancement features in an operational enroute ATC environment. Our models of controller workload encoded the assumptions we made regarding the way in which each of the enhancement systems might be implemented. In some cases, these views did not conform in all details to the various designs postulated by specialists in the FAA[6] or elsewhere,[7] but the staffing analyses we performed required operational descriptions that were both realistic and consistent with the current enroute ATC development programs. Where these descriptions were not available in sufficient detail, we developed the necessary operational procedures.

The case study of UG3RD staffing requirements for the Atlanta Center described in this report parallels that of the Los Angeles Center. We apply the analytical methodologies we developed for Los Angeles to project Atlanta Center operations. Although we use data collected from seven sectors at the Atlanta Center as the bases for the RECEP and ATF models, the descriptions (with some minor revisions) of enhancement system operations postulated for the Los Angeles Center are assumed to apply.

C. Method of Approach

We are concerned with the impact of automation on ATC capacity. Based on our observations of ATC operations, we concluded that in almost all cases, the limits on capacity are associated with sector control team activity requirements, that is, controller workload. Hence, we choose to focus on controllers, controller teams, and team organization. Because ATC services are based on complex decision making by many people, we decided that our approach had to be based on measurements of present operations; this provides a realistic base from which to evolve operating descriptions of postulated enhancement systems. Therefore, we use operations data collected at the Atlanta Center where the NAS Stage A3d.2 was in full use with flight data processing (FDP) and radar data processing (RDP).

Because capacity is so closely related to controller operations, we convert functional and equipment descriptions of the enhancement features into terms of changes to current controller task activities. These revised task activities are formulated into the RECEP model to determine sector capacities for each enhancement system. These individual sector capacity estimates are in turn integrated into the ATF model to determine the traffic capacity and delay characteristics of a selected multisector study area of the Atlanta Center. This information is used to estimate controller manning requirements for each UG3RD system for the study area during the peak shift of the peak day (90th percentile). Standard staffing relationships[8,9] and observed facility manning policies are used to transform the study area manning requirements into annual controller staffing requirements. Estimates are also made of the noncontroller staffing requirements in accordance with the operational and maintenance characteristics of the various enhancement systems. Consultations with Atlanta Center personnel were used to guide our staffing estimation procedure.

We note that these staffing estimates rely heavily on the validity of the RECEP and ATF models. The basic RECEP technique has been applied to some 16 sectors in enroute and terminal facilities,[1-3] while the RECEP formulation as used in this report has been applied to four enroute sectors at the Los Angeles Center.[4,5] In all cases, the resulting RECEP capacity estimates were consistent with those of the facility personnel. Although these results may not be considered a formal validation of the RECEP model, they do indicate it to be a reasonable representation of control operations. The ATF network model, which is relatively new and had previously been applied only during the Los Angeles Center case study, has not been subject to formal validation.

D. Organization of This Report

Section II of this report describes the modeling of sector team workload and traffic capacity based on the data describing current NAS Stage A System operation at the Atlanta Center. Section III details the sector team task activity revisions, workload structures, and capacities associated with various postulated enhancement features. Section IV describes the estimation of multisector manning requirements for each system and the relationships for translating manning into facility staffing requirements. Section V describes the estimation of the Air Traffic and Airway Facilities services staffing requirements for the entire facility. A summary description of the enhancement systems and a discussion of the staffing results are presented in the Executive Summary at the beginning of this report. Further details and analysis data are included as appendixes.

II NAS STAGE A BASE SYSTEM

The current third generation ATC system is the base from which the upgraded systems are to evolve. The system's FDP/RDP capabilities at the Atlanta Center facilitate:

- Automated flight data processing/forwarding.
- Automated tracking displays with alphanumerics (including ground speed,* Mode C, and reported altitudes).
- Automatic and manual display filtering.
- Surveillance data mosaicking.
- Simplified clearance/coordination procedures.
- Central flow control.

The sector radar (R) controller, the critical decision maker, performs routine, surveillance, and conflict processing activities and is supported by a data (D) controller. The sector team's routine tasks include air/ground (A/G) voice communication (R controller only), FDP/RDP manual operations, flight strip manual operations, intersector (including interfacility) interphone voice communications, and intrasector direct (face-to-face) voice consultations. Surveillance of digitized, plan view display (PVD) aircraft situation, identity, and related alphanumeric data facilitates controller flight-following. Controllers rely on mentally projected flight trajectories to detect and assess potential conflicts; these situations are resolved by A/G communications. Sector traffic flow organization and structuring is conducted in accordance with established facility-integrated procedural rules, which may be adjusted when nonstandard local flow control operations are instituted.

Although the two-man team (R and D controllers) is the normal mode of manning a sector, one-man (R controller only) and three-man operations are possible. In the latter case, an additional tracker (T) position is

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*The ground speed display capability was not operational during our Los Angeles Center observations.

manned.* The T controller performs FDP/RDP manual operations and flight strip processing, while the D controller performs interphone communications and assists the T controller.

The sector team operation is supported by an assistant (A) controller, who delivers flight strips to each sector team. One A controller typically services two sectors. Sector teams are grouped into areas, each of which is administered by a team supervisor. A flow controller and (military) mission coordinator are responsible for traffic coordination for the center, while a data systems specialist coordinates computer programming operational support. An assistant chief supervises all traffic control activities. In addition to these Air Traffic Service personnel (including controllers) located in the control room, a systems engineer (Airway Facilities Service) coordinates maintenance operations. Additional supervisory, programming, and maintenance personnel support control room operations.

The distribution of workload among positions within a sector is responsive to the time-varying traffic processing requirements. As the number of aircraft in a sector increases, the corresponding increase in the frequency of R controller decision-making actions generates more manual and verbal activity distributed among the appropriate positions. Each controller's ability to handle his workload is limited by the time available. SRI has developed a method of quantitative assessment of traffic constraints associated with controllers' decision-making, manual, and verbal activities. This RECEP produces a workload value that corresponds to the traffic capacity of a sector team.

RECEP is used in this section to describe workload and capacity relations for both two-man (System 1A) and three-man (System 1B) sector team operations under the NAS Stage A Base System.†

A. NAS Stage A Two-Man Sector Team Operation (System 1A)

Two RECEP formulations are used to assess simultaneously the team (D and R controllers) and R controller workload limitations on capacity. The first is a model of sector team operation based on measurements of controller activities at the Atlanta and Los Angeles centers, which were

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*The tracker (T) position is termed the data/radar (D/R) position at the Los Angeles Center.

†Reference 4 contains further details regarding RECEP model structure and control operations.

using the NAS Enroute Stage A3d.2 system (including RDP/FDP programs). The second, a model of R controller operation, is also empirically based, but is augmented with an inferentially derived description of controller behavior. The R controller model is constructed in part by allocating portions of the two-man team work to the R position.

1. Two-Man Team Workload

During previous observations of four sectors at the Los Angeles Center, we identified control events and task behavior patterns and their frequencies of occurrence and performance times.[5] Two basic sector control activities were differentiated: routine work and conflict processing work.

Routine work is the use of standard control procedures and techniques to facilitate traffic flow through each sector. It is generated in some form by every flight, and a sector team's routine workload varies in direct proportion to the flow rate. On the other hand, conflict processing work is the result of controller-perceived prospective violation of the separation minima allowable between aircraft. It is generated by aircraft interactions whose occurrences vary at a greater-than-direct proportional rate with traffic flow.

a. Two-Man Team Routine Work

The following routine control functions were identified:

- Control jurisdiction transfer
- Traffic structuring
- Pilot request
- Pointout
- General intersector coordination
- General system operation.

The control jurisdiction transfer is the collection of control events required to hand off an aircraft from one sector to another. Traffic structuring refers to the procedural-based, decision-making process of guiding aircraft through a sector. Pilot requests result in real-time flight modifications, adding work. Pointouts are actions required by a sector team to retain control of aircraft briefly in or near another's airspace. General intersector coordination includes those informational transfers that are performed to keep cognizant of multisector traffic movement, but are not part of handoff, traffic structuring, pilot request, or pointout activities. General system operation refers to the remaining activities not included in the above categories, activities such as equipment operation and flight data maintenance.

These functions provided an adequate basis for a first-order calibration of sector team workload limitations on traffic capacity, but they lacked sufficient operational detail to support subsequent productivity evaluations of potential design modifications to ATC system equipment. For this purpose, routine sector team activities were differentiated on the basis of identifiable control events, each of which represents the operational consequence of a specific set of task actions, as shown in Table 1. Each control event describes a recognizable operation, the workload contribution of which is placed in one of the following task performance categories:

- A/G radio communication
- FDP/RDP operation
- Flight strip processing
- Interphone communication
- Direct voice communication.

The set of events identified in Table 1 includes the event set observed at the Los Angeles Center, but is expanded to include events observed at the Atlanta Center. The routine control events and the Atlanta Center data observations are described in Appendix A.

Routine Event Performance Times--The individual task performance times shown in Table 1 are stopwatch measurements of observed minimum execution times at the Los Angeles Center. These represent sector team work capabilities during capacity traffic conditions, when controllers are assumed to be operating at peak efficiency. Spot checks during the Atlanta Center data observations (where traffic was relatively moderate because of two airline strikes) did not contradict the original Los Angeles Center task performance time data.

The basic events of Table 1 are a set of performance items necessary for event execution; supplemental events are performed only when required. For example, under the control jurisdiction transfer function, the basic handoff acceptance event is performed silently and requires 2 man-sec of FDP/RDP keyboard or trackball manual operation to

Table 1

ROUTINE EVENT MINIMUM PERFORMANCE TIME ESTIMATES
TWO-MAN SECTOR OPERATION
SYSTEM 1A--NAS STAGE A BASE

Routine Control Event Description		Minimum Task Performance Time* (man-sec/task)					Minimum Event Performance Time (man-sec/event)
Event Function	Basic Event and Supplemental Event	A/G Communication	FDP/RDP Operation	Flight Strip Processing	Interphone Communication	Direct Voice Communication†	
Control jurisdiction transfer	Handoff acceptance		2	1			3
	Flight data update		3				3
	Intersector coordination				7	6	13
	New flight strip preparation			10			10
	Handoff initiation-automatic			1			1
	Manual initiation-silent		3				3
	Intersector coordination				7	6	13
Traffic structuring	Initial pilot call-in	4		1			5
	Flight data altitude insert		3	1			4
	Altitude instruction	4		2			6
	Flight data altitude amendment		3				3
	Intersector coordination				5	6	11
	Heading instruction	5		2			7
	Flight data amendment		10				10
	Intersector coordination				5	6	11
	Speed instruction	5		2			7
	Intersector coordination				5	6	11
	Altimeter setting instruction	3		1			4
	Runway assignment instruction	3					3
	Pilot altitude report	5		2			7
	Flight data altitude insert		3				3
	Pilot heading report	5		2			7
	Pilot speed report	5		2			7
	Traffic advisory	4					4
	Transponder code assignment	4					4
	Flight data code amendment		3	2			5
	Miscellaneous A/G coordination	5					5
	Frequency change instruction	4		1			5
	Intersector coordination				4	6	10
Pilot request	Altitude revision	6		2			8
	Flight data altitude amendment		3				3
	Intersector coordination				5	6	11
	Route/heading revision	8		2			10
	Flight data route amendment		10				10
	Intersector coordination				6	8	14
	Speed revision	6		2			8
	Clearance delivery	20	3	2			25
	Miscellaneous pilot request	8					8
Pointout	Pointout acceptance				7	8	15
	Data block suppression		3				3
	Pointout initiation		3	2	7	8	20
General intersector coordination	Control instruction approval				5	6	11
	Planning advisory				5	6	11
	Aircraft status advisory				5	6	11
	Control jurisdiction advisory				6	6	12
	Clearance delivery			2	20	6	28
	Flight data update		3				3
General system operation	Flight data estimate update		1	3			4
	Data block/leader line offset		2				2
	Data block forcing/removal		3				3
	Miscellaneous data service		3				3
	Flight strip sequencing/removal			2			2
	Equipment adjustment		3				3

*Task performance time estimates are based on data collected at the Los Angeles Center.

†Indicated value is double the measured direct voice communication time duration.

effect the handoff and 1 man-sec of flight strip manual marking to record its occurrence. In some cases, supplemental FDP keypunch operations are necessary to input additional flight data. For instance, a sector team receiving an aircraft taking off from a non-ARTS III equipped terminal control facility would input an airport departure message to update the FDP data file. This latter action, which requires 3 man-sec, is an additional activity bringing the total time to 6 man-sec of sector team work for these activities. A supplemental intersector coordination accompanying the basic silent handoff typically requires a 7-sec interphone communication and a 3-sec oral message relay or consultation between the R and D controllers. Since the oral consultation simultaneously consumes 3 sec of both controllers' time, this direct voice communication requires 6 man-sec of sector team work, which is shown in Table 1. On rare occasions, an unexpected aircraft "pop-up" requires manual preparation of a new paper flight strip, which consumes an additional 10 man-sec.

The basic handoff initiation event is automatically performed by the NAS Stage A3d.2 computer system when an aircraft arrives at some predefined location (preset by program parameters) at or near sector boundaries, and requires only 1 man-sec of flight strip manual marking by a controller. The supplemental 3 man-sec manual initiation occurs when a controller prefers to hand off the aircraft at some location other than that specified by the automatic handoff parameters.

All traffic structuring and pilot request basic events are initiated by an A/G communication and generally include some form of flight strip marking. The performance time of each A/G communication task, which entails negotiation and confirmation between pilot and controller, is measured from the beginning transmission to the ending transmission for both parties and includes time devoted to decision making. Similarly, interphone and direct voice communication includes both decision-making and transmission time.

Flight strip marking is of two types: confirmation or recording of a specific event by means of a written check mark or circle on the flight strip, which takes 1 man-sec, and data updating, writing a numeric speed, altitude, heading, or beacon code revision on the flight strip, which takes 2 man-sec. In cases where altitude clearances do not conform to current flight plans, the FDP flight data file is amended by manual keyboard entry. FDP operations of this kind typically consume 3 man-sec, but more elaborate entries, such as route data amendment, take longer.

Although these manual task descriptions are characteristic, two exceptions are noted under the general system operation function. The flight data estimate update event requires the D controller to accept, by means of a 1-sec keyboard operation, FDP computer-generated flight data messages on his computer readout device (CRD), and to copy the displayed information (e.g., aircraft expected arrival time, airport departure time, altitude route, or beacon code revisions); it takes at least 3 sec to hand-copy this data onto proposal flight strips. The 2-sec flight strip sequencing/removal event refers to the on-line manual arranging and ordering of strips.

Routine Event Frequency--Seven sectors, representing different primary traffic flow characteristics, were selected for observation:

- Sector 36 (Allatoona, ALU)--high enroute traffic, FL330* and above.
- Sector 37 (Crossville, CSV)--departure transition traffic, FL240-FL310.
- Sector 38 (North Departure, NDEP)--departure traffic, FL120-FL230.
- Sector 41 (Norcross, OCR)--arrival traffic, FL120-FL230.
- Sector 42 (Lanier, 2LI)--arrival transition, traffic, FL240-FL310.
- Sector 46 (Commerce, 2CP)--low arrival traffic, surface to FL110.
- Sector 52 (Hinch Mountain, HCH)--low enroute traffic, surface to FL230.

One additional sector, 51 (Rome, RMG), representing an eighth traffic flow characteristic--low departure traffic, surface to FL110--was also observed, but data collection was not successful because of faulty recording devices.

The Atlanta Center sectors are configured in a radial traffic flow design centered on the Atlanta terminal area. Four departure corridors take climbing traffic from Atlanta to the north, east, south, and west, while four arrival corridors take descending traffic into Atlanta from the northeast, southeast, southwest, and northwest. Sectors are structured stepwise along these corridors.

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* FL (flight level) is pressure altitude in hundreds of feet; FL330 = 33,000 ft.

Sectors 37 and 38 handle aircraft along the northbound departure corridor, while Sectors 41 and 42 handle aircraft along the arrival corridor from the northeast. Sector 38 accepts outbound aircraft, primarily airline flights, from the Atlanta Terminal Radar Control (TRACON). Sector 37 processes transitioning aircraft climbing out of Sector 38, while Sector 42 processes transitioning traffic descending into Sector 41. Sector 36 overlies Sectors 37 and 38 (as well as others) and handles high cruising overflights as well as some transitioning aircraft into and out of sectors below it.

Sectors 46, 51, and 52 differ from the above sectors in that they handle primarily nonairline flights in lower airspace. They handle low overflights and transitioning traffic into and out of airports outside the Atlanta terminal area. In addition, Sector 46, which underlies Sector 41 in the northeast arrival corridor, processes traffic into the Atlanta TRACON airspace. Similarly, Sector 51 (no data records retained) underlies Sector 38 in the northbound departure corridor and processes aircraft out of the TRACON airspace.

As expected, traffic control techniques vary from sector to sector according to traffic flow characteristics and control requirements. The differences and similarities in control operations are illustrated by the measurements of event frequencies summarized in Table 2. Each frequency value is the ratio of the total number of events observed to occur in a sector over a long period of time to the total number of aircraft generating the events; therefore, each frequency value is an empirically derived representation of the expected rate of event occurrence associated with each aircraft. The data bases for these event frequencies are described in Appendix A.

Routine Workload Weighting--The control event data measurements provide a mechanism for estimating the team routine workload associated with a sector flight. Calculated workload weightings for each event are obtained by multiplying event performance times by appropriate event frequencies. The resulting team (R and D controllers) routine workload weightings by sector (as summarized in Appendix C) for Sectors 36, 37, 38, 41, 42, 46, and 52 are 51, 64, 77, 92, 66, 81, and 103 man-sec/aircraft, respectively.

b. Two-Man Team Conflict Processing Work

Aircraft conflict situations arise when there is a prospective violation of the minimum separation allowable between aircraft. Because prevention of such situations requires corrective action in advance,

Table 2

ROUTINE EVENT FREQUENCY ESTIMATES
ATLANTA CENTER, TWO-MAN SECTOR OPERATIONS
SYSTEM 1A--NAS STAGE A BASE

Routine Control Event	Event Minimum Performance Time† (man-sec/event)	Event Frequency per Sector (event/aircraft)						
		High Enroute (36) Allatoona	Departure Transition (37) Crossville	Departure (38) North Departure	Arrival (41) Norcross	Arrival Transition (42) Lanier	Low Arrival (46) Commerce	Low Enroute (52) Hinch Mountain
Control jurisdiction transfer								
Handoff acceptance	3	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Flight data update	3	0	0	0	0	0	0	0
Intersector coordination	13	0	0*	0.13	0.12	0	0.33	0.99
New flight strip preparation	10	0	0	0	0	0	0.17	0.09
Handoff initiation-automatic	1	0.25	0.17	0	0.29	0.40	0.25	0.18
Manual initiation-silent	3	0.75	0.83	1.00	0.71	0.60	0.75	0.82
Intersector coordination	13	0	0*	0.19	0.06	0	0.58	0.55
Traffic structuring								
Initial pilot call-in	5	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Flight data altitude insert	4	0	0	0	0	0	0.17	0.09
Altitude instruction	6	1.04	1.48	1.19	1.47	1.95	1.08	1.00
Flight data altitude amendment	3	0	0.09	0	0.88	0.10	0	0.18
Intersector coordination	11	0	0.25*	0.06	0.18	0.25	0.25	0.27
Heading instruction	7	0.50	0.65	1.31	0.82	0.30	0.17	0.45
Flight data route amendment	10	0.17	0.13	0	0	0	0.08	0.09
Intersector coordination	11	0	0*	0.06	0.06	0	0	0.09
Speed instruction	7	0	0	0	1.00	0.25	0	0
Intersector coordination	11	0	0.10*	0	0.12	0.10	0	0
Altimeter setting instruction	4	0	0	0.25	0.94	0	0.25	0.18
Runway assignment instruction	3	0	0	0	0	0	0	0
Pilot altitude report	7	0.13	0.30	0.25	0.82	0.40	0.42	0.45
Flight data altitude insert	3	0	0	0	0	0	0	0
Pilot heading report	7	0.08	0.26	0	0.41	0.15	0.67	0.64
Pilot speed report	7	0	0	0	0.24	0.10	0	0.09
Traffic advisory	4	0.67	0.17	0	0.06	0.30	0.17	0.09
Transponder code assignment	4	0	0	0.19	0.18	0	0.08	0.18
Flight data code	5	0	0	0	0	0	0	0.18
Miscellaneous A/G coordination	5	0	0	0	0	0	0.08	0.09
Frequency change instruction	5	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Intersector coordination	10	0.04	0*	0	0	0	0	0
Pilot request								
Altitude revision	8	0.08	0.17	0	0.24	0.05	0.17	0.09
Flight data altitude amendment	3	0.04	0.13	0	0.18	0.05	0	0
Intersector coordination	11	0.04	0*	0	0.06	0	0	0
Route/heading revision	10	0.04	0	0	0	0.05	0	0
Flight data route amendment	10	0.04	0	0	0	0	0	0
Intersector coordination	14	0	0.05*	0	0	0.05	0	0
Speed revision	8	0	0	0	0	0	0	0
Clearance delivery	25	0	0	0	0	0	0	0.09
Miscellaneous pilot request	8	0	0	0	0	0	0	0
Pointout								
Pointout acceptance	15	0	0.13	0.06	0	0.05	0.08	0
Data block suppression	3	0	0.13	0	0	0.05	0	0
Pointout initiation	20	0.04	0.09	0.44	0.18	0.15	0	0.18
General intersector coordination								
Control instruction approval	11	0.08	0.30*	0.56	0.35	0.30	0.58	0.36
Planning advisory	11	0.08	0.10*	0.13	0.24	0.10	0.33	0
Aircraft status advisory	11	0.08	0.10*	0.13	0.18	0.10	0.08	0.55
Control jurisdiction advisory	12	0.13	0.05*	0.19	0.29	0.05	0.17	0.18
Clearance delivery	28	0	0*	0	0	0	0.08	0.18
Flight data update	3	0	0	0	0	0	0	0.18
General system operation								
Flight data estimate update	4	0.29	0.48	1.00	0.53	0.70	0.50	1.18
Data block/leader line offset	2	0.50†	0.50†	0.50†	0.50†	0.50†	0.50†	0.50†
Data block forcing/removal	3	1.00†	1.00†	1.00†	1.00†	1.00†	1.00†	1.00†
Miscellaneous data service	3	0.25	0.04	0	0.12	0.15	0.08	0.36
Flight strip sequencing/removal	2	3.00†	3.00†	3.00†	3.00†	3.00†	3.00†	3.00†
Equipment adjustment	3	0.10†	0.10†	0.10†	0.10†	0.10†	0.10†	0.10†

*Indicated value estimated, assumed identical to Sector 42 of the Atlanta Center.

†Indicated value estimated, based on data previously collected at the Los Angeles Center and on Atlanta Center observations.

conflict avoidance by the controller necessitates a rather well-developed capability to perceive potential conflict, to mentally project flight trajectories. The R controller activities are detection and assessment, and resolution of potential conflicts.

The detection and assessment task entails situation recognition and action selection based on traffic data derived from PVD surveillance and flight strips; the resolution is the issuance and negotiation of control instructions by means of A/G communication. Effective detection and assessment depend, to a large extent, on judgment and familiarity with procedures developed through control experience. Observations reveal that journeymen R controllers have refined these capabilities to such a degree that situation resolution instructions are typically issued when conflicting aircraft first enter the sector (i.e., on first communication with the R controller). The corrective actions, which usually occur five or more minutes before violation would be imminent, are performed as soon as possible to avoid possible controller distractions by other critical situations.

Conflict Event Performance Time--Controller interviews and review of videotaped actions reveal that two conflict reactions are pertinent to controller workload: potential crossing conflict and potential overtaking conflict.

Crossing conflicts occur at the intersection or merging of air routes, while overtakes occur along routes; in either case, aircraft may be in climb, descent, or cruise. The characteristics of each event that affect workload are distinguished by the time required to perform the detection and assessment and the resolution tasks (see Table 3).

The decision-making time (20 sec) devoted to detection is the same for both conflict events, while the resolution task time of a potential crossing conflict (40 sec) is twice that of a potential overtaking conflict. This is because controllers generally rely on vectoring or altitude revision to correct crossing conflicts and often later instruct an aircraft to return to its original course.

Conflict Event Frequency--SRI has developed a number of simple mathematical relationships for estimating the expected number of potential crossing and overtaking conflict events in a sector over a

Table 3

CONFLICT EVENT PERFORMANCE TIME ESTIMATES
ATLANTA CENTER, TWO-MAN SECTOR OPERATION
SYSTEM 1A--NAS STAGE A BASE

Conflict Event	Minimum Task Performance Time* (man-sec/task)		Minimum Event Performance Time (man-sec/event)
	Detection and Assessment	Resolution	
Crossing	20	40	60
Overtaking	20	20	40

*Based on data collected at the Los Angeles Center and observations of Atlanta Center operations.

specified time period.† These mathematical models relate the frequency of conflicts to sector-specific parameters describing the aircraft flow rates and speeds along each route, the separation minima, the intersection and merging angles between the routes, the numbers of intersections and merges, the length of routes, and the number of flight levels at which conflicts can occur. The mathematical formulations are structured to reflect specific sector and traffic characteristics affecting conflict events.

The application of the modeling techniques to the seven sectors is described in Appendix B and results in the conflict event frequency factors shown in Table 4. Since conflict event frequency is related to the intersections of pairs of aircraft, rather than directly to each aircraft, the factors estimate expected event occurrence as quadratic or bilinear functions of hourly sector traffic flow.

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†The models have been used on numerous occasions by SRI to evaluate sector traffic capacities at various enroute and terminal area control facilities, and they appear to be quite realistic representations of observed traffic situations.[1-5]

Table 4

ESTIMATED FREQUENCY OF CONFLICT EVENTS PER SECTOR
ATLANTA CENTER, TWO-MAN SECTOR OPERATION
SYSTEM 1A--NAS STAGE A BASE

Sector	Conflict Event Frequency Factor [(conflicts/hr)/(aircraft/hr)^2]	
	Crossing	Overtaking
High enroute (36)	4.8×10^{-3}	0.9×10^{-3}
Departure transition (37)	4.4×10^{-3}	0.5×10^{-3}
Departure (38)	0	0.7×10^{-3}
Arrival (41)	2.7×10^{-3}	6.4×10^{-3}
Arrival transition (42)	3.5×10^{-3}	5.8×10^{-3}
Low arrival (46)	6.6×10^{-3}	0.7×10^{-3}
Low enroute (52)	5.3×10^{-3}	4.3×10^{-3}

Conflict workload weightings analogous to routine workload weightings [i.e., (man-sec/hr)/(aircraft/hr)^2] may be obtained by multiplying the conflict event performance times by the appropriate frequency factor.

2. Radar Controller Workload

A RECEP formulation similar to the team model was developed to describe R controller workload under two-man sector operation. R controller items of work are surveillance, routine work, and conflict processing.

a. R Controller Surveillance Work

Surveillance activities could not be adequately measured during the field observation and, therefore, are not included in the calibration of team workload. However, since routine PVD surveillance is an important R position responsibility, we formulated assumptions regarding surveillance frequency and time duration.

Information on PVD surveillance was developed from interviews with controllers and reflects their perceptions. To maintain a mental picture of traffic movement, they are likely to look at an aircraft's data display once every minute, 1 to 1.5 sec/look being sufficient time to identify aircraft and recognize situations. The assumptions--1.25 sec/look and 1 look/aircraft-min--result in the surveillance workload weightings presented in Table 5.

It is reasonable that the rate of surveillance work per aircraft is sensitive to the size of the sector; aircraft are in Sectors 37 and 46 for longer periods than in the other sectors, and they generate proportionately more surveillance work.

Table 5

R CONTROLLER SURVEILLANCE WORKLOAD WEIGHTING, BY SECTOR
ATLANTA CENTER, TWO-MAN SECTOR OPERATION
SYSTEM 1A--NAS STAGE A BASE

Sector	Aircraft Average Transit Time (min)	Surveillance Workload Weighting* (man-sec/aircraft)
High enroute (36)	20	25
Departure transition (37)	21	26.25
Departure (38)	12	15
Arrival (41)	19	23.75
Arrival transition (42)	18	22.5
Low arrival (46)	21	26.25
Low enroute (52)	14	17.5

*Based on 1.25 man-sec/aircraft-min.

b. R Controller Routine Work

During intense traffic activity, the R controller concentrates on the traffic in his sector, primarily occupying himself with basic traffic structuring, pilot requests, and equipment operation. As a result, he performs all A/G communications as well as tasks associated with active flight strips (including all traffic structuring and pilot request flight strip processing), various RDP-related actions, and his half of direct voice communications. The resulting task performance times are shown in Table 6. Workload weightings based on the event frequencies of Table 2 are summarized in Appendix C for both the two-man team and the R controller alone.

c. R Controller Conflict Work

The two-man conflict processing workload is allocated entirely to the R position.

3. Workload Modeling

Both the two-man team (R and D controllers) and R controller workload models were developed during the Los Angeles Center case study. The team model is based on data measurements of observed routine and conflict processing controller activities (as described in the preceding paragraphs) and is used to estimate the sector control team workload time devoted to these activities as a function of traffic flow rate. Sector team workload time, W_T, measured in man-min/hr, is calculated using an additive model of the work components:

$$W_T = k_1 N + k_2 N^2 + k_3 N^2 ,$$

where

N is the number of aircraft/hr through the sector.

k_1 is the team routine workload weighting, measured in man-min/aircraft.

k_2 is the crossing conflict workload weighting measured in (man-min/hr)/(aircraft/hr)^2.

k_3 is the overtaking conflict workload weighting measured in (man-min/hr)/(aircraft/hr)^2.

Table 6

R-CONTROLLER EVENT MINIMUM PERFORMANCE TIME ESTIMATES
TWO-MAN SECTOR OPERATION
SYSTEM 1A--NAS STAGE A BASE

Routine Control Event Description		Minimum Task Performance Time (man-sec/task)					Minimum Event Performance Time (man-sec/event)
Event Function	Basic Event and Supplemental Event	A/G Communication	FDP/RDP Operation	Flight Strip Processing	Interphone Communication	Direct Voice Communication	
Control jurisdiction transfer	Handoff acceptance						
	Flight data update						
	Intersector coordination					3	3
	New flight strip preparation						
	Handoff initiation-automatic						
	Manual initiation-silent						
	Intersector coordination					3	3
Traffic structuring	Initial pilot call-in	4		1			5
	Flight data altitude insert			1			1
	Altitude instruction	4		2			6
	Flight data altitude amendment						
	Intersector coordination					3	3
	Heading instruction	5		2			7
	Flight data amendment						
	Intersector coordination					3	3
	Speed instruction	5		2			7
	Intersector coordination					3	3
	Altimeter setting instruction	3		1			4
	Runway assignment instruction	3					3
	Pilot altitude report	5		2			7
	Flight data altitude insert						
	Pilot heading report	5		2			7
	Pilot speed report	5		2			7
	Traffic advisory	4					4
	Transponder code assignment	4					4
	Flight data code amendment			2			2
	Miscellaneous A/G coordination	5					5
	Frequency change instruction	4		1			5
	Intersector coordination					3	3
Pilot request	Altitude revision	6		2			8
	Flight data altitude amendment						
	Intersector coordination					3	3
	Route/heading revision	8		2			10
	Flight data route amendment						
	Intersector coordination					4	4
	Speed revision	6		2			8
	Clearance delivery	20		2			22
	Miscellaneous pilot request	8					8
Pointout	Pointout acceptance					4	4
	Data block suppression		3				3
	Pointout initiation					4	4
General intersector coordination	Control instruction approval					3	3
	Planning advisory					3	3
	Aircraft status advisory					3	3
	Control jurisdiction advisory					3	3
	Clearance delivery					3	3
	Flight data update						
General system operation	Flight data estimate update						
	Data block/leader line offset		2				2
	Data block forcing/removal		3				3
	Miscellaneous data service						
	Flight strip sequencing/removal						
	Equipment adjustment		3				3

Using the team workload model to construct the R controller model, we allocated (as described in the preceding paragraphs) portions of the team's routine work and all conflict processing work to the R controller and inferentially derived R controller surveillance work. R controller workload time, W_R, measured in man-min/hr, is calculated using the additive model of the work components:

$$W_R = k_1'N + k_2N^2 + k_3N^2 + k_4N \quad ,$$

where

N, k_2, and k_3 are described as above for the team model.

k_1' is the R controller routine workload weighting in man-min/aircraft.

k_4 is the surveillance workload weighting in man-min/aircraft.

The importance of the workload component structure of the team and R controller models is the capability to distinguish the control work requirements of different sectors in a manner that is sensitive to each sector's operational characteristics. Sector routine workload (k_1N or $k_1'N$) increases in direct proportion to the traffic flow rate, but varies from one sector to another depending on the pattern of traffic flow through each sector as well as each sector's procedural rules. For example, the routine workload weighting (k_1 or k_1') for an arrival sector (where vectoring instructions are frequent) would differ from that of a high enroute sector (where vectoring is not as frequent).

Recall that surveillance workload weighting (k_4) increases in direct proportion to sector flight time; therefore, surveillance workload (k_4N) is sensitive to the geographic size of a sector as well as the traffic flow rate. Potential crossing and overtaking conflict workloads (k_2N^2) or k_3N^2) increase with the square of the traffic flow rate. The conflict workload weightings (k_2, k_3) calculated for one sector would differ from those of another, depending on the complexity of each sector's route structure and its procedural rules. In particular, the derivations of the conflict workload weightings (using the conflict event frequencies as described in Appendix B) can model a variety of aircraft crossing and merging situations including level/level, level/climb, climb/climb, level/descent, and so forth.

The structure of the workload model equations enables us to differentiate the traffic capacities of various sectors based on workload characteristics. Our capacity estimation procedure is described in the following paragraphs. As part of this description, we will briefly show how we calibrated the team model of observed sector capacities. The calibrated team model is "descriptive" in nature and, analogous to regression analysis, empirically relates observed data (controller activities) to an outcome (sector capacity). The R controller model is an attempt to develop a "causative" model of controller behavior by accounting for all the work associated with this position. It was therefore necessary to include inferentially derived (from controller interviews) surveillance workload, which is not based on observed data. A similar attempt to derive a causative model for the D controller was not successful because we could not determine with certainty his surveillance requirements (complicated by D controller requirements to respond to R controller, PVD, CRD, and FDP activities).

4. Sector Traffic Capacities

We use workload to define the traffic capacity of a sector; in doing so, we assume that the number of aircraft that can be handled through a sector during any given time is limited by controller or control team capability to perform required communication, data maintenance, and decision making. Our observations of sector operations indicate that there is a maximum total time that a controller or control team can spend performing control tasks. During the Los Angeles Center case study, we calibrated the two-man sector team workload model using interviewed controllers' estimates of sector capacities and found that 66 man-min/hr of team routine and conflict work corresponded to reported capacities measured in aircraft/hr.[5] Using the calibrated Los Angeles Center sector capacities, we determined that the R controller workload threshold is 48 man-min/hr.[5]

We use these previously established workload thresholds--66 man-min/hr for the two-man sector team and 48 man-min/hr for the R controller--to estimate capacities for the seven sectors observed at the Atlanta Center. We simultaneously apply the team and R controller model to each sector to determine which one (team or R controller) constrains sector capacity. The capacity estimation procedure is to calculate team and R controller workload for successive 5 aircraft/hr increments in traffic flow, and to interpolate the sector traffic capacity corresponding to the critical workload threshold. The resulting point estimates of sector capacities obtained by both models are shown in Table 7. Sectors 36, 37, 38, 41, 42, and 46 are constrained by the R controller workload that results with capacity estimates of 42, 38, 50, 30, 37, and 35 aircraft/hr, respectively. Sector 52 is constrained by the team workload that results with a capacity estimate of 33 aircraft/hr.

Table 7

SECTOR TRAFFIC CAPACITY ESTIMATES
ATLANTA CENTER, TWO-MAN TEAM OPERATION
SYSTEM 1A--NAS STAGE A BASE

Sector	Sector Capacity (aircraft/hr)		
	Controller Estimate*	SRI Workload Model	
		R-D Team†	R Controller‡
High enroute (36)	40-45	57	42§
Departure transition (37)	35-40	50	38§
Departure (38)	45-50	50	50§
Arrival (41)	30-35	38	30§
Arrival transition (42)	35-40	46	37§
Low arrival (46)	30-35	40	35§
Low enroute (52)	30-35	33§	35

*Controller estimates of sector capacities obtained during interviews at Atlanta Center.

†The two-man team capacity is that hourly traffic rate that generates 66 man-min/hr of team routine and conflict work.

‡The R controller capacity is that hourly traffic rate that generates 48 man-min/hr of R controller routine, surveillance, and conflict work.

§SRI sector capacity point estimate.

For comparison, we also show in Table 7 the sector capacities estimated by Atlanta Center controllers. These estimates, obtained in interviews during our data collection effort, correspond to our workload modeling-based capacity estimates. In a subsequent review of our capacity estimates, an Atlanta Center supervisory staff member evinced general agreement. However, he conjectured that our capacity point estimates for Sectors 36 and 38 may be slightly high by a few aircraft/hr, while the estimate for Sector 41 may be low by about five aircraft/hr. Since the use of these estimates is to provide a baseline for relative productivity of enhanced systems, these small capacity differences will not measurably affect subsequent comparisons in the report. Therefore, we will use the point estimates derived by the workload models and the capacity thresholds of 66 and 48 man-min/hr for the two-man team and the R controller, respectively.

B. NAS Stage A Three-Man Sector Team (System 1B)

Three-man sector teams were not in operation during our scheduled data collection periods, and modeling of their task activities is based on controller interviews[5] and observations without data collection of three-man operations.[1-3] Controllers report that this manning strategy requires the T controller to work closely with the R controller, while the D controller is operating in a less reactive role. The T controller performs the time-critical, FDP/RDP manual operations in reaction to R controller actions and assists in flight strip processing. The D controller performs much of the interphone communications and the less traffic-reactive FDP/RDP manual operations (e.g., flight data estimate updating) and flight strip processing (e.g., sequencing/removal). We note that at the Atlanta Center the T controller is physically situated between two adjacent sector consoles so that he can use both sectors' FDP/RDP keyboards to manually initiate and accept handoffs between the two sectors. However, in this so-called "half-man" operation, his primary function during busy periods is to directly support only one of the two R controllers, thus effectively being integrated into the control operations of one sector team.

Since the R-T control operation is similar in structure to the R-D team operation of the two-man sector manning strategy, the 66 man-min/hr workload limit is assumed to apply to the R-T team. The corresponding R-T team routine event performance times are shown in Table 8. Tasks performed by the D controller are not included in this model formulation as his workload will not constrain traffic capacity.

The 48 man-min/hr workload limit applies to the R controller. R controller task allocations are similar to those described for the two-man operation except for transfer of some traffic structuring flight strip processing and FDP/RDP operations to the T controller. We assume that the T controller will take over the flight strip processing associated with the altitude instruction and transponder code assignment events (in conjunction with the FDP/RDP manual tasks required for these events), as well as the FDP/RDP manual operations for pointout acceptance-data block suppression and data block/leader line offset events (which parallel his handoff activities).

Table 8

R-T TEAM ROUTINE EVENT MINIMUM PERFORMANCE TIME ESTIMATES
ATLANTA CENTER, THREE-MAN SECTOR OPERATION
SYSTEM 1B--NAS STAGE A BASE

Routine Control Event Description		Minimum Task Performance Time* (man-sec/task)					Minimum Event Performance Time* (man-sec/event)
Event Function	Basic Event and Supplemental Event	A/G Communication	FDP/RDP Operation	Flight Strip Processing	Interphone Communication	Direct Voice Communication†	
Control jurisdiction transfer	Handoff acceptance		2	1			3
	Flight data update		3				3
	Intersector coordination				0(7)		6(13)
	New flight strip preparation			0(10)			0(10)
	Handoff initiation-automatic			1			1
	Manual initiation-silent		3				3
	Intersector coordination				7	6	13
Traffic structuring	Initial pilot call-in	4		1			5
	Flight data altitude insert		3	1			4
	Altitude instruction	4		2			6
	Flight data altitude amendment		3				3
	Intersector coordination				0(5)	6	6(11)
	Heading instruction	5		2			7
	Flight data amendment		10				10
	Intersector coordination				0(5)	6	6(11)
	Speed instruction	5		2			7
	Intersector coordination				0(5)	6	6(11)
	Altimeter setting instruction	3		1			4
	Runway assignment instruction	3					3
	Pilot altitude report	5		2			7
	Flight data altitude insert		3				3
	Pilot heading report	5		2			7
	Pilot speed report	5		2			7
	Traffic advisory	4					4
	Transponder code assignment	4					4
	Flight data code amendment		3	2			5
	Miscellaneous A/G coordination	5					5
	Frequency change instruction	4		1			5
	Intersector coordination				0(4)	6	6(10)
Pilot request	Altitude revision	6		2			8
	Flight data altitude amendment		3				3
	Intersector coordination				0(5)	6	6(11)
	Route/heading revision	8		2			10
	Flight data route amendment		10				10
	Intersector coordination				0(6)	8	8(14)
	Speed revision	6		2			8
	Clearance delivery	20	3	2			25
	Miscellaneous pilot request	8					8
Pointout	Pointout acceptance				0(7)	8	8(15)
	Data block suppression		3				3
	Pointout initiation		3	2	7	8	20
General intersector coordination	Control instruction approval				0(5)	6	6(11)
	Planning advisory				0(5)	6	6(11)
	Aircraft status advisory				0(5)	6	6(11)
	Control jurisdiction advisory				0(6)	6	6(12)
	Clearance delivery			0(2)	0(20)	6	6(28)
	Flight data update		0(3)				0(3)
General system operation	Flight data estimate update		0(1)	0(3)			0(4)
	Data block/leader line offset		2				2
	Data block forcing/removal		3				3
	Miscellaneous data service		3				3
	Flight strip sequencing/removal			0(2)			0(2)
	Equipment adjustment		3				3

*Revised System 1A performance times are indicated in parentheses.

†Indicated value is double the measured direct voice communication time duration.

Conflict processing and surveillance work are the same as those described for two-man sector operations. Routine event frequencies are as shown in Table 2, and routine workload weightings are summarized in Appendix C.

Sector traffic capacity is the traffic flow rate that generates the quantity of work corresponding to the R-T controller team (66 man-min/hr) or R controller (48 man-min/hr) workload threshold, whichever is critical. Under three-man sector operations, the capacities of Sectors 36, 37, 38, 41, 42, 46, and 52 are 44, 42, 55, 32, 40, 37, and 37 aircraft/hr, respectively. In each case, the R controller (48 man-min/hr) limits capacity.

III ENHANCEMENT SYSTEMS

In this section we describe the technological and operational aspects of various proposed UG3RD enhancement features and assess their impacts on sector workload and traffic capacity. These features are:

- Automated data handling
- Enroute metering
- Automated local flow control
- Conflict probe
- Area navigation (RNAV)
- Discrete Address Beacon System (DABS) data link
- DABS-based intermittent positive control (IPC).

The enhancement feature descriptions are based on documents[6,7] describing the FAA engineering and development plan for enroute ATC and the UG3RD ATC System, on consultations with Los Angeles Center personnel, and on our experience and judgment. The descriptions are SRI's views on how the various features might be implemented in an operational enroute environment and do not necessarily conform to the referenced documentation.

We consider each feature, in the order of the above list, to be incrementally added to the preceding feature. The current NAS Stage A System described in the preceding section is taken to be the base system.

A. Automated Data Handling (System 2)

Automated data handling includes the implementation at sector positions of the following automation items:

- Electronic tabular flight data display
- RDP/PVD refinements.

1. Electronic Tabular Flight Data Display

The tabular display is the major item of interest because of its impact on sector controller activities and its sector configuration redesign implications. The tabular display, an electronic alphanumeric presentation of flight data currently printed on the paper flight strips, would replace the flight progress board. The display is assumed to be refreshed automatically by the FDP computer system and to be accessible by sector team keyboard entry devices. It is designed to eliminate manual flight strip processing by consolidating all on-line data presentation and maintenance into an FDP computer-interactive format (thus nullifying current system requirements to simultaneously perform redundant FDP and flight strip processing operations) and to facilitate sector team hand-off and pointout operations.

Use of the tabular display would affect control work by altering the task performance items as shown in Table 9. For example, the FDP computer system is capable of recognizing handoff initiation and acceptance events and automatically indicating their occurrence on a tabular display of flight data for each aircraft. This capability eliminates the 1 man-sec manual recording on flight strips of a handoff event. However, preparation of new flight files for unexpected aircraft pop-ups must still be performed (obtained from Table 1 by transforming the associated 10 man-sec flight strip processing task into an FDP operation of equal time duration). Silent handoff initiation could be manually performed by a 1 man-sec "button pushing" operation on the aircraft's electronic flight data tabulation, rather than the current 3 man-sec FDP/RDP operation.

For traffic structuring and pilot request events, the R controllers' flight strip processing tasks become D controller FDP operations. Event recording tasks (i.e., recording the occurrence of a pilot call-in, altimeter setting, or frequency change instruction) are assumed to be accomplished by simple direct entry devices on the tabular display; they would not take longer than the current (flight strip) performance times of 1 man-sec each. Since current FDP data entries require 3 man-sec to perform the necessary keyboard operations, this value is assumed to apply to data entry operations using the tabular display. Therefore, implementation of the tabular display would actually increase data entry operations by 1 man-sec relative to current flight strip entries. The 3 man-sec data entry time may be a pessimistic estimate if one considers the possibility of designing improved man-machine interaction devices as part of the tabular display, but it is nevertheless adopted for lack of more precise data. The FDP operations required for accepting handoffs could also give a visual signal (e.g., blinking light) from the aircraft's flight data tabulation, which could be removed by pushing a button upon issuance of the radio

Table 9

R-D TEAM ROUTINE EVENT MINIMUM PERFORMANCE TIME ESTIMATES
TWO-MAN SECTOR OPERATION
SYSTEM 2--AUTOMATED DATA HANDLING

Routine Control Event Description		Minimum Task Performance Time* (man-sec/task)					Minimum Event Performance Time* (man-sec/event)
Event Function	Basic Event and Supplemental Event	A/G Communication	FDP/RDP Operation	Flight Strip Processing	Interphone Communication	Direct Voice Communication†	
Control jurisdiction transfer	Handoff acceptance		2	0(1)			2(3)
	Flight data update		3				3
	Intersector coordination				7	6	13
	New flight strip preparation		10(0)	0(10)			10
	Handoff initiation-automatic			0(1)			0(1)
	Manual initiation-silent		1(3)				1(3)
	Intersector coordination				7	6	13
Traffic structuring	Initial pilot call-in	4	1(0)	0(1)			5
	Flight data altitude insert		3	0(1)			3(4)
	Altitude instruction	4	3(0)	0(2)			7(6)
	Flight data altitude amendment		0(3)				0(3)
	Intersector coordination				5	6	11
	Heading instruction	5	3(0)	0(2)			8(7)
	Flight data amendment		10				10
	Intersector coordination				5	6	11
	Speed instruction	5	3(0)	0(2)			8(7)
	Intersector coordination				5	6	11
	Altimeter setting instruction	3	1(0)	0(1)			4
	Runway assignment instruction	3					3
	Pilot altitude report	5	3(0)	0(2)			8(7)
	Flight data altitude insert		0(3)				0(3)
	Pilot heading report	5	3(0)	0(2)			8(7)
	Pilot speed report	5	3(0)	0(2)			8(7)
	Traffic advisory	4					4
	Transponder code assignment	4					4
	Flight data code amendment		3	0(2)			3(5)
	Miscellaneous A/G coordination	5					5
	Frequency change instruction	4	1(0)	0(1)			5
	Intersector coordination				4	6	10
Pilot request	Altitude revision	6	3(0)	0(2)			9(8)
	Flight data altitude amendment		0(3)				0(3)
	Intersector coordination				5	6	11
	Route/heading revision	8	3(0)	0(2)			11(10)
	Flight data route amendment		10				10
	Intersector coordination				6	8	14
	Speed revision	6	3(0)	0(2)			9(8)
	Clearance delivery	20	3	0(2)			23(25)
	Miscellaneous pilot request	8					8
Pointout	Pointout acceptance		3(0)		0(7)	0(8)	3(15)
	Data block suppression		3				3
	Pointout initiation		3	0(2)	0(7)	0(8)	3(20)
General intersector coordination	Control instruction approval				5	6	11
	Planning advisory				5	6	11
	Aircraft status advisory				5	6	11
	Control jurisdiction advisory				6	6	12
	Clearance delivery			0(2)	20	6	26(28)
	Flight data update		3				3
General system operation	Flight data estimate update		1	0(3)			1(4)
	Data block/leader line offset		2				2
	Data block forcing/removal		3				3
	Miscellaneous data service		3				3
	Flight strip sequencing/removal			0(2)			0(2)
	Equipment adjustment		3				3

*Revised System 1A performance times are indicated in parentheses.

†Indicated value is double the measured direct voice communication time duration.

frequency change. We assume that a 1 man-sec manual button push would replace the current 1 man-sec flight strip marking associated with a frequency change instruction.

Although FDP/RDP keyboard pointout currently forces a data block display onto the recipient sector's PVD, no similar means is available to silently accept the pointout. The receiving sector has no flight strip on the aircraft in question, and verbal intersector communications are used to transmit needed flight data as well as to confirm pointout recognition. This data transferral could be effected by simultaneously forcing pertinent flight data onto the receiving sector tabular display when pointout initiation is performed, thus negating the need for the interphone and associated intrasector voice consultations. As shown in Table 9, acceptance of the pointout is assumed to be conducted by means of an FDP/RDP operation taking 3 man-sec.

Important reductions in general system operation work associated with D controller operations are attributed to the tabular display's potential for eliminating much of the manual flight data estimate update and flight strip sequencing/removal activities. The FDP computer system could automatically transfer flight data updates to the tabular display. The only action required by the D controller would be an FDP keyboard operation to acknowledge receipt of the update message--a single action currently taking 1 man-sec. A computer-driven tabular display would be capable also of automatically sequencing and removing the flight data presentations, thus eliminating the manual flight strip arranging operations currently conducted by the D controller.

Assuming that these operations can be successfully incorporated into a tabular display design,* we find it clear that the flight strip printing process and the A controller would no longer be needed.

2. RDP/PVD Refinements

Two minor system modifications are meant to eliminate certain activities performed by the R controller to adjust the PVD. These are an automatic data block/leader line offset and revised automatic data block forcing/removal.

The intent of the automatic data block/leader line offset is to eliminate the RDP-related manual keyboard operations performed to reduce PVD clutter caused by overlapping alphanumeric data presentations.

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*Fault tolerance based on mini- or macro-computer backup is discussed in Reference 4.

At present, radar target data block displays are automatically removed from the PVD according to parameters set for the NAS Stage A System. These parameters specify the time after handoff acceptance at which data blocks are removed from the handoff initiator's PVD. In many cases, the controller initiating handoff would prefer to retain the data block display for a longer time even though an aircraft is no longer under his jurisdiction (e.g., to be able to distinguish a sector's outgoing from incoming aircraft), and he forces the data block display back onto his PVD by means of manual RDP keyboard operations. A parameter setting sensitive to the data block display retention requirements of individual sectors would eliminate these manual RDP operations.

The effects of these features on the frequencies of routine control events are presented in Table 10. All occurrences of manual data block/leader line offset and data block forcing/removal are assumed eliminated.

3. Sector Traffic Capacities

Conflict processing and surveillance work allocations are as described for System 1A in Tables 3, 4, and 5. Similarly, System 2 team and R controller routine work is allocated as in System 1A, and resulting workload weightings are summarized in Appendix C. Using the corresponding workload models, the capacities of Sectors 36, 37, 38, 41, 42, and 46 are constrained by the R controller and are 47, 45, 66, 34, 43, and 40 aircraft/hr, respectively. Sector 52 is constrained by team workload to 38 aircraft/hr.

Since automated data handling eliminates significant manual task activities, only negligible additional capacity gain can be achieved by using a three-man operation. The tabular display automation performs much of the work that would otherwise have been off-loaded onto the third man. This latter sector manning strategy is not further considered.

We note that since A controllers are no longer needed, the tabular display reduces the typical sector manning level from 2.5 to 2.0 controllers/sector.

B. Enroute Metering

Enroute metering is viewed as an extension of terminal metering and spacing, which is a device planned for use by feeder controllers for maximizing airport runway utilization. Enroute operational impact would be procedural in that preferential routes and flow restrictions (e.g.,

Table 10

ROUTINE EVENT FREQUENCY ESTIMATES
ATLANTA CENTER, TWO-MAN SECTOR OPERATIONS
SYSTEM 2--AUTOMATED DATA HANDLING

Routine Control Event	Event Minimum Performance Time (man-sec/event)	Event Frequency per Sector (event/aircraft)*						
		High Enroute (36) Allatoona	Departure Transition (37) Crossville	Departure (38) North Departure	Arrival (41) Norcross	Arrival Transition (42) Lanier	Low Arrival (46) Commerce	Low Enroute (52) Hinch Mountain
Control jurisdiction transfer								
Handoff acceptance	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Flight data update	3	0	0	0	0	0	0	0
Intersector coordination	13	0	0	0.13	0.12	0	0.33	0.99
New flight strip preparation	10	0	0	0	0	0	0.17	0.09
Handoff initiation-automatic	0	0.25	0.17	0	0.29	0.40	0.25	0.18
Manual initiation-silent	1	0.75	0.83	1.00	0.71	0.60	0.75	0.82
Intersector coordination	13	0	0	0.19	0.06	0	0.58	0.55
Traffic structuring								
Initial pilot call-in	5	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Flight data altitude insert	3	0	0	0	0	0	0.17	0.09
Altitude instruction	7	1.04	1.48	1.19	1.47	1.95	1.08	1.00
Flight data altitude amendment	0	0	0.09	0	0.88	0.10	0	0.18
Intersector coordination	11	0	0.25	0.06	0.18	0.25	0.25	0.27
Heading instruction	8	0.50	0.65	1.31	0.82	0.30	0.17	0.45
Flight data route amendment	10	0.17	0.13	0	0	0	0.08	0.09
Intersector coordination	11	0	0	0.06	0.06	0	0	0.09
Speed instruction	8	0	0	0	1.00	0.25	0	0
Intersector coordination	11	0	0.10	0	0.12	0.10	0	0
Altimeter setting instruction	4	0	0	0.25	0.94	0	0.25	0.18
Runway assignment instruction	3	0	0	0	0	0	0	0
Pilot altitude report	8	0.13	0.30	0.25	0.82	0.40	0.42	0.45
Flight data altitude insert	3	0	0	0	0	0	0	0
Pilot heading report	8	0.08	0.26	0	0.41	0.15	0.67	0.64
Pilot speed report	8	0	0	0	0.24	0.10	0	0.09
Traffic advisory	4	0.67	0.17	0	0.06	0.30	0.17	0.09
Transponder code assignment	4	0	0	0.19	0.18	0	0.08	0.18
Flight data code	3	0	0	0	0	0	0	0.18
Miscellaneous A/G coordination	5	0	0	0	0	0	0.08	0.09
Frequency change instruction	5	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Intersector coordination	10	0.04	0	0	0	0	0	0
Pilot request								
Altitude revision	9	0.08	0.17	0	0.24	0.05	0.17	0.09
Flight data altitude amendment	0	0.04	0.13	0	0.18	0.05	0	0
Intersector coordination	11	0.04	0	0	0.06	0	0	0
Route/heading revision	11	0.04	0	0	0	0.05	0	0
Flight data route amendment	10	0.04	0	0	0	0	0	0
Intersector coordination	14	0	0.05	0	0	0.05	0	0
Speed revision	9	0	0	0	0	0	0	0
Clearance delivery	23	0	0	0	0	0	0	0.09
Miscellaneous pilot request	8	0	0	0	0	0	0	0
Pointout								
Pointout acceptance	3	0	0.13	0.06	0	0.05	0.08	0
Data block suppression	3	0	0.13	0	0	0.05	0	0
Pointout initiation	3	0.04	0.09	0.44	0.18	0.15	0	0.18
General intersector coordination								
Control instruction approval	11	0.08	0.30	0.56	0.35	0.30	0.58	0.36
Planning advisory	11	0.08	0.10	0.13	0.24	0.10	0.33	0
Aircraft status advisory	11	0.08	0.10	0.13	0.18	0.10	0.08	0.55
Control jurisdiction advisory	12	0.13	0.05	0.19	0.29	0.05	0.17	0.18
Clearance delivery	26	0	0	0	0	0	0.08	0.18
Flight data update	3	0	0	0	0	0	0	0.18
General system operation								
Flight data estimate update	1	0.29	0.48	1.00	0.53	0.70	0.50	1.18
Data block/leader line offset	2	0.00(0.50)	0.00(0.50)	0.00(0.50)	0.00(0.50)	0.00(0.50)	0.00(0.50)	0.00(0.50)
Data block forcing/removal	3	0.00(1.00)	0.00(1.00)	0.00(1.00)	0.00(1.00)	0.00(1.00)	0.00(1.00)	0.00(1.00)
Miscellaneous data service	3	0.25	0.04	0	0.12	0.15	0.08	0.36
Flight strip sequencing/removal	0	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Equipment adjustment	3	0.10	0.10	0.10	0.10	0.10	0.10	0.10

* Revised System 1A event frequencies are shown in parentheses.

in-trail separations, speed restrictions, enroute holding) would conform to terminal metering specifications. Without more advanced automation such as data link, we do not envision significant time-over-fix sequencing by controllers of arrival aircraft on an inbound route in the enroute airspace; the additional decision making and A/G communications required to precisely control time-over-fixes or to reorder aircraft would be prohibitive and could be disruptive to routine traffic flow procedures. (Sequence adjustments might be made as required at route merge points or during turning movements in the terminal airspace where more precise aircraft/runway situation data are available).

The difference between enroute metering and current operations would be the use of more dynamic procedural rules to guide the rate of aircraft handoffs from the enroute to the terminal control facilities. Procedural changes (e.g., in-trail separation revisions) could be coordinated by the facility flow controller. However, since procedural changes would be generated by computer, they could be transmitted directly to sector positions by means of the electronic tabular display or the CRD.

Since analogous although less dynamic procedural requirements are currently in effect,* we do not envision significant sector capacity impact from enroute metering. Even though we will not further examine this enhancement feature, we recognize that it could provide important support to terminal operations. Therefore, enroute metering could be considered as an incremental enhancement to the tabular display system, but with negligible impact on enroute sector capacity.

C. Automated Local Flow Control (System 3)

Automated local flow control is analogous to enroute metering but is designed to maximize sector capacity utilization. The real-time high-integrity data processing capabilities of NAS Stage A, in conjunction with computerized traffic assessment devices, enable the implementation of this enhancement.

We had previously performed a preliminary evaluation of such a concept and found it to be a promising means for achieving productivity gains.[4]

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*At the Atlanta Center, the flow controller monitors a centerwide presentation on a PVD, coordinates (by means of interphone) with the Atlanta TRACON and the center's area officers, and negotiates aircraft metering rates into the terminal airspace as well as advising aircraft reroutings in the center's airspace.

This operation entails the implementation of on-line computerized capacity/load prediction and workload balancing algorithms. The capacity/load algorithm, integrated with the current digitized FDP/RDP data base, probes for sector excess workload situations generated by traffic surges. The workload distribution algorithm devises schemes to dissipate traffic peaks by selectively delaying aircraft in appropriate sectors. This process is designed to moderate short-term traffic peaks and would not solve long-term massive traffic congestion problems.

Implementation could be achieved through the automatic issuance of in-trail separation directives to sector teams (by means of CRD messages). Since sector teams retain command of the minute-by-minute decision making required to set up traffic in conformance with the traffic restriction directives, separation assurance degradation would not be experienced during a failure in the automated local flow control system; operations would revert to current manual (i.e., without computer augmentation) local flow control procedures. Overall operations would be managed by a facility planning (flow) controller who coordinates with adjacent facilities and the Central Flow Control Facility (CFCF).

Since automated local flow control is a means of maximizing controller capabilities, we do not evaluate its impact on individual sector operations. However, we do examine in the next section its capacity impacts on multi-sector environment.

D. Conflict Probe

Projections of aircraft flight trajectories by computer calculations of the digitized FDP/RDP data might be used in two ways to assist controllers in processing potential conflict situations: first, to alert controllers of imminent potential conflicts and to suggest corrective actions; second, to assess conflicts over a long-term horizon to determine conflict-free flight path clearances. In either case, A/G communications are required to transmit control instructions.

1. Conflict Alert

The current conflict alert device provides warning of an imminent potential confliction that occasionally may be "missed" by the controllers. It does not impact the routine sector control workload because the conflict alert projects minimum separation violation a few minutes or less ahead of its occurrence, while the controller generally projects conflicts further ahead in time. We will not further examine this device with regard to capacity and manning impacts, although safety is the issue relative to its benefit potential.

2. Flight Plan Probe

A conflict probe with longer look-ahead capabilities is difficult to assess. To avoid excessive "false alarms," a degree of flight plan description that is not currently part of the computer data files may be required. The projection of the minute-by-minute variation in aircraft trajectories, which are grasped by controllers for short-term projection purposes, would need to be incorporated into a conflict-free path generation device. This capability is particularly critical in a terminal-oriented environment such as that of the Atlanta Center, in which merging traffic flows are a major part of basic operational procedures, or in any high-density traffic operation.

Operationally, a flight plan probe may be used to assess clearance decisions immediately after airport takeoff, during routine clearance change issuance (e.g., route amendment, altitude revision), and at entry into a sector. The first two assessments would entail a fairly extensive look-ahead horizon (e.g., a few sectors), which may prove infeasible because of high false-alarm rates.* The latter assessment appears more likely of success if the look-ahead horizon is restricted to a single sector. With this sector conflict probe, more resolution alternatives may be available, since both aircraft in a potential conflict are in a single sector's jurisdiction; the flight paths of either or both aircraft may be revised. In addition, the procedural rules governing a single sector's traffic control operation may be more readily adapted to computerization than those of a moving multisector projection horizon. Therefore, we will examine the sector conflict probe's effects on operations with the understanding that the technological capability of projecting conflicts in an operational environment at low false-alarm rates is neither confirmed nor rejected.

3. Sector Conflict Probe (System 4)

The sector conflict probe's effects on controller task performance times are estimated as shown in Table 11. Detection and assessment are performed by the computerized probe, and resolution directives/

*Current FAA-sponsored research is analyzing the accuracy of flight plan data projections. Results are not available at present.

Table 11

CONFLICT EVENT PERFORMANCE TIME ESTIMATES
ATLANTA CENTER, TWO-MAN SECTOR OPERATION
SYSTEM 4--SECTOR CONFLICT PROBE

Conflict Event	Minimum Task Performance Time* (man-sec/task)		Minimum Event Performance Time* (man-sec/event)
	Detection and Assessment	Resolution	
Crossing	5(20)	40	45(60)
Overtaking	5(20)	20	25(40)

*Revised System 2 performance times are indicated in parentheses.

suggestions are displayed to the R controller. We judge that 5 sec will be sufficient to assimilate this information. Similar to current operations, actual resolution is performed by A/G communications. A reduction of 15 sec in total conflict processing time results.

Two-man team and R controller routine work is identical to that of the tabular display system (Tables 9 and 10); surveillance work is also unchanged. Traffic capacities corresponding to these workload structures for Sectors 36, 37, 38, 41, 42, and 46 are constrained by the R controller model to 40, 47, 37, 38, 45, and 42 aircraft/hr. Sector 52 is constrained by team workload to 40 aircraft/hr.

E. Area Navigation (System 5)

RNAV incorporates navigation devices to achieve closely spaced arrival and departure and multilane direct routes for high-density terminal and enroute airspace. Terminal airspace uses are not considered here. The concept we consider includes the establishment of an RNAV route system using fixed waypoints to facilitate two-dimensional (2D) computerized navigation.

The 2D RNAV waypoint network could be configured to conform closely to traffic routing patterns. Since analogous NAVAID locations are currently in effect, the number of routine instructions required to clear aircraft through the navigation network should not be significantly reduced. Use of 2D RNAV to reduce crossing conflict resolution A/G instructions may not be feasible because of the difficulty of integrating vectoring maneuvers with an established waypoint network; it might be as difficult to vector the aircraft as it is to establish and transmit temporary waypoint fixes (e.g., latitude and longitude) to the pilot.

The main enroute benefit of RNAV appears to be the ability to reduce overtaking conflicts by establishing closely spaced parallel routes. By assigning successive aircraft to offset routes, controllers could eliminate aircraft overtaking situations. This capability is reflected in the estimated frequency of conflict events shown in Table 12. The frequency of overtaking conflicts is assumed to be directly proportional to the percentage of aircraft equipped with RNAV equipment.

We assume that RNAV does not affect the two-man team and R controller routine (Tables 9 and 10 apply), surveillance, and crossing conflict work. The traffic capacities resulting from the proportional effects of RNAV avionics equipage on overtaking conflict work are shown in Table 13. Significant traffic capacity gains are realized in Sectors 41 and 42, which currently have a high proportion of overtaking conflicts. However, since the traffic capacities do not increase noticeably in all sectors, we will consider only the 100% RNAV avionics level in subsequent capacity estimates.

F. DABS Data Link

The DABS data link transmits digital data to pilots, including general control instructions and collision avoidance directives.[7] It is not intended to transmit extensive nonstandard messages in a high-density environment.

The data link integrated with extensive computerization is the basis for the so-called "control-by-exception" concept. We view this concept as somewhat more revolutionary than evolutionary, since it would transform the controller into a systems manager who is not routinely engaged in minute-by-minute tactical decision making. Rather, he would monitor and regulate a computerized sector control operation; the latter would automatically issue, by means of data link, many routine and conflict processing clearances and instructions according to traffic situations and procedural rules. The controller would intervene when necessary to

Table 12

ESTIMATED FREQUENCY OF CONFLICT EVENTS PER SECTOR
ATLANTA CENTER, TWO-MAN SECTOR OPERATION
SYSTEM 5--RNAV

Conflict Event	RNAV Equipped Aircraft (%)	Conflict Event Frequency Factor, by Sector [(conflicts/hr)/(aircraft/hr)^2]						
		High Enroute (36)	Departure Transition (37)	Departure (38)	Arrival (41)	Arrival Transition (42)	Low Arrival (46)	Low Enroute (52)
Crossing	0%-100%	4.8×10^{-3}*	4.4×10^{-3}*	0	2.7×10^{-3}*	3.5×10^{-3}*	6.6×10^{-3}*	5.3×10^{-3}*
Overtaking	0	0.9×10^{-3}*	0.5×10^{-3}*	0.7×10^{-3}*	6.4×10^{-3}*	5.8×10^{-3}*	0.7×10^{-3}*	4.3×10^{-3}*
	50	0.45×10^{-3}	0.25×10^{-3}	0.35×10^{-3}	3.2×10^{-3}	2.9×10^{-3}	0.35×10^{-3}	2.15×10^{-3}
	100	0	0	0	0	0	0	0

*Indicated event frequency = System 4 corresponding frequency.

Table 13

SECTOR TRAFFIC CAPACITY SENSITIVITY TO RNAV EQUIPPED AIRCRAFT
ATLANTA CENTER, TWO-MAN SECTOR OPERATION
SYSTEM 5--RNAV

Sector	Sector Capacity, by RNAV Equipped Aircraft* (aircraft/hr)		
	0%†	50%	100%
High enroute (36)	50	50	51
Departure transition (37)	47	47	48
Departure (38)	67	67	68
Arrival (41)	38	39	41
Arrival transition (42)	45	47	50
Low arrival (46)	42	42	43
Low enroute (52)	40	41	42

*All sectors except Sector 52 are constrained by R controller.

†Indicated capacity = System 4 corresponding capacity.

adjust procedural rules, to respond to pilot requests, to resolve non-standard situations, and to transmit A/G messages that are too long for the DABS data link. In essence, he would concentrate on minute-by-minute procedural decision making and perform minute-by-minute tactical decision making only when required. We assume that sectors will be retained as the basic control jurisdictional unit to provide fault tolerance in the event of data link or computer system malfunction (where operations fall back to a nondata link ATC system).

Under the control-by-exception concept, we assume that a sector controller need not review and approve each instruction. If he were required to read, mentally assimilate, and approve each instruction (duplicating the automated operation), workload advantages would not be realized. This concept assumes the implementation of automatic conflict processing using data link to issue potential conflict resolution instructions. By this means, potential conflicts are avoided or resolved without dependence on or restriction by human decision making. However, assuming human controllers retain responsibility for separation assurance, the question arises as to the degree to which controllers would actually remove themselves from the capability to perform minute-by-minute tactical decision making. Therefore, we assume that controllers will continue to perform intensive PVD surveillance to retain real-time mental picture-keeping (which would be vital in the event of some computer-processing failures) and to maintain cognizance of computer-generated traffic structuring and conflict processing strategies.

Our examination of capacity and staffing impacts of the DABS data link is based on a restructuring of the sector team and R controller workload items. Since this restructuring alleviates some reactive task requirements of the joint R and D controller operation, we consider both the two-man (System 6A) and one-man (System 6B) sector team manning strategies.

1. <u>DABS Data Link, Two-Man Sector Team (System 6A)</u>

The revised routine event performance times for the two-man team are shown in Table 14. Since the control-by-exception computerization will be performing much of the routine traffic structuring clearances, the controller need not perform handoff acceptance FDP/RDP operations. A/G communications for the standard altitude, heading, speed, altimeter setting, runway assignment, and frequency change instructions are assumed to be replaced by data link transmissions. However, when such activities are nonstandard and require intersector coordination, we assume that controller A/G communications and FDP/RDP manual operations will be required.

Table 14

R-D TEAM ROUTINE EVENT MINIMUM PERFORMANCE TIME ESTIMATES
TWO-MAN SECTOR OPERATION
SYSTEM 6A--DABS DATA LINK

Routine Control Event Description		Minimum Task Performance Time* (man-sec/task)					Minimum Event Performance Time* (man-sec/event)
Event Function	Basic Event and Supplemental Event	A/G Communication	FDP/RDP Operation	Flight Strip Processing	Interphone Communication	Direct Voice Communication†	
Control jurisdiction transfer	Handoff acceptance		0(2)				0(2)
	Flight data update		3				3
	Intersector coordination		2(0)		7	6	15(13)
	New flight strip preparation		10				10
	Handoff initiation-automatic						0
	Manual initiation-silent		1				1
	Intersector coordination				7	6	13
Traffic structuring	Initial pilot call-in	4	1				5
	Flight data altitude insert		3				3
	Altitude instruction	0(4)	3‡				3(7)
	Flight data altitude amendment						0
	Intersector coordination	4(0)	3(0)		5	6	18(11)
	Heading instruction	0(5)	3‡				3(8)
	Flight data amendment		0(10)				0(10)
	Intersector coordination	5(0)	10(0)		5	6	26(11)
	Speed instruction	0(5)	3‡				3(8)
	Intersector coordination	5(0)	3(0)		5	6	19(11)
	Altimeter setting instruction	0(3)	0(1)				0(4)
	Runway assignment instruction	0(3)					0(3)
	Pilot altitude report	5	3				8
	Flight data altitude insert						0
	Pilot heading report	5	3				8
	Pilot speed report	5	3				8
	Traffic advisory	4					4
	Transponder code assignment	4					4
	Flight data code amendment		3				3
	Miscellaneous A/G coordination	5					5
	Frequency change instruction	0(4)	2‡(1)				2(5)
	Intersector coordination	4(0)			4	6	14(10)
Pilot request	Altitude revision	6	3				9
	Flight data altitude amendment						0
	Intersector coordination				5	6	11
	Route/heading revision	8	3				11
	Flight data route amendment		10				10
	Intersector coordination				6	8	14
	Speed revision	6	3				9
	Clearance delivery	20	3				23
	Miscellaneous pilot request	8					8
Pointout	Pointout acceptance		3				3
	Data block suppression		3				3
	Pointout initiation		3				3
General intersector coordination	Control instruction approval				5	6	11
	Planning advisory				5	6	11
	Aircraft status advisory				5	6	11
	Control jurisdiction advisory				6	6	12
	Clearance delivery				20	6	26
	Flight data update		3				3
General system operation	Flight data estimate update		1				1
	Data block/leader line offset		2				2
	Data block forcing/removal		3				3
	Miscellaneous data service		3				3
	Flight strip sequencing/removal						0
	Equipment adjustment		3				3

*Revised System 2 performance times are indicated in parentheses.

†Indicated value is double the measured direct voice communication time duration.

‡Message cognizance.

Also shown in Table 14 under the FDP/RDP heading are "message cognizance" activities. These reflect the controller surveillance work required to maintain awareness of the computerized traffic structuring strategies. Although FDP/RDP keyboard activities are not necessarily assumed, these task items provide a surrogate mechanism to estimate controller work associated with data link transmissions. In actuality, rather than reviewing each individual transmission, the controller would probably be provided with a data display describing the overall traffic-oriented procedural intentions of the computer operation.

Revised conflict event performance times are shown in Table 15. We assume that, in accordance with their *separation assurance* responsibilities, controllers will maintain close surveillance of conflict processing operations. Since actual conflict resolution instructions would be issued by data link, we halve the controller's resolution time to allow him to check aircraft conformance.

Routine surveillance work is not changed from the preceding system.

Table 15

CONFLICT EVENT PERFORMANCE TIME ESTIMATES
ATLANTA CENTER, TWO-MAN SECTOR OPERATION
SYSTEM 6A--100% AIRCRAFT EQUIPPED DABS DATA LINK

Conflict Event	Minimum Task Performance Time* (man-sec/task)		Minimum Event Performance Time* (man-sec/event)
	Detection and Assessment	Resolution	
Crossing	5	20(40)	24(45)
Overtaking	5	10(20)	15(25)

*Revised System 5 performance times are indicated in parentheses.

2. DABS Data Link, One-Man Sector Team (System 6B)

Under one-man sector operations, the R controller performs the routine work of the two-man sector team. However, since sector team consultations are no longer applicable, all direct voice communications are eliminated. Therefore, Table 14 with direct voice tasks set equal to zero applies. Conflict surveillance work are as described for the two-man team.

3. Sector Traffic Capacities

The above workload estimates are made assuming a 100% data link equipped aircraft fleet. To account for variations in the percent of data link equipped aircraft, the team and R controller routine workload weightings and conflict event performance times are scaled proportionately, as shown in Tables 16 and 17. The resulting sector traffic capacities corresponding to the 100% RNAV avionics level are shown in Table 18. (Although one-man sector capacities at the zero-percent data link avionics level are shown, the operation is probably not feasible because of R controller difficulty in performing A/G communications simultaneously with corresponding reactive manual tasks.) Since the sector capacities vary measurably according to the percentage of data link equipped aircraft, we will consider both the 50% and 100% data link avionics levels in subsequent analyses.

G. DABS Intermittent Positive Control

IPC provides traffic advisories and threat avoidance commands to VFR pilots on an as-needed basis.[7] Extended to IFR operations, IPC would operate on imminent (e.g., lead time of 1 to 2 min) conflict situations that are "missed" by controllers. This is assumed to be a safety enhancement device that would not impact the capacity considerations associated with normal sector task activities.

However, DABS IPC may be needed to provide fault tolerance in the event of failures in the other enhancement operations (particularly conflict processing automation). Therefore, IPC would be necessary for the successful implementation of these other features. We do not further evaluate IPC; it is considered to be an incremental add-on to the data link system but with no independent capacity impact.

Table 16

ROUTINE WORK SENSITIVITY TO DABS DATA LINK AVIONICS

System	Data Link Equipped Aircraft (%)	Team and R Controller* Routine Workload Weighting, by Sector (man-sec/aircraft)						
		High Enroute (36)	Departure Transition (37)	Departure (38)	Arrival (41)	Arrival Transition (42)	Low Arrival (46)	Low Enroute (52)
6A Data link (two-man sector team)	0%	38(21)†	49(25)†	55(27)†	77(41)†	51(27)†	68(29)†	85(34)†
	50	31.5(19)	42.5(23.5)	47(24)	66.5(37)	44.5(25.5)	63.5(27.5)	81(32.5)
	100	25(17)	36(22)	39(21)	56(33)	38(24)	59(26)	77(31)
6B Data link (one-man sector team)	0%	(35)§	(43)§	(46)§	(67)§	(45)§	(54)§	(66)§
	50	(28.5)§	(36.5)§	(38.5)§	(57)§	(38.5)§	(49)§	(62)§
	100	(22)§	(30)§	(31)§	(47)§	(32)§	(44)§	(58)§

*R controller work is indicated in parentheses.

†Indicated routine work = System 5 corresponding team or R controller work.

§No team work applicable. Indicated R controller routine work = System 6A total team routine work minus System 6A team direct voice communication.

Table 17

CONFLICT EVENT PERFORMANCE TIME SENSITIVITY
TO DABS DATA LINK AVIONICS

Data Link Equipped Aircraft (%)	Crossing Conflict Task Times (sec)			Overtaking Conflict Task Times (sec)		
	Detection and Assessment	Resolution*	Total	Detection and Assessment	Resolution*	Total
0%	5†	40†	45†	5†	20†	25†
50	5	30	35	5	15	20
100	5	20	25	5	10	15

*Conflict resolution cognizance and confirmation.

†Indicated performance time = System 5 corresponding performance time.

Table 18

SECTOR TRAFFIC CAPACITY SENSITIVITY TO DABS DATA LINK AVIONICS

System	Data Link Equipped Aircraft (%)	Traffic Capacity, by Sector* (aircraft/hr)						
		High Enroute (36)	Departure Transition (37)	Departure (38)	Arrival (41)	Arrival Transition (42)	Low Arrival (46)	Low Enroute (52)
6A Data link (two-man sector team)	0%	51	48	68	41	50	43	42†
	50	55	50	74	44	53	45	44†
	100	59	53	80	48	56	48	48†
6B Data link (one-man sector team)	0%	42	38	47	30	39	32	32
	50	48	42	54	34	43	35	33
	100	54	47	63	39	49	39	36

*100% RNAV equipped aircraft assumed.

†Traffic capacity is constrained by team workload.

IV FACILITY STAFFING RELATIONSHIPS

In this section we develop a basis for transforming the individual sector capacity impacts of the various enhancement systems into facility staffing estimates. We use a selected region of the Atlanta Center to assess multisector capacity and staffing impacts. The latter are scaled to the facility level by means of expansion factors.

Each enroute center is actually manned by two staffs: Air Traffic Service and Airway Facilities Service. Each staff has its own operational responsibilities and administrative management. The Air Traffic Service operates the ATC system, while the Airway Facilities Service maintains the ATC equipment. We will develop separate procedures for estimating each of these staffs for the facility as a function of traffic demand forecast.

A. Air Traffic Service Staffing Relationships

The current Atlanta Center Air Traffic Service (AT) staff is shown in Table 19. Based on discussions with personnel at the Atlanta and Los Angeles centers and on a review of published staffing standards,[8] we conclude that the required number of controllers, team supervisors, and area officers varies according to traffic level and workload capabilities. The number of these positions depends on system operating requirements; the remaining staff should remain fixed (subject to unique requirements). In the following paragraphs we determine air traffic staffing relationships in accordance with this personnel grouping.

1. Controller Staffing Relationships

As part of a previous research effort,[4] we developed the computerized Air Traffic Flow (ATF) network simulation model and used it to assess multisector capacity and productivity effects of postulated automation implementations at the Los Angeles Center.[5] ATF simulates aggregate traffic route flows and determines delays corresponding to specified sector capacities and local flow control strategies.[4]

In this section, we apply ATF analysis to the nine-sector study area shown in Figure 1. The Atlanta Center airspace currently includes

Table 19

CURRENT AIR TRAFFIC SERVICE ANNUAL STAFF, ATLANTA CENTER

Staff Function	Authorized Annual Staffing* (persons)
Administrative	
Chief	1
Deputy Chief	1
Evaluation/Proficiency Development Officer (EPDO)	1
Evaluation/Proficiency Development Specialist (EPDS)	6
EPDS (Rotational)	6
Military Liaison Officer	1
Military Liaison Specialist	3
Data Systems Officer	1
Area Officer	5
Area Specialist	4
Personnel Management Specialist	1
Personnel Management Assistant	1
Administrative Assistant	1
Secretary	1
Secretary	7
Clerk/Stenographer	3
Cartographer	2
Card Punch Operator	1
Clerk-Typist	0
Total administrative	46
Operational	
Assistant Chief	7
Flow Controller	7
Team Supervisor	42
Data Systems Specialist	23
Supervisory Teletypist	1
Teletypist	7
Flight Data Monitor	5
Subtotal	92
Controller	505
Total operational	597
Total	643

*Source: "Manpower Status Chart, Atlanta ARTC Center" (7 December 1975).

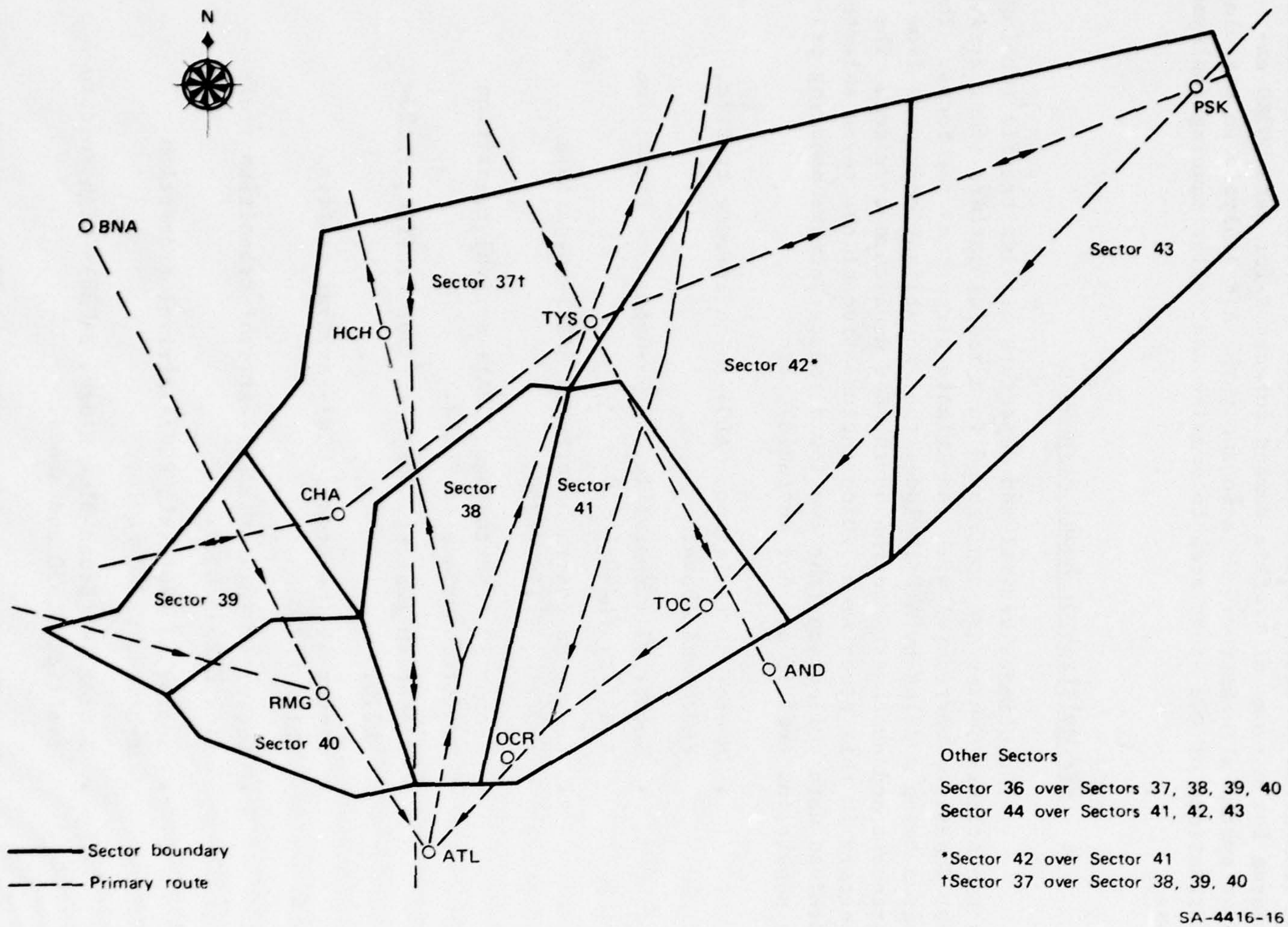

FIGURE 1 ATLANTA CENTER MULTISECTOR STUDY AREA

41 sectors, of which the nine sectors under study control primarily airline arrival, departure, and cruise traffic north of the Atlanta airport. The ATF simulation estimates delays experienced by aircraft in the multisector area for a range of traffic demand forecasts for each UG3RD enhancement system alternative. We also apply the ATF analysis to postulated resectorizations of the study area to examine controller manning deployment options.

a. ATF Multisector Model Structure

The primary arrival and departure airline traffic routings within the Atlanta Center are configured in a radial pattern (four arrival and four departure corridors) with the Atlanta airport as the focus. The study area being modeled by ATF includes the two arrival corridors from the northeast and northwest and the northbound departure corridor. The nine sectors in this study area, which include five of the seven selected for workload data collection (the two low airspace sectors handling primarily nonairline traffic are not included), are:

- Sector 36 (Allatoona, ALU)--high enroute traffic, FL330 and above.
- Sector 37 (Crossville, CSV)--departure transition traffic, FL240-FL310.
- Sector 38 (North Departure, NDEP)--departure traffic, FL120-FL230.
- Sector 39 (Chattanooga, CHA)--arrival transition traffic, surface to FL270.
- Sector 40 (Dallas, 9DP)--arrival traffic, FL120-FL270.
- Sector 41 (Norcross, OCR)--arrival traffic, FL120-FL230.
- Sector 42 (Lanier, 2LI)--arrival transition traffic, FL240-FL310.
- Sector 43 (Pulaski, PSK)--arrival transition traffic, FL240-FL310.
- Sector 44 (Baden-Blue Ridge, BAUBU)--high enroute traffic, FL330 and above.

With reference to Figure 1, Sectors 39 and 40 are in the northwest arrival corridor; Sectors 41, 42, and 43 are in the northeast arrival corridor, and Sectors 37 and 38 are in the northbound departure corridor. The sectors overlap in each corridor to form stepwise configurations that handle climbing and descending traffic transitioning in and out of the Atlanta TRACON. Sectors 36 and 44 overlay the other sectors (as noted in Figure 1) and handle primarily cruising overflights and some transitioning aircraft.

Arrivals into Atlanta Center from directly north generally enter Sector 42 at FL310 or lower, begin descent immediately, and continue the descent in Sector 41 until they are handed off to the Atlanta TRACON near OCF at FL120. The arrivals from the east over PSK in Sector 43 or Sector 44 are somewhat higher and do not begin descent until approaching the border of Sector 42. They are merged with the arrivals from the north in Sector 41 and handed off to the Atlanta TRACON near OCR at FL120. Arrivals along the two routes from the northwest enter Sector 40 at FL270 and descend to FL120 just south of RMG, where they are handed off to the Atlanta TRACON.

Departures to the north diverge in Sector 38 and proceed over HCH and TYS in Sector 39. Departing traffic generally crosses the center boundaries between FL240 and FL310.

Three major cruise routes through the area are modeled. One is a two-directional east/west route through Sectors 37, 42, and 43 in the FL240 to FL310 range, and through the overlying Sectors 36 and 44 at FL330 and above. Primary fixes along the route are CHA, TYS, and PSK. Also in the high airspace at FL330 and above are two generally north/south routes. The first crosses Sector 36 and passes over the Atlanta airport (ATL), and the other crosses Sectors 36 and 44 and passes over TYS and AND.

A large number of smaller volume routes are also in the area modeled, but are not shown in Figure 1, and include the arrival and departure routes into and out of the Chattanooga airport (CHA). Military activity makes up about 10% of the total traffic and conforms reasonably well to the routes followed by civil aircraft.

<u>Sector and Route Network Representation</u>--The sectorization and routing structure shown in Figure 1 is abstracted for input to the ATF network model, as shown schematically in Figure 2. Since the high sectors overlap lower ones in a stepwise arrangement, we juxtapose in Figure 2 the sector schematic presentations to diagram the route network. The two high sectors--36 and 44 (at the top of Figure 2)--overlay Sectors 37, 39, 42, and 43; these latter four in turn overlap the low airspace sectors--38, 40, and 41. Diagrammatic connectors (circled) are

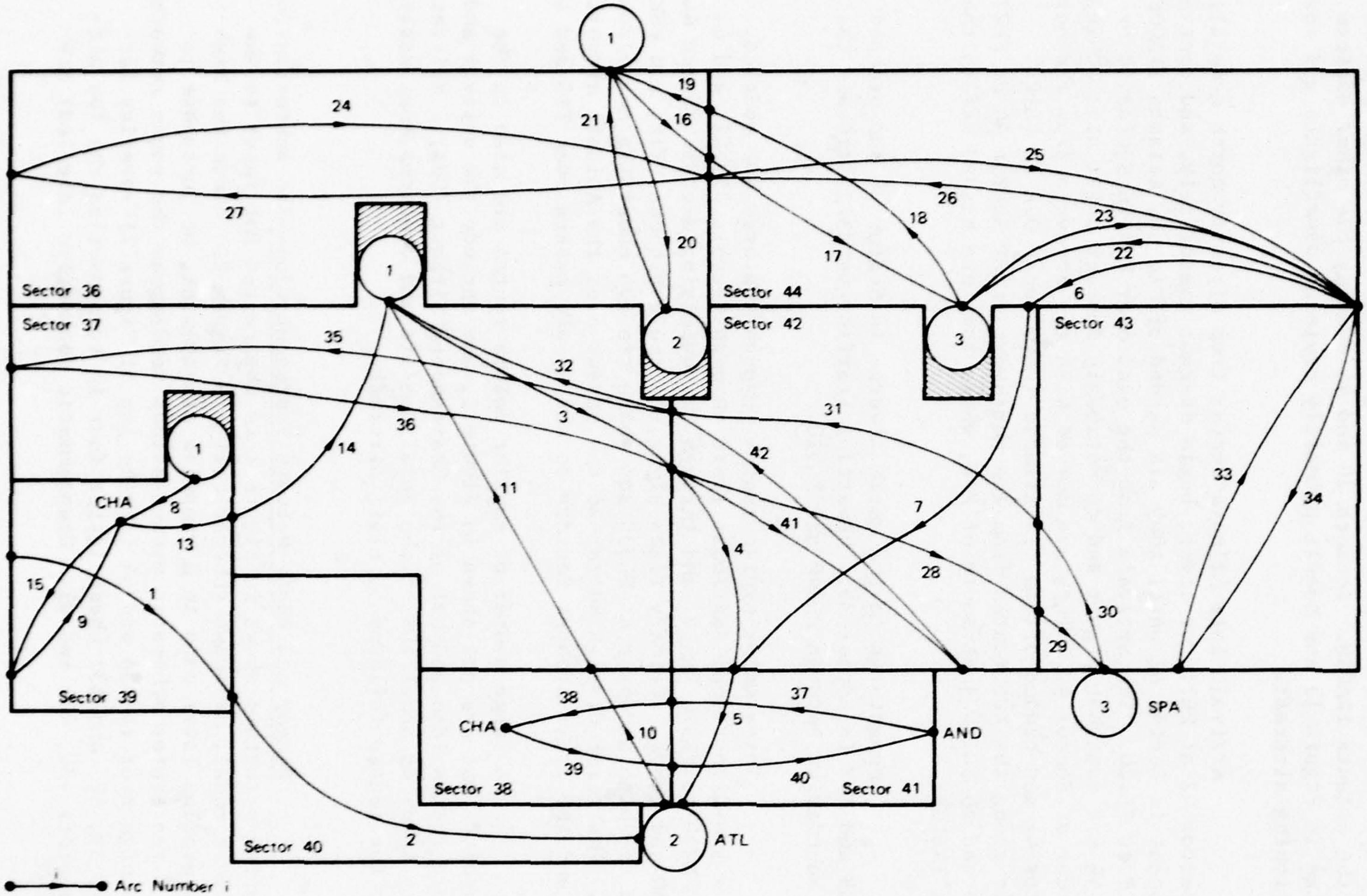

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FIGURE 2 SCHEMATIC OF STUDY AREA ROUTE MODEL included in Figure 2 to facilitate mental piecing (by superimposing connectors) of the juxtaposed sectors.

In the conversion from the actual configuration to the schematic, the only important properties (for ATF modeling) of a route segment are the transit time, the origin sector, the destination sector, and the sector including the route segment.[4] Therefore, if two or more route segments (arcs) originate at the same sector, end at the same sector, and are included in the same sector, they may be combined into one arc if desired. Arc number identities are indicated in Figure 2.

Some of the actual routes have two-directional traffic, while others have only one-directional flow. For two-directional routes, two arcs were defined to represent the actual route. Consequently, in the schematic, each arc shown represents one-dimensional traffic flow. This representation results in a system of nine sectors, 26 routes (or origin-destination pairs), and 42 arcs.

<u>UG3RD System Alternatives Representation</u>--We differentiate the UG3RD alternatives in ATF by using the sector capacities appropriate to each system. Sector capacity data are input to the ATF model to define the traffic loading capabilities of the multisector study area for a particular UG3RD system. The ATF model constrains traffic flow, by imposing delays, to ensure that traffic flow through each sector at some instant in time does not exceed that sector's predetermined capacity. The UG3RD systems and their representative sector capacities are shown in Table 20. These capacities are developed from the RECEP-based workload-capacity models.

Of the nine sectors, capacity estimates for five (Sectors 36, 37, 38, 41, and 42) are established for each UG3RD system in the preceding sections of this report. To determine capacities for the other four sectors, we performed conflict modeling for each sector (Appendix B) and inferred the appropriate routine workload requirements from the workload data collected for the five sectors. The routine workload weighting applied to Sectors 39 and 43 equals that measured for Sector 42 because the three are arrival transition sectors. Sector 40's workload is equal to that measured for Sector 41 because both are arrival sectors, and Sector 44's workload is equal to that measured for Sector 36 because both are high enroute sectors. (The workload data are summarized in Appendix D.) Despite the equivalence of the routine workload/aircraft, conflict processing and surveillance are sufficiently sensitive to sector operations to enable differentiation of capacities based on either team or R controller constraints.

Table 20

ESTIMATED SECTOR TRAFFIC CAPACITIES FOR ENHANCEMENT SYSTEMS--CONFIGURATION 1

Enhancement System	Equipped Aircraft: RNAV (%)	Equipped Aircraft: Data Link (%)	Standard Sector Manning (controllers)	Traffic Capacity, by Sector* (aircraft/hr): 36	37	38	39	40	41	42	43	44
1A. NAS Stage A Base	0%	0%	2.5†	42	38	50	45	33	30	37	42	40
1B. NAS Stage A	0	0	3.5‡	44	42	55	50	35	32	40	45	43
2. + Automated data handling	0	0	2§	47	45	66	55	40	34	43	49	45
3. + Automated local flow control	0	0	2§	47	45	66	55	40	34	43	49	45
4. + Sector conflict probe	0	0	2§	50	47	67	57	43	38	45	51	49
5. + RNAV	100	0	2§	51	48	68	59	47	41	50	52	50
6A. + Data link (two-man sectors)	100	50	2§	55	50	74	62	51	44	53	56	54
	100	100	2§	59	53	80	65	55	48	56	60	57
or												
6B. + Data link (one-man sectors)	100	50	1**	48	42	54	49	38	34	43	45	46
	100	100	1**	54	47	63	56	44	39	49	52	53

*Traffic capacity constrained by R controller workload.

†Sector manning includes radar (R), data (D), and one-half assistant (A) positions.

‡Sector manning includes radar (R), data (D), tracker (T), and one-half assistant (A) positions.

§Sector manning includes radar (R) and data (D) positions.

**Sector manning includes radar (R) position.

The standard sector manning levels of Table 20 allows for 1 controller/sector (R position manned), 2 controllers/sector (R and D positions manned), 2.5 controllers/sector (an A position supporting each 2-man team), and 3.5 controllers/sector (T position also manned). These represent the peak-shift typical sector manning strategies for the respective systems.

Resectorization--We assume, as is the current practice, that sector design reconfigurations will be required as traffic increases (regardless of which system alternative is under consideration). Reconfiguration entails modifying the sector boundary, route, and procedural rule structure of a facility, and normally requires sector splitting and airspace reallocation to create new sectors. This resectorization adds the sectors and controllers needed to increase the capacity of a multisector area and thereby constrain delays as traffic increases.

We simulate, using ATF, three postulated sector configurations for the multisector area:

- Configuration 1: current 9-sector arrangement (Figure 2).
- Configuration 2: 13 sectors (current 9 sectors, with Sectors 39, 40, 41, and 42 each split into two).
- Configuration 3: 18 sectors (original 9 sectors each split into two).

This sector splitting approach for defining sectorization alternatives is similar to the one used during the previous Los Angeles Center case study,[4] in which we applied a sector split model* to roughly estimate capacities resulting from reconfigurations of a low arrival and a high enroute-transition sector. We estimated that splitting the low sector into two sectors would increase the capacity of the original sector airspace by 40%, and splitting the high sector would increase its airspace capacity by 80%. Using these results, we judge that analogous reconfigurations of the Atlanta Center would increase the airspace capacities of arrival Sector 41 and departure Sector 38 by 40%, those of

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*The sector split model accounts for additional control work induced by new sector boundaries. Handoff, intersector coordination, pointouts, and some traffic structuring work are affected.

transition Sectors 37, 39, 42, and 43 by 60%, and those of high enroute Sectors 36 and 44 by 80%. We judge that the capacity of arrival Sector 40 will increase by 20% (rather than 40%) because of airspace limitations. These relationships are used in the ATF model to approximate the sector airspace capacities associated with the postulated sector splits of Configurations 2 and 3. This rather simplified approach to modeling sectorization is used because of the uncertainty in predicting future reconfiguration implementations.

Traffic Loading--Traffic demand over a nine-hour period is summarized in Table 21. Hourly arrivals into the 26 routes are taken from Atlanta Center flight strip records for a single day shift during December 1975. The exact arrival times at the study area boundary were not known, so for modeling we assume the arrivals to be randomly distributed over successive 20-minute periods. For parametric analysis, this demand is scaled proportionally to provide traffic data at higher demand levels. Scaling is based on successive 25% increments of civil traffic; the number of military aircraft is not increased.

The first hour's traffic loading is used to initialize ATF and is not considered during subsequent delay estimates. Hours 2 through 9 represent the eight-hour day shift beginning at 8:00 am. A total of 486 aircraft, of which 50 (10%) are military, arrives during this eight-hour study period, and is used as the current or base-level traffic in the subsequent analyses. This traffic level is roughly comparable to the fiscal year 1975 busy-day traffic reported for the nine sectors.

b. Capacity, Manning, and Staffing Comparisons

The ATF simulation model loads traffic onto the route network and processes the traffic from sector to sector until capacity overload becomes imminent. ATF then delays aircraft (without rerouting) along routes upstream of the congested sector to prevent overloading. This process propagates delays through the upstream sectors to the study area boundaries. The sector capacity constraints input into the ATF model for each system alternative are based on workload modeling relationships. Therefore, the resulting delay estimates represent the sector workload distribution effects of local flow control operations and do not include the routine procedural delays associated with the route structure design, routine ATC speed, altitude restrictions, or the like. We assume the route structure and routine clearance requirements to be fixed.

Table 21

TRAFFIC ARRIVAL, BY ROUTE

Route Number	Route Arcs	Aircraft Arrival,* by Hour								
		1	2	3	4	5	6	7	8	9
1†	1→2	1	3	18	3	18	11(1)	7(2)	10 (1)	17 (2)
2†	3→4→5	0	0	4	6(1)	8	3	2	5	9 (1)
3†	6→7→5	1	4	11	7	5	5	6	6 (1)	4
4†	8	0	0	0	2	0	0	0	2	0
5†	9	0	0	3	0	1	0	0	0	0
6†	10→11	2	0	1	4	13	12	4	4	11 (1)
7†	13→14	2	0	1	1	0	0	0	1	0
8†	15	0	2	1	0	1	1	0	3	3
9	16→17	0	0	0	6	3	4	0	3	2
10	18→19	0	1(1)	0	1	4(2)	1	2(1)	6	4
11	20	0	0	0	1	6(1)	5	5(1)	3	1 (1)
12	21	1	0	1	3	1	3(2)	2	2	2 (1)
13	22	1(1)	0	0	2	1	2	3	5	5
14	23	0	0	6	11	7	1	6	7 (1)	2
15	24→25	0	2(2)	0	3(2)	3	3(2)	2(1)	4 (1)	1
16	26→27	0	1(1)	3	1(1)	1	5(1)	0	2 (1)	1 (1)
17	3→28→29	0	0	0	2	2	1	0	0	0
18	30→31→32	0	1	0	0	0	0	1	1 (1)	0
19	3→41	0	0	1	0	0	3(1)	2	3 (1)	3 (1)
20	42→32	0	0	0	2(1)	1(1)	1	1	4 (2)	2 (1)
21	33	1	0	1	0	4	1	1	0	1
22	34	0	2	3	4	2	1	2	3 (1)	0
23	30→31→35	1	0	2	2(1)	2(1)	0	1(1)	0	2
24	36→28→29	0	0	0	2	1	0	0	0	0
25	37→38	0	0	0	1	1	2(2)	1	1	3
26	39→40	0	0	0	0	0	0	1	0	3 (1)
Total		10(1)	16(4)	56	64(6)	85(5)	65(9)	49(6)	75(10)	76(10)

Total Aircraft in Eight Hours--486

Total Military Aircraft in Eight Hours--50

*Military traffic arrivals are in parentheses.

†Local flow control routes.

To facilitate capacity, manning, and staffing comparisons among the alternative UG3RD systems, we will determine the study area traffic loadings corresponding to a common level of service. This common level of service is assumed to be the average aircraft delay (as estimated by ATF) during current NAS Stage A operations. Current Atlanta Center operations during the day shift are a mixture of two-man (System 1A) and three-man (System 1B) sector manning strategies in which one T controller supports, as needed, either the Sector 42 or Sector 44 R and D controller team, while another T controller supports either the Sector 36 or Sector 37 team. Since the ATF model structure is not currently capable of representing dynamic manning strategies, we simulate two manning cases. The first case uses the sector capacities of Table 20 for continuous three-man operations at the high enroute sectors (36 and 44) and continuous two-man operations in the remaining seven sectors, all using the eight-hour shift. The second case simulates three-man operations at the transition sectors (37 and 42) and two-man operations at the other sectors. In both cases, ATF modeling for the nine-sector configuration under traffic loading of 486 aircraft per eight-hour shift resulted in an average delay of 0.03 min/aircraft. This ATF-determined delay level represents the common level of service at which we wish to compare UG3RD systems. We define the multisector capacity to be the area traffic loading that generates in the ATF model an average aircraft delay of 0.03 min over the eight-hour shift.

Capacity and Manning--ATF traffic loading-delay results for each UG3RD system are shown in Figures 3, 4, and 5 for each of the three configurations. Two delay propagation algorithms are used. The first represents the current local flow control operation that propagates delays along the major radial routes indicated in Table 21* and is used to model Systems 1A, 1B, and 2. The second algorithm represents a postulated automated local flow control that propagates delays along selected routes (not only the major radials) and is used to model Systems 3, 4, 5, 6A, and 6B.

Area capacities corresponding to the current level of delay are obtained from these graphs and are listed in Table 22 for each ATC system. These data, adjusted for the sector controller manning requirements of each system, are represented in Figure 6.

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*Atlanta Center current local flow control operations also reroute some aircraft from one radial route to another, but the capability to model rerouting strategies is not currently part of ATF.

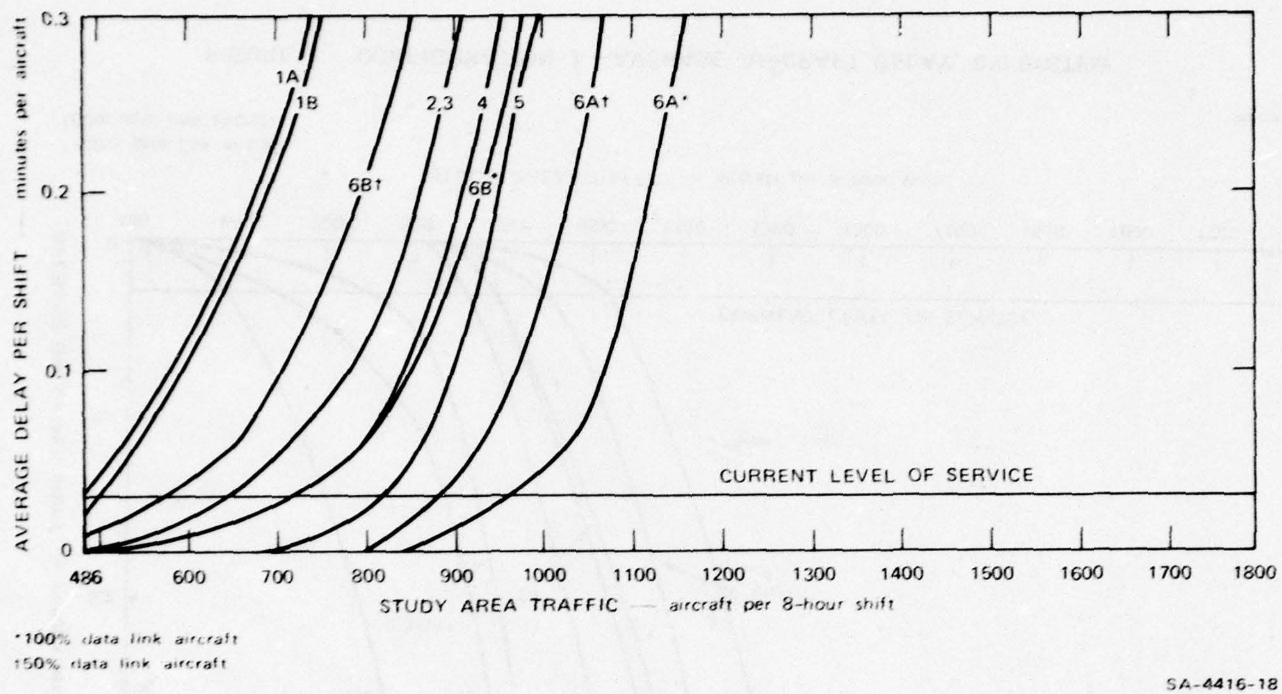
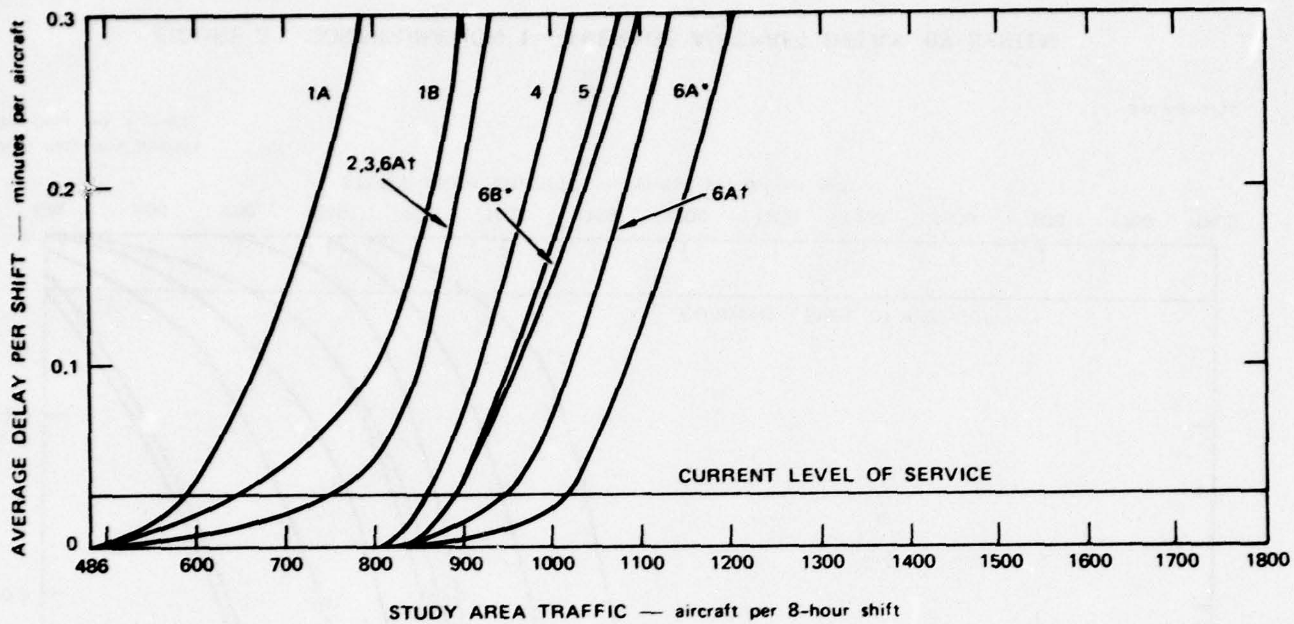


FIGURE 3 CONFIGURATION 1—AVERAGE AIRCRAFT DELAY, BY SYSTEM



*100% data link aircraft
†50% data link aircraft

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FIGURE 4 CONFIGURATION 2—AVERAGE AIRCRAFT DELAY, BY SYSTEM

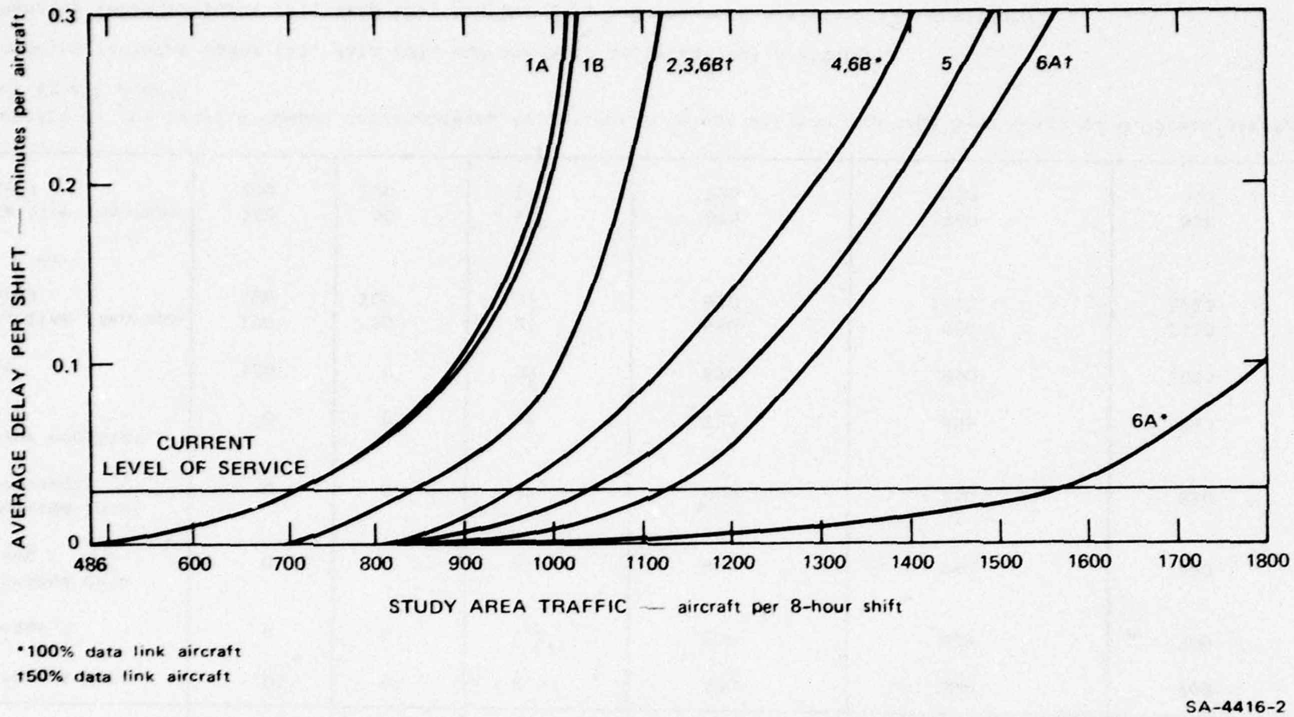

FIGURE 5 CONFIGURATION 3—AVERAGE AIRCRAFT DELAY, BY SYSTEM

Table 22

ESTIMATED MULTISECTOR CAPACITY AT CURRENT LEVEL OF DELAY

Enhancement System	Equipped Aircraft		Standard Sector Manning (controllers)	Area Capacity* (aircraft/8-hr shift)		
	RNAV (%)	Data Link (%)		Configuration 1 (9 sectors)	Configuration 2 (13 sectors)	Configuration 3 (18 sectors)
1A. NAS Stage A Base	0%	0%	$2.5^{\dagger}$	480	590	700
1B. NAS Stage A	0	0	$3.5^{\ddagger}$	500	650	700
2. + Automated data handling	0	0	$2^{\S}$	650	760	830
3. + Automated local flow control	0	0	$2^{\S}$	650	760	830
4. + Sector conflict probe	0	0	$2^{\S}$	725	865	945
5. + RNAV	100	0	$2^{\S}$	820	900	1035
6A. + Data link (two-man sectors)	100 100	50 100	$2^{\S}$ $2^{\S}$	880 950	960 1025	1135 1575
or						
6B. + Data link (one-man sectors)	100 100	50 100	1^{**} 1^{**}	575 725	760 900	830 945

*Area capacity is the traffic demand corresponding to current level of service (average 8-hr delay of 0.03 min/aircraft estimated by ATF model).

†Sector manning includes radar (R), data (D), and one-half assistant (A) positions.

‡Sector manning includes radar (R), data (D), tracker (T), and one-half assistant (A) positions.

§Sector manning includes radar (R), and data (D) positions.

**Sector manning includes radar (R) position.

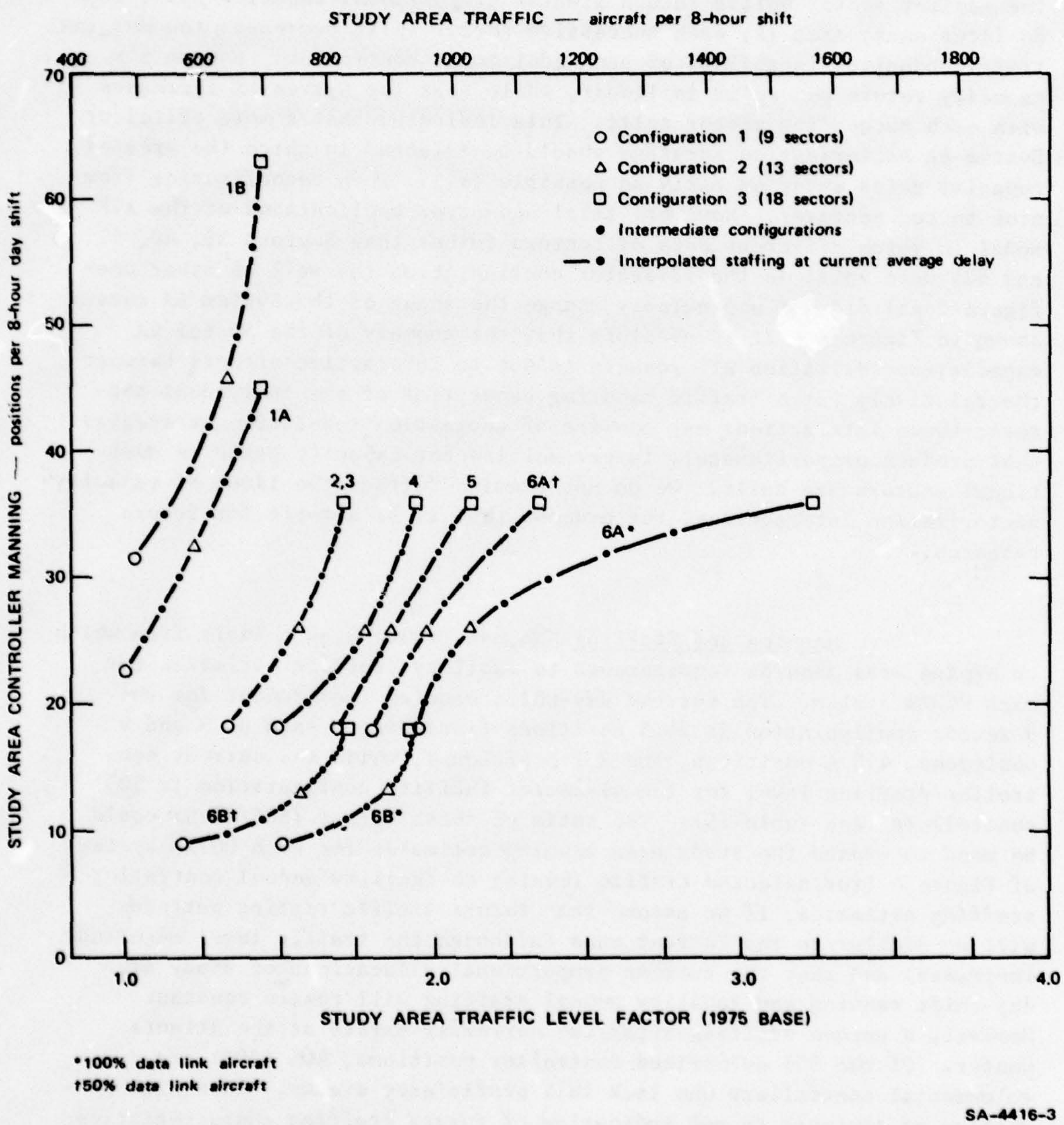

FIGURE 6 STUDY AREA CONTROLLER MANNING REQUIREMENTS AT CURRENT LEVEL OF SERVICE, BY SYSTEM: ATLANTA CENTER

Figure 6 presents the study area, day-shift controller manning required by each system to maintain the current level of delay over a range of traffic demands. Piecewise linear interpolations (between configuration capacities) are used for analytical convenience to describe the manning requirements of each system. The sectorizations modeled for Systems 1A, 1B, 2, 3, 4, and 6B behave "efficiently" in that the earlier sector splits return greater proportional capacity gains than do later ones; that is, each successive sector split decreases the marginal traffic handling capability of each additional controller. System 5's capacity return per split is linear, while that for System 6A increases with each succeeding sector split. This indicates that a more efficient System 6A sectorization strategy should be selected in which the greater capacity gains occur as early as possible (e.g., when reconfiguring from nine to ten sectors). However, trial-and-error applications of the ATF model in which different sets of sectors (other than Sectors 39, 40, 41, and 42) were split in the 13-sector configuration (as well as other configurations) did not appreciably change the shape of the System 6A curves shown in Figure 6. It is possible that the anomaly of the System 6A capacity-sectorization ATF results is due to interactive effects between the relatively large traffic handling capacities of the individual sectors; these interactions may consist of congestion resolution strategies that produce proportionately larger multisector capacity gains as additional sectors are split. We do not examine further the issue of capacity-sectorization interactions, but propose that it be a topic for future research.

Manning and Staffing--We use Figure 6 as a basis from which to expand area manning requirements to facility staffing estimates for each UG3RD system. The current day-shift manning requirement for the 9-sector configuration is 24.5 positions (including 9 each of R and D positions, 4.5 A positions, and 2 T positions), while the current controller staffing level for the 41-sector facility configuration is 505 controllers (see Table 19). The ratio of these values (505/24.5) could be used to expand the study area manning estimates for each UG3RD system of Figure 6 (for selected traffic levels) to facility annual controller staffing estimates, if we assume that future traffic routing patterns will be similar to the current ones (although the traffic level magnitude increases) and that the current proportional allocations of study area day-shift manning and facility annual staffing will remain constant. However, a unique staffing situation currently exists at the Atlanta Center. Of the 505 authorized controller positions, 40% (209) are developmental controllers who lack full proficiency status. This high proportion of trainees is not indicative of future staffing characteristics and should not be used for extrapolating staffing needs for the 1980s and beyond. Therefore, we use the controller staffing requirements based on the Atlanta Center 1975 busy-day report. These requirements are calculated by the FAA using standard staffing relationships[8] and result in a facility annual staffing estimate of 476 controllers* (including flight data function manning as well as 24-hour manning and annual and sick leave relief allowances). The ratio of the Atlanta Center calculated annual controller staffing requirement (476) to the study area day-shift manning requirement (24.5) is 19.43. We will use this expansion factor to transform the study area manning requirements of each system for the range of traffic demand levels (as shown in Figure 6) into annual controller staffing estimates.

2. Team Supervisor, Area Officer, and Area Specialist Staffing Relationships

A team supervisor mans a control room position and is in charge of the controllers operating the sectors in his area. (Team supervisors and controllers are assigned to specified groups of sectors with which they are familiar and do not work other areas.) The team supervisor coordinates sector and flow control activities and administers work schedules and team assignments. An area officer is in a staff management/ support position and coordinates an area's procedural agreements with other staff members and other facilities. He is assisted by an area specialist.

Since the operations of both team supervisors and area officers and specialists are based on familiarity with specific control areas, their staffing level varies with the number of control areas required. The current 41 sectors of the Atlanta Center are grouped into six areas.

Using standard staffing requirements[8] and assuming the number of areas will increase directly with the number of sectors, we estimate the required annual staffing corresponding to various area configurations as shown in Table 23. The required number of team supervisors and area officers and specialists is shown in this table as a function of the number of sectors in the facility.

Figure 6 is used to estimate the number of sectors required in the facility for each UG3RD system for various traffic demand levels. The number of sectors required in the study area is obtained by interpolation from this figure. Multiplying the number of study area sectors

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*Data source is "ARTCC Staffing Standard Summary Past Year 1975," a computer printout provided by the FAA (AVP).

Table 23

ESTIMATED REQUIREMENTS FOR AIR TRAFFIC SERVICE TEAM SUPERVISOR, AREA OFFICER, AND AREA SPECIALIST ATLANTA CENTER

Number of Sectors	Number of Areas	Annual Staffing (persons)		
		Team Supervisor	Area Officer and Specialist	Total
1-7	1	7	3	10
8-14	2	14	3	17
15-21	3	21	3	24
22-28	4	28	5	33
29-35	5	35	7	42
36-42	6	42	9	51
43-49	7	49	11	60
50-56	8	56	13	69
57-63	9	63	15	78
64-70	10	70	17	87
71-77	11	77	19	96
78-84	12	84	21	105

by 4.56 (nine study area sectors currently correspond to 41 facility sectors) obtains an estimate of the number of facility sectors. Again, this expansion assumes that traffic routing patterns and proportional allocations of sectors among the study area and the remainder of the facility will be stable as traffic increases.

3. Other Support and Supervisory Staffing Relationships

The annual staffing level of the remaining air traffic support and supervisory personnel does not depend on traffic level. From previous discussions with Los Angeles Center personnel, it appears that most of this staff will not be affected by the implementation of the enhancement systems. We assume that only the number of programmers will vary according to system implementation. This situation is shown in Table 24.

Table 24

ESTIMATED REQUIREMENTS FOR AIR TRAFFIC
SERVICE FACILITY SUPPORT AND SUPERVISORY FIXED STAFF
ATLANTA CENTER

Staff Function	Annual Staffing per System (persons)					
	1A and 1B	2	3	4	5	6A and 6B
Current data systems specialists (including programmers)	23	23	23	23	23	23
Additional programmers	0	0	1	1	1	4
Other*	64	64	64	64	64	64
Total	87	87	88	88	88	91

*Exclusive of controllers, team supervisors, and area officers and specialists (see Table 23).

Air traffic programmers are responsible for maintaining the currency of the operational software. The basic programs and major software revisions normally are not written at the facility, but by contractor or FAA personnel (e.g., NAFEC). However, the Atlanta Center does develop extensive software. The Los Angeles Center personnel did not foresee significant staffing increases due to the proposed enhancement items (provided the enhancements are introduced in a reasonably phased manner), while the Atlanta Center currently maintains advanced programming capabilities. Nevertheless, to be conservative, we assume that both automated local flow control (System 3) and the DABS data link/control-by-exception (System 6A or 6B) will require incremental additions to the programmer staff. For example, we expect that automated local flow control will continually require minor on-site software revisions to maintain currency with regard to changing traffic control procedures; we assume one additional programmer would be required. Similarly, the control-by-exception software must be kept current; since this software is more elaborate, we assume that three additional programmers would be needed.

B. Airway Facilities Service Staffing Relationships

The current Atlanta Center Airway Facilities Service (AF) staff is shown in Table 25. This staffing level is required to maintain the ATC equipment and is related to traffic level only through the quantity of equipment units required. Personnel of the Atlanta and Los Angeles centers indicated that major staffing adjustments would not be warranted by enhancement system implementation because much of the new equipment would replace existing equipment and would not constitute a drastic increase in inventory. The tabular display, for example, would replace the current flight strip printers. Furthermore, the solid-state electronics of the tabular display would be easier to maintain than the electrical/mechanical devices. However, allowances should be made for some minor increases in maintenance workload and for requirements to develop new technological expertise.

The personnel of interest are the electronic technicians of the AF teams, the technicians-in-depth of the technical staff, and the electrical engineers of the systems performance unit.

Five AF teams are required to provide full-time maintenance service. The teams' electronic technicians are responsible for maintaining the control sector console and related equipment as well as other facility equipment. A significant increase in the number of sectors may generate sufficient additional maintenance workload to warrant more electronic technicians. Using the current 41-sector, six-area configuration as a base, we assume that one additional electronic technician for each of the five AF teams will be required for each additional control area. Resulting facility staffing requirements are shown in Table 26.

The need for new technological expertise could require additional technicians-in-depth and system performance electrical engineers. We assume that implementation of automated data handling (System 2) and DABS (System 6A or 6B) will increase by one the staffing requirements for each of these positions, as shown in Table 27.

Table 25

CURRENT AIRWAY FACILITIES SERVICE ANNUAL STAFF
ATLANTA CENTER

Staff Function	Position	Annual Staffing (persons)	Total
Office of Manager	Sector manager	1	
	Assistant manager	1	
	Secretary	1	
	Clerk/stenographer	1	4
Technical Staff	Technician-in-depth (ET/TID)	3	3
Dev/Relief Staff	Supervisory electronic technician (SET)	1	
	Electronic technician (ET/TR)	2	3
Logistics Staff	General supply specialist	1	
	General supply assistant	1	2
Systems Performance Unit	Supervisory electronic technician (SET)	1	
	Electrical engineer (EE/ET)	5	6
Environmental Support (ES)			
ES Supervisor Staff	Supervisory engineering technician (SGE/SET)	2	2
ES Unit	Engineering technician	10	
	General facility equipment technician (GFET)	9	19
Five AF Teams	Systems engineer (SEE)	5	
	Assistant system engineer (SEE/SET)	6	11
Five CC Units	Supervisory electronic technician (SET)	5	
	Electronic technician (ET)	27	
	Computer operator	7	39
Five CDC Units	Supervisory electronic technician (SET)	5	
	Electronic technician (ET)	36	41
TOTAL			130

*Source: "AFS Organization-Staffing Chart," Atlanta Center (December 1975).

Table 26

ESTIMATED REQUIREMENTS
FOR AF TEAM ELECTRONIC TECHNICIANS
ATLANTA CENTER

Number of Sectors	Number of Areas	Annual AF Team Electronic Technician Staffing (persons)
36-42	6	63
43-49	7	68
50-56	8	73
57-63	9	78
64-70	10	83
71-77	11	88
78-84	12	93

Table 27

ESTIMATED REQUIREMENTS
FOR AIRWAY FACILITIES SERVICE FIXED ANNUAL STAFF REQUIREMENTS
ATLANTA CENTER

Position	Annual Staffing per System (persons)					
	1A and 1B	2	3	4	5	6A and 6B
Technical staff, technician-in-depth	3	4	4	4	4	5
System performance unit, electrical engineer	5	6	6	6	6	7
Other*	59	59	59	59	59	59
Total	67	69	69	69	69	71

*Exclusive of AF team electronic technicians (see Table 26).

V FACILITY STAFFING ESTIMATES

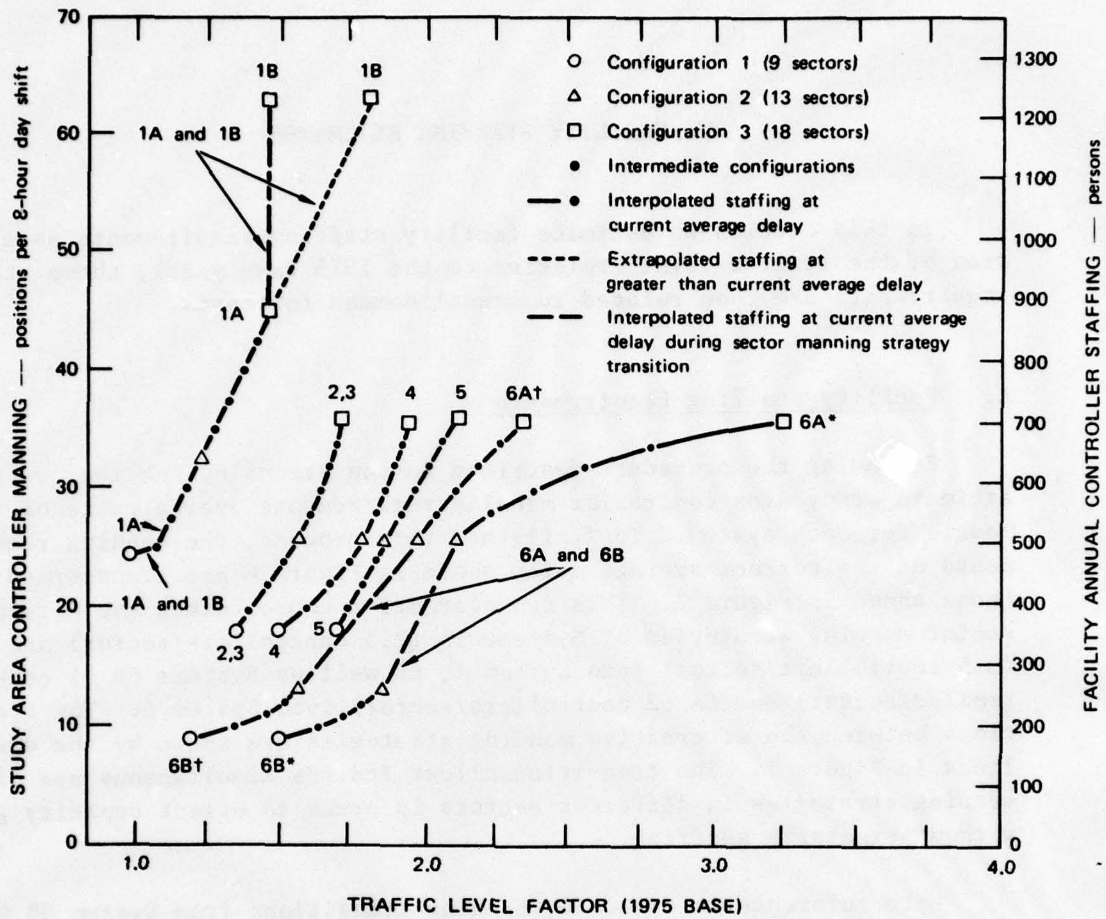
In this section we estimate facility staffing requirements as a function of the traffic level (relative to the 1975 base year); these staffing requirements are then related to annual demand forecasts.

A. Facility Staffing Requirements

Following the procedure described in the preceding section, we first estimate study area controller manning requirements over a range of traffic levels for each system. To facilitate this process, the manning requirements at the current average delay shown in Figure 6 are transformed into those shown in Figure 7. This transformation consolidates the alternative sector manning strategies of Systems 1A (2.5 controllers/sector) and 1B (3.5 controllers/sector) into System 1, as well as Systems 6B (1 controller/sector) and 6A (2 controllers/sector) into System 6. The transitions between the alternative manning strategies are shown by the dashed lines in Figure 7. The transition allows for the simultaneous use of both manning strategies in different sectors in order to effect capacity gains without excessive staffing.

With reference to Figure 7, manning transitions from System 6B to 6A with 50% and 100% data link aircraft are assumed to occur during the 13-sector configuration. Once all 13 sectors are manned by two controllers each (rather than the original one controller each), additional sector splits are used to handle increasing traffic levels. The current average delay is assumed to be maintained during each transition and reconfiguration.

In the case of Systems 1A and 1B, a transition from the current 3.5 men in two of the original nine sectors to 2.5 men in ten sectors is assumed to accompany the initial resectoring from nine to ten sectors. Successive sector splits are then assumed to occur until the original 9 sectors are configured into 18, each manned at the 2.5 level. At this point, transition to 3.5 men/sector is assumed. However, corresponding capacity gains at the current average delay cannot be achieved. This situation is indicated by the vertical dashed linear curve in Figure 7, in which the additional manning required to transition from System 1A to 1B during the 18-sector configuration does not increase capacity (at the current level of service). Since a strategy to increase manning



*100% data link aircraft

†50% data link aircraft

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FIGURE 7 STUDY AREA MANNING AND FACILITY CONTROLLER STAFFING ESTIMATES, BY SYSTEM: ATLANTA CENTER

without increasing capacity or decreasing delay is not realistic, we assume that the transition to 3.5 sector manning would realize a capacity gain if accompanied by increased average delay. This manning transition is approximated in Figure 7 by the sloping dashed line, which is a linear extrapolation at the System 1A curve. No manning transitions are needed for Systems 2, 3, 4, and 5 since 2 men/sector is standard for each.

By interpolation from Figure 7, we obtain the number of sectors and the controller manning required in the study area by each system at selected traffic levels. These area requirements are expanded into facility requirements using the expansion factors developed in the preceding section: 4.56 facility sectors/study area sector and 19.43 facility annual staffing controllers/study area day-shift manning controller. The resulting facility sectorization and annual staffing requirements are summarized for Systems 1, 2, 3, 4, 5, 6 (with 50% of the aircraft equipped with data link), and 6 (with 100% of the aircraft equipped with data link) in Tables 28 through 34, respectively.

In estimating the facility requirements, we place limits on the number of sectors. The maximum study area configuration of 18 sectors corresponds to a maximum facility configuration of 82 sectors, which is double the current 41 sectors. We assume that airspace limitations will preclude any further sectorization increases. We also use the current 41-sector configuration as the minimum sectorization level. Although it is feasible to combine sectors to create a less-than-41-sector configuration, we assume that such is not desirable because of the excessive size of the resulting sectors and the difficulty in recovering from system failures with too few sectors.

Recall that staffing estimates in Tables 28 through 34 are based on the study area manning required to maintain the current average delay. However, when the traffic level exceeds the capacity of the 82-sector facility configuration, we assume the facility staffing level will remain constant while delay increases. Similarly, when the traffic level is less than the capacity of the 41-sector configuration, delays will be less than the current average delay. These assumptions are included in the staffing requirements of Tables 28 through 34, which are transformed into the staffing factors shown in Tables 35, 36, and 37. These factors relate facility requirements to the 1975 staffing base for the Atlanta Center (Air Traffic Service, Airway Facilities Service, and both) for each system for a range of traffic levels.

B. Facility Staffing Forecasts

We use the traffic forecasts in Table 38 to translate the facility staffing requirements into staffing forecasts for 1980-2000. The resulting annual staffing forecasts (Air Traffic and Airway Facilities services) for each system are shown in Figure 8. The minimum and maximum staffing levels are limited by the facility sectorization constraints. The irregularity of the two System 6 staffing curves is due to the traffic demand surge projected in the mid-to-late 1980s and the transition from one- to two-man sector manning strategies.

A summary description of the enhancement systems and a discussion of the staffing estimation results are presented in the Executive Summary at the beginning of this report.

Table 28

SECTORIZATION AND STAFFING ESTIMATES
ATLANTA CENTER
SYSTEM 1--NAS STAGE A

	Traffic Level (1975 base)					
	1.0	1.2	1.4	1.44*	1.6*	≥1.8*†
Number of Facility Sectors	41‡	59§	78§	82§	82‡	82**
Facility annual staff (persons)						
Air traffic						
Controllers	476	631	826	874	1020	1224
Team supervisors, area officers/specialists	51	78	105	105	105	105
Other AT personnel	87	87	87	87	87	87
Total AT	614	796	1018	1066	1212	1416
Airway facilities						
AF team electronic technicians	63	78	93	93	93	93
Other AF personnel	67	67	67	67	67	67
Total AF	130	145	160	160	160	160
Facility total	744	941	1178	1226	1372	1576

*Extrapolated staffing at greater than current level of delay.

†Maximum staffing, greater than current level of delay.

‡Standard sector manning is 2.5 and 3.5 controllers (Systems 1A and 1B).

§Standard sector manning is 2.5 controllers (System 1A).

**Standard sector manning is 3.5 controllers (System 1B).

Table 29

SECTORIZATION AND STAFFING ESTIMATES
ATLANTA CENTER
SYSTEM 2--INCLUDING AUTOMATED DATA HANDLING

	Traffic Level (1975 base)			
	≤1.34*	1.4	1.6	≥1.71†
Number of facility sectors	41‡	47‡	65‡	82‡
Facility annual staff (persons)				
Air traffic				
Controllers	350	398	554	699
Team supervisors, area officers/specialists	51	60	87	105
Other AT personnel	87	87	87	87
Total AT	488	545	728	891
Airway facilities				
AF team electronic technicians	63	68	83	93
Other AF personnel	69	69	69	69
Total AF	132	137	152	162
Facility total	620	682	880	1053

*Minimum staffing, less than current level of delay.

†Maximum staffing, greater than current level of delay.

‡Standard sector manning is two controllers.

Table 30

SECTORIZATION AND STAFFING ESTIMATES
ATLANTA CENTER
SYSTEM 3--INCLUDING AUTOMATED LOCAL FLOW CONTROL

	Traffic Level (1975 base)			
	≤1.34*	1.4	1.6	≥1.71†
Number of facility sectors	41‡	47‡	65‡	82‡
Facility annual staff (persons)				
Air traffic				
Controllers	350	398	554	699
Team supervisors, area officers/specialists	51	60	87	105
Other AT personnel	88	88	88	88
Total AT	489	546	729	892
Airway facilities				
AF team electronic technicians	63	68	83	93
Other AF personnel	69	69	69	69
Total AF	132	137	152	162
Facility total	621	683	881	1054

*Minimum staffing, less than current level of delay.

†Maximum staffing, greater than current level of delay.

‡Standard sector manning is two controllers.

Table 31

SECTORIZATION AND STAFFING ESTIMATES
ATLANTA CENTER
SYSTEM 4--INCLUDING SECTOR CONFLICT PROBE

	Traffic Level (1975 base)			
	≤1.49*	1.6	1.8	≥1.94†
Number of facility sectors	**41‡**	**47‡**	**65‡**	**82‡**
Facility annual staff (persons)				
Air traffic				
Controllers	350	398	525	699
Team supervisors, area officers/specialists	51	60	78	105
Other AT personnel	88	88	88	88
Total AT	489	546	691	892
Airway facilities				
AF team electronic technicians	63	68	78	93
Other AF personnel	69	69	69	69
Total AF	132	137	147	162
Facility total	621	683	838	1054

*Minimum staffing, less than current level of delay.

†Maximum staffing, greater than current level of delay.

‡Standard sector manning is two controllers.

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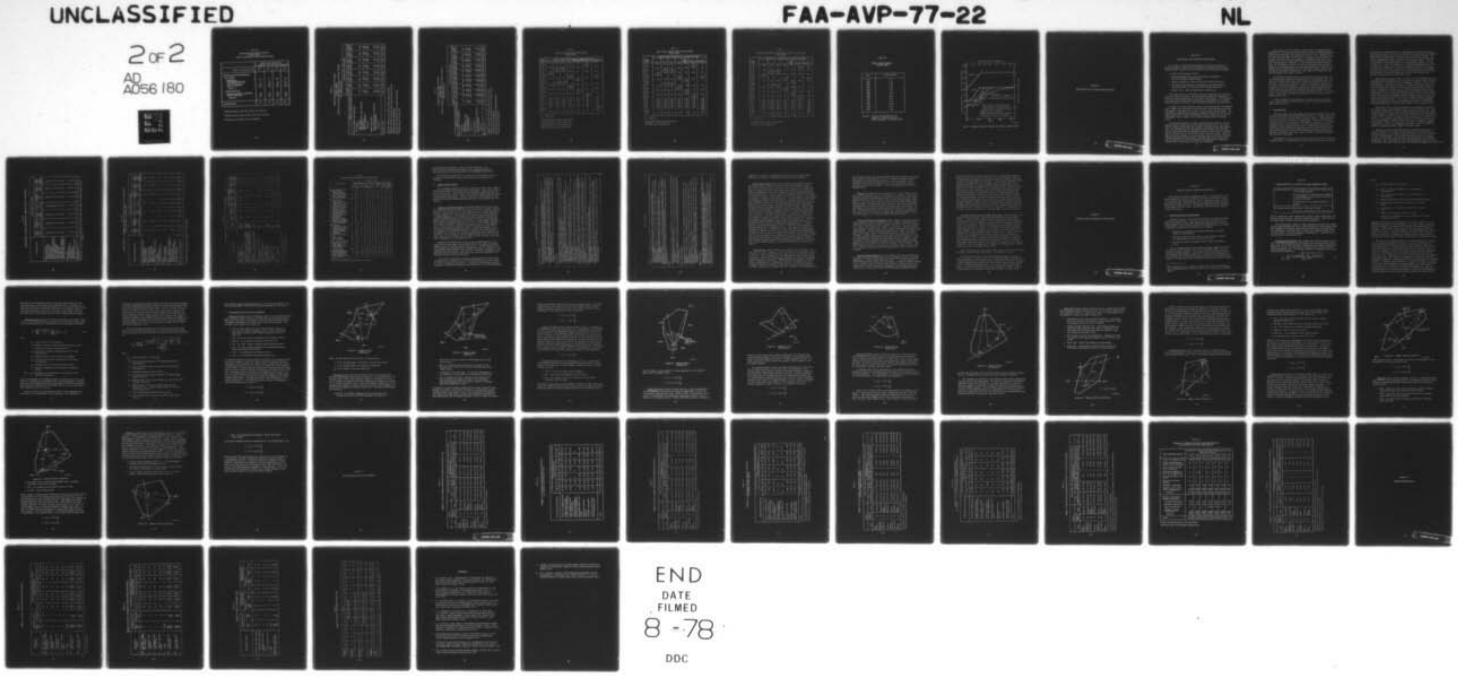

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Table 32

SECTORIZATION AND STAFFING ESTIMATES
ATLANTA CENTER
SYSTEM 5--INCLUDING 100% RNAV EQUIPPED AIRCRAFT

	Traffic Level (1975 base)			
	≤1.69*	1.8	2.0	≥2.13†
Number of facility sectors	41‡	52‡	73‡	82‡
Facility annual staff (persons)				
Air traffic				
Controllers	350	447	622	699
Team supervisors, area officers/specialists	51	69	96	105
Other AT personnel	88	88	88	88
Total AT	489	604	806	892
Airway facilities				
AF team electronic technicians	63	73	88	93
Other AF personnel	69	69	69	69
Total AF	132	142	157	162
Facility total	621	746	963	1054

*Minimum staffing, less than current level of delay.

†Maximum staffing, greater than current level of delay.

‡Standard sector manning is two controllers.

Table 33

SECTORIZATION AND STAFFING ESTIMATES
ATLANTA CENTER
SYSTEM 6--INCLUDING 50% DABS DATA LINK EQUIPPED AIRCRAFT
(100% RNAV Equipped)

	Traffic Level (1975 base)							
	≤1.18*	1.2	1.4	1.6	1.8	2.0	2.2	≥2.34†
Number of facility sectors	41‡	42‡	48‡	59§	59§	62**	74**	82**
Facility annual staff (persons)								
Air traffic								
Controllers	175	180	204	262	389	525	631	699
Team supervisors, area officers/ specialists	51	51	60	78	78	78	96	105
Other AT personnel	91	91	91	91	91	91	91	91
Total AT	317	322	355	431	558	694	818	895
Airway facilities								
AF team electronic technicians	63	63	68	78	78	78	88	93
Other AF personnel	71	71	71	71	71	71	71	71
Total AF	134	134	139	149	149	149	159	164
Facility total	451	456	494	580	707	843	977	1059

*Minimum staffing, less than current level of delay.

†Maximum staffing, greater than current level of delay.

‡One-man sectors (System 6B).

§One-man and two-man sectors (Systems 6B and 6A).

**Two-man sectors (System 6A).

Table 34

SECTORIZATION AND STAFFING ESTIMATES
ATLANTA CENTER
SYSTEM 6--INCLUDING 100% DABS DATA LINK EQUIPPED AIRCRAFT
(100% RNAV Equipped)

	Traffic Level (1975 base)										
	≤1.49*	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	≥3.24†
Number of facility sectors	41‡	44‡	57‡	59§	63**	70**	74**	78**	80**	82**	82**
Facility annual staff (persons)											
Air traffic											
Controllers	175	189	243	408	534	593	631	661	680	696	699
Team supervisors, area officers/specialists	51	60	78	78	78	87	96	105	105	105	105
Other AT personnel	91	91	91	91	91	91	91	91	91	91	91
Total AT	317	340	412	577	703	771	818	857	876	892	895
Airway facilities											
AF team electronic technicians	63	68	78	78	78	83	88	93	93	93	93
Other AF personnel	71	71	71	71	71	71	71	71	71	71	71
Total AF	134	139	149	149	149	154	159	164	164	164	164
Facility total	451	479	561	726	852	925	977	1021	1040	1056	1059

*Minimum staff level, less than current level of delay.

†Maximum staff level, greater than current level of delay.

‡One-man sectors (System 6B).

§One-man and two-man sectors (Systems 6B and 6A).

**Two-man sectors (System 6A).

Table 35

AIR TRAFFIC SERVICE STAFFING FACTOR ESTIMATES
ATLANTA CENTER

Traffic	Facility Annual Staffing Factor, by System (1975 base)*						
Level	1	2	3	4	5(100% RNAV)	6(50% D.L.)	6(100% D.L.)
1.0	1.0†	0.80	0.80	0.80	0.80	0.52	0.52
(1.18)						(0.52)†	
1.2	1.30	0.80	0.80	0.80	0.80	0.52	0.52
(1.34)		(0.80)†	(0.80)†				
1.4	1.66	0.89	0.89	0.80	0.80	0.58	0.52
(1.44)	(1.73)‡						
(1.49)				(0.80)†			(0.52)†
1.6	1.97	1.19	1.19	0.89	0.80	0.70	0.55
(1.69)					(0.80)†		
(1.71)		(1.45)‡§	(1.45)‡§				
1.8	2.31§	1.45	1.45	1.13	0.98	0.91	0.67
(1.94)				(1.45)‡§			
2.0	2.31	1.45	1.45	1.45	1.31	1.13	0.94
(2.13)					(1.45)‡§		
2.2	2.31	1.45	1.45	1.45	1.45	1.33	1.14
(2.34)						(1.46)‡§	
2.4	2.31	1.45	1.45	1.45	1.45	1.46	1.26
2.6	2.31	1.45	1.45	1.45	1.45	1.46	1.33
2.8	2.31	1.45	1.45	1.45	1.45	1.46	1.40
3.0	2.31	1.45	1.45	1.45	1.45	1.46	1.43
3.2	2.31	1.45	1.45	1.45	1.45	1.46	1.45
(3.24)							(1.46)‡§
3.4	2.31	1.45	1.43	1.45	1.45	1.46	1.46

D. L. = data link.

*Staffing factor data based on Tables 28-34.

†Minimum staffing at current average delay.

‡Maximum staffing at current average delay.

§Maximum staffing at sectorization limit.

Table 36

AIRWAY FACILITIES SERVICE STAFFING FACTOR ESTIMATES
ATLANTA CENTER

Traffic Level	Facility Annual Staffing Factor, by System (1975 base)*						
	1	2	3	4	5 (100% RNAV)	6 (50% D.L.)	6 (100% D.L.)
1.0	1.0†	1.02	1.02	1.02	1.02	1.03	1.03
(1.18)						(1.03)†	
1.2	1.12†	1.02	1.02	1.02	1.02	1.03†	1.03
(1.34)		(1.02)†	(1.02)†				
1.4	1.23†	1.05†	1.05†	1.02	1.02	1.07†	1.03
(1.44)	(1.23)†						
(1.49)				(1.02)†			(1.03)†
1.6	1.23	1.17†	1.17†	1.05†	1.02	1.15†	1.07†
(1.69)					(1.02)†		
(1.71)		(1.25)†	(1.25)†				
1.8	1.23	1.25	1.25	1.13†	1.09†	1.15†	1.15†
(1.94)				(1.25)†			
2.0	1.23	1.25	1.25	1.25	1.21†	1.15†	1.15†
(2.13)					(1.25)†		
2.2	1.23	1.25	1.25	1.25	1.25	1.22†	1.15†
(2.34)						(1.26)†	
2.4	1.23	1.25	1.25	1.25	1.25	1.26	1.18†
2.6	1.23	1.25	1.25	1.25	1.25	1.26	1.22†
2.8	1.23	1.25	1.25	1.25	1.25	1.26	1.26†
3.0	1.23	1.25	1.25	1.25	1.25	1.26	1.26†
3.2	1.23	1.25	1.25	1.25	1.25	1.26	1.26†
(3.24)							(1.26)†
3.4	1.23	1.25	1.25	1.25	1.25	1.26	1.26

D.L. = data link.

*Staffing factor data based on Tables 28-34.

†Staffing at current average delay.

Table 37

AIR TRAFFIC AND AIRWAY FACILITIES SERVICES STAFFING FACTOR ESTIMATES
ATLANTA CENTER

Traffic Level	Facility Annual Staffing Factor, by System (1975 base)*						
	1	2	3	4	5 (100% RNAV)	6 (50% D.L.)	6 (100% D.L.)
1.0	1.00†	0.83	0.83	0.83	0.83	0.61	0.61
(1.18)						(0.61)†	0.61
1.2	1.26†	0.83	0.83	0.83	0.83	0.61†	0.61
(1.34)		(0.83)†	(0.83)†				
1.4	1.58†	0.92†	0.92†	0.83	0.83	0.66†	0.61
(1.44)	(1.65)†						
(1.49)				(0.83)†			(0.61)†
1.6	1.84	1.18†	1.18†	0.92†	0.83	0.78†	0.64†
(1.69)					(0.83)†		
(1.71)		(1.42)†	(1.42)†				
1.8	2.12	1.42	1.42	1.13†	1.00†	0.95†	0.75†
(1.94)				(1.42)†			
2.0	2.12	1.42	1.42	1.42	1.29†	1.13†	0.98†
(2.13)					(1.42)†		
2.2	2.12	1.42	1.42	1.42	1.42	1.31†	1.15†
(2.34)						(1.42)†	
2.4	2.12	1.42	1.42	1.42	1.42	1.42	1.24†
2.6	2.12	1.42	1.42	1.42	1.42	1.42	1.31†
2.8	2.12	1.42	1.42	1.42	1.42	1.42	1.37†
3.0	2.12	1.42	1.42	1.42	1.42	1.42	1.40†
3.2	2.12	1.42	1.42	1.42	1.42	1.42	1.42†
(3.24)							(1.42)†
3.4	2.12	1.42	1.42	1.42	1.42	1.42	1.42

D.L. = data link.

*Staffing factor data based on Tables 28-34.

†Staffing at current average delay.

Table 38

TRAFFIC DEMAND FORECAST,
ATLANTA CENTER

Year	Traffic Level*
1975	1.0
1980	1.25
1982	1.40
1984	1.54
1986	1.75
1988	1.96
1990	2.20
1992	2.35
1994	2.50
1996	2.64
1998	2.79
2000	2.94

*Source: "IFR Aircraft Handled by User Category," Office Of Aviation Policy (AVP-120), FAA (March 1975)

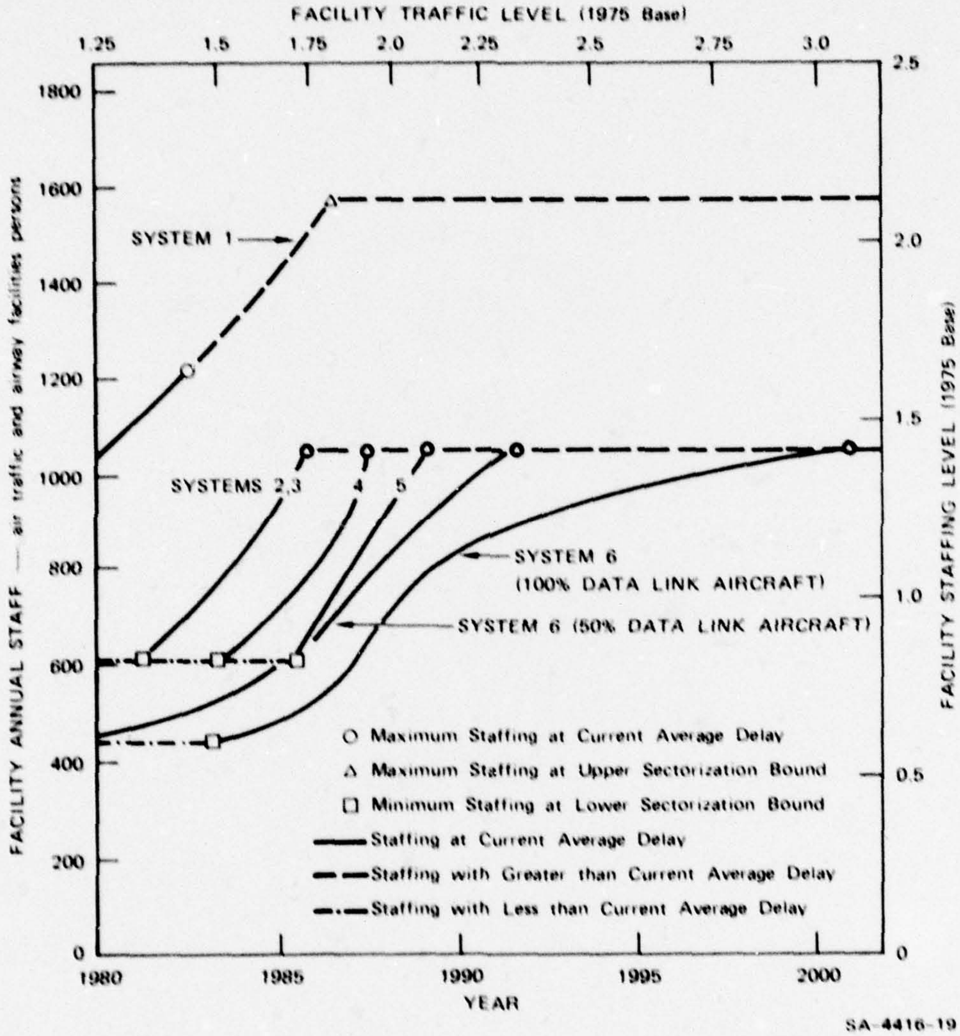

FIGURE 8 ANNUAL STAFFING FORECASTS, BY SYSTEM: ATLANTA CENTER

Appendix A

ROUTINE WORK DATA COLLECTION AND REDUCTION

Appendix A

ROUTINE WORK DATA COLLECTION AND REDUCTION

As a result of various ATC-related data collection exercises,[1-4] SRI has developed a data collection/reduction procedure for NAS Stage A equipped enroute facilities that is based on the following data sources:

- Video tape recordings of PVDs.
- Audio (including video tape sound track) recordings of A/G and interphone communications.
- Manual recordings of observed controller physical actions.
- NAS Stage A data analysis and reduction tool (DART) computer printout records of R and D position FDP/RDP operations.
- Flight strips, used and marked-on by controllers.

These data are collected during a one-hour observation of a selected sector's control activities. Each observation session is followed by a one-hour structured interview of the sector's controllers. The interviewer uses video tape playback during examination and discussion of the operational strategies, procedures, and techniques employed by the controllers.

As part of the data reduction process, data measurements are assembled into a format that facilitates cross-reference of the observed activities and permits a reconstruction, in part, of the routine control events. The information on operational procedures obtained during the controller interviews, along with the data observations, provides perspective on control requirements that is useful in the logical reconstruction of routine events.

We used this procedure to collect data from four sectors at the Los Angeles Center[4] during the five-day period 24-28 June 1974. The center was then using the NAS Stage A3d.2 system, including FDP and RDP capabilities. In reconstructing the Los Angeles Center sector team activities from the data collected, we developed the routine control event structure that is the basis for the one shown in Table 1 of this report. Since the data collection sessions at the Los Angeles Center were conducted during moderate-to-heavy traffic activity, we assume that these routine events are representative of control requirements during capacity conditions (during which nonessential activities are minimized).

Also, as part of the Los Angeles Center effort, we made stopwatch measurements of observed controller manual activities (FDP/RDP operations, flight strip processing) and recorded and observed oral communications (A/G radio and interphone communications and direct voice communication). For each identified task, we selected a "reasonable" minimum task performance time from the data measurements to represent task work requirements during capacity conditions. In determining minimum performance times, we considered only those observed or recorded activities that we judged to be performed completely (satisfied information transaction or message content requirements) and with efficiency (without delay, interruption, or extraneous information). These data are the basis for the task performance times shown in Table 1.

We conducted a similar data collection effort for seven sectors at the Atlanta Center during the five-day period 15-19 December 1975. The center was using the NAS Stage A3d.2 System, including FDP and RDP capabilities. Two airline strikes were in effect during data collection, and traffic activity was moderate. Despite the absence of heavy traffic loadings, the data collected and reconstructed substantiated the basic routine control event structure resulting from the Los Angeles Center effort, and indicated the need for some minor modifications. A restricted effort to spot-check the task performance times also supported the Los Angeles Center data.

In the remainder of this appendix, we review the data collection results and describe the routine control events for the Atlanta Center data collection effort.

1. Data Reduction

The data sources that were reduced in detail for Atlanta Center were the audio recordings and the DART computer printouts. Flight strips were also collected, but not individually studied in detail. Although observations of controller actions were made, manual task activities and performance times were not recorded systematically. Because of our previous Los Angeles data collection effort, we could ascertain routine events using the audio tapes and DART printouts. Flight strips and video tape recordings, which included A/G communications on the sound track, were used to develop data for the conflict modeling procedures described in Appendix B, while the video tapes were also used to structure and guide our controller interviews.

We conducted a one-hour data collection session for each of the seven selected sectors. During each hour, the R position A/G and the D position interphone oral communications were simultaneously recorded by separate audio tape recorders. The A/G and interphone recording tapes were manually transcribed by writing down the message and the aircraft identity. The written transcriptions were reduced to data statistics by counting each routine communication event according to its message content. This process resulted in the tabulation of A/G communications shown by sectors in Table A-1. A similar tabulation of interphone communications is shown in Table A-2; however, this tabulation required some cross-referencing with A/G data to identify the event if a question existed. (For example, reference to the A/G transcriptions for a particular aircraft would determine whether an interphone communication on altitude clearance was a traffic structuring or a pilot request event.)

DART computer printout records of R and D position FDP/RDP data entry and display-related operations were obtained from Atlanta Center data systems personnel. Each DART record corresponded to about a 1.25-hr period overlapping the 1-hr data collection. The DART records were reduced to data statistics by counting each FDP/RDP operation according to its function. An operation's function (e.g., handoff initiation, data block/leader line offset, altitude amendment) can be identified from the DART printout by the quick action key and data format. This process resulted in the tabulation of the FDP/RDP operations shown by sector in Table A-3. Again, cross-referencing with the A/G or interphone data was sometimes required to identify events. (For example, reference to A/G transcriptions for a particular aircraft would determine whether a flight data altitude amendment was a traffic structuring or a pilot request event.)

These three tables were then mutually cross-referenced to construct the routine control event tabulation shown by sector in Table A-4. This construction required us to make logical interpretations of event characteristics based on judgment and the average hourly flow rate; the latter is the average of a sector's aircraft exits and entries, as calculated in Table A-1. For example, the number of handoff acceptance, initial pilot call-in, and frequency change instruction events is assumed to be equal to the hourly traffic flow rate, while the number of automatic handoff initiations is equal to the algebraic difference between the numbers of handoff acceptance and manual handoff initiation events.

Because of an audio tape malfunction, no interphone data were obtained for Sector 37. In Table 2, we substituted the interphone frequencies of Sector 42 for those of Sector 37 because both are transition sectors. Because manual task activity observations were not recorded, no data were obtained for flight strip sequencing/removal and equipment adjustment. Also, the number of events observed at some sectors for data block/leader line offset and data block forcing/removal appeared too large to be

Table A-1

OBSERVED NUMBER OF AIR/GROUND COMMUNICATIONS, CURRENT NAS STAGE A, ATLANTA CENTER

A/G Communication	Event Occurrence per Sector						
	High Enroute (36) Allatoona	Departure Transition (37) Crossville	Departure (38) North Departure	Arrival (41) Norcross	Arrival Transition (42) Lanier	Low Arrival (46) Commerce	Low Enroute (52) Hinch Mountain
Traffic structuring							
Initial pilot call-in	24	24	17	17	19	12	11
Altitude instruction	25	34	19	25	39	13	11
Heading instruction	12	15	21	14	6	2	5
Speed instruction	0	0	0	17	5	0	0
Altimeter setting instruction	0	0	4	16	0	3	2
Runway assignment instruction	0	0	0	0	0	0	0
Pilot altitude report	3	7	4	14	8	5	5
Pilot heading report	2	6	0	7	3	8	7
Pilot speed report	0	0	0	4	2	0	1
Traffic advisory	16	4	0	1	6	2	1
Transponder code assignment	0	0	3	3	0	1	2
Miscellaneous A/G coordination	0	0	0	0	0	1	1
Frequency change instruction	23	22	15	17	21	11	11
Pilot request							
Altitude revision	2	4	0	4	1	2	1
Route/heading revision	1	0	0	0	1	0	0
Speed revision	0	0	0	0	0	0	0
Clearance delivery	0	0	0	0	0	0	1
Miscellaneous pilot request	0	0	0	0	0	0	0
Average hourly flow rate (aircraft/hr)*	24	23	16	17	20	12	11

* Average hourly flow rate = (number of initial pilot call-in events plus number of frequency change instruction events) ÷ 2.

Table A-2

OBSERVED NUMBER OF INTERPHONE COMMUNICATIONS AND NEW FLIGHT STRIP PREPARATIONS
CURRENT NAS STAGE A, ATLANTA CENTER

Interphone Communication	Event Occurrence per Sector						
	High Enroute (36) Allatoona	Departure Transition (37) Crossville	Departure (38) North Departure	Arrival (41) Norcross	Arrival Transition (42) Lanier	Low Arrival (46) Commerce	Low Enroute (52) Hinch Mountain
Control jurisdiction transfer							
Handoff acceptance	0	*	2	2	0	4	10
Handoff initiation	0	*	3	1	0	7	6
Traffic structuring							
Altitude instruction	0	*	1	3	5	3	3
Heading instruction	0	*	1	1	0	0	1
Speed instruction	0	*	0	2	2	0	0
Frequency change instruction	1	*	0	0	0	0	0
Pilot request							
Altitude revision	1	*	0	1	0	0	0
Route/heading revision	0	*	0	0	1	0	0
Pointout							
Pointout acceptance	0	*	1	0	1	1	0
Pointout initiation	1	*	7	3	3	0	2
General intersector coordination							
Control instruction approval	2	*	9	6	6	7	4
Planning advisory	2	*	2	4	2	4	0
Aircraft status advisory	2	*	2	3	2	1	6
Control jurisdiction advisory	3	*	3	5	1	2	2
Clearance delivery	0	*	0	0	0	1	2
New flight strip preparation	0	0	0	0	0	2	1

*Interphone tape recording not usable for transcription.

Table A-3

OBSERVED NUMBER OF FDP/RDP OPERATIONS, CURRENT NAS STAGE A, ATLANTA CENTER

FDP/RDP Operation	Quick Action Key	Event Occurrence Per Sector						
		High Enroute (36) Allatoona	Departure Transition (37) Crossville	Departure (38) North Departure	Arrival (41) Norcross	Arrival Transition (42) Lanier	Low Arrival (46) Commerce	Low Enroute (52) Hinch Mountain
Control jurisdiction transfer								
Handoff acceptance	QN,QZ,QT	24	23	16	17	20	12	11
Flight data update	DM	0	0	0	0	0	0	10
Handoff initiation, manual (silent)	QN,QZ,QX	18	19	16	12	12	9	9
Traffic structuring								
Initial pilot call-in, flight data altitude insert	QR,RA	0	0	0	0	0	2	1
Altitude instruction, flight data, altitude amendment	QZ,QQ,AM	0	2	0	15	2	0	2
Heading instruction, flight data route amendment	QU,AM	4	3	0	0	0	1	1
Pilot altitude report, flight data altitude insert	QR,RA	0	0	0	0	0	0	0
Transponder code assignment, flight data code update	QB,DQ	0	0	0	0	0	0	2
Pilot request								
Altitude revision, flight data altitude amendment	QZ,AM	1	3	0	3	1	0	0
Route/heading revision, flight data route amendment	QU,AM	1	0	0	0	0	0	0
Clearance delivery, flight data update	DM	0	0	0	0	0	0	1
Pointout								
Pointout acceptance, data block suppression	QP	0	3	0	0	1	0	0
Pointout initiation	QP	1	2	7	3	3	0	2
General intersector coordination								
Clearance delivery, flight data update	DM	0	0	0	0	0	0	2
General system operation								
Flight data estimate update	*	7	11	16	9	14	6	13
Data block/leader line offset	QN,QZ	21	26	0	14	31	0	6
Data block forcing/removal	QN,QZ	39	25	16	25	50	12	6
Miscellaneous data service								
Wind request	UR	6	1	0	2	2	0	0
Altitude limits modification	QD	0	0	0	0	1	0	0
Strip request	SR	0	0	0	0	0	1	2
Flight plan/track removal	RS	0	0	0	0	0	0	2
Other								
Flight plan readout request[†]	QF,FR	5	0	0	0	0	2	4
Track/route display[‡]	QU	6	0	0	5	1	0	0

[*] Computer readout device (CRD) data update message.

[†] Concurrent with interphone communication.

[‡] Concurrent with conflict detection/assessment.

Table A-4

NUMBER OF ROUTINE CONTROL EVENTS, CURRENT NAS STAGE A, ATLANTA CENTER

Routine Control Event	Occurrences per Sector						
	High Enroute (36) Allatoona	Departure Transition (37) Crossville	Departure (38) North Departure	Arrival (41) Norcross	Arrival Transition (42) Lanier	Low Arrival (46) Commerce	Low Enroute (52) Hinch Mountain
Control jurisdiction transfer							
Handoff acceptance	24	23	16	17	20	12	11
Flight data update	0	0	0	0	0	0	0
Intersector coordination	0	*	2	2	0	4	10
New flight strip preparation	0	0	0	0	0	2	1
Handoff initiation-automatic	6	4	0	5	8	3	2
Manual initiation-silent	18	19	16	12	12	9	9
Intersector coordination	0	*	3	1	0	7	6
Traffic structuring							
Initial pilot call-in	24	23	16	17	20	12	11
Flight data altitude insert	0	0	0	0	0	2	1
Altitude instruction	25	34	19	25	39	13	11
Flight data altitude amendment	0	2	0	15	2	0	2
Intersector coordination	0	*	1	3	5	3	3
Heading instruction	12	15	21	14	6	2	5
Flight data route amendment	4	3	0	0	0	1	1
Intersector coordination	0	*	1	1	0	0	1
Speed instruction	0	0	0	17	5	0	0
Intersector coordination	0	*	0	2	2	0	0
Altimeter setting instruction	0	0	4	16	0	3	2
Runway assignment instruction	0	0	0	0	0	0	0
Pilot altitude report	3	7	4	14	8	5	5
Flight data altitude insert	0	0	0	0	0	0	0
Pilot heading report	2	6	0	7	3	8	7
Pilot speed report	0	0	0	4	2	0	1
Traffic advisory	16	4	0	1	6	2	1
Transponder code assignment	0	0	3	3	0	1	2
Flight data code amendment	0	0	0	0	0	0	2
Miscellaneous A/G coordination	0	0	0	0	0	1	1
Frequency change instruction	24	23	16	17	20	12	11
Intersector coordination	1	*	0	0	0	0	0
Pilot request							
Altitude revision	2	4	0	4	1	2	1
Flight data altitude amendment	1	3	0	3	1	0	0
Intersector coordination	1	*	0	1	0	0	0
Route/heading revision	1	0	0	0	1	0	0
Flight data route amendment	1	0	0	0	0	0	0
Intersector coordination	0	*	0	0	1	0	0
Speed revision	0	0	0	0	0	0	0
Clearance delivery	0	0	0	0	0	0	1
Miscellaneous pilot request	0	0	0	0	0	0	0
Pointout							
Pointout acceptance	0	3	1	0	1	1	0
Data block suppression	0	3	0	0	1	0	0
Pointout initiation	1	2	7	3	3	0	2
General intersector coordination							
Control instruction approval	2	*	9	6	6	7	4
Planning advisory	2	*	2	4	2	4	0
Aircraft status advisory	2	*	2	3	2	1	6
Control jurisdiction advisory	3	*	3	5	1	2	2
Clearance delivery	0	*	0	0	0	1	2
Flight data update	0	0	0	0	0	0	2
General system operation							
Flight data estimate update	7	11	16	9	14	6	13
Data block/leader line offset	21†	26†	0†	14†	31†	0†	6†
Data block forcing/removal	39†	25†	16†	25†	50†	12†	6†
Miscellaneous data service	6	1	0	2	3	1	4
Flight strip sequencing/removal	*	*	*	*	*	*	*
Equipment adjustment	*	*	*	*	*	*	*

*Data not obtained at Atlanta Center.

†Number of occurrences judged to be nonrepresentative of capacity conditions.

representative of capacity or heavy traffic conditions. For each of these four events we assigned event frequencies (Table 2) that were adjusted in accordance with the Los Angeles Center data.

We obtained the numbers of new flight strip preparation events by counting the hand-written flight strips (which were not printed by computer).

2. Routine Control Events

The following discussion provides an overview of the routine control events we associated with enroute sector operations. These events, which are listed in Table 1, are developed from our data observations and controller interviews to define control activities as logical representations of operational requirements. Table A-5 includes a brief summary of the controller activities associated with each event, and parallels this discussion.

Control Jurisdiction Transfer--A handoff between two sectors transfers authority over an aircraft and full access to the aircraft's computer data file from one team to the other (direct control is effected when the aircraft crew switches onto the receiving sector's A/G radio frequency). A silent handoff (i.e., a procedure not routinely requiring intersector interphone communication) is initiated either automatically by the NAS Stage A computerized operations or manually by a sector team using FDP/RDP keyboard or trackball operations, or both. Either handoff initiation mode causes a blinking "H" and the receiving sector's identity numbers (e.g., "H-36") from the aircraft's data block to appear on the PVDs of both the initiating and receiving sectors. Handoff acceptance is performed manually using FDP/RDP operations and causes the flashing "H" to be replaced by the letter "O," which is retained for about one minute on both PVDs. The receiving sector team manually marks the letter "R" (for radar contact) on its flight strip for that aircraft, and the initiating sector team marks a circle around its "R."

Handoffs between NAS Stage A sectors and non-NAS Stage A or non-ARTS III facilities cannot be performed silently and require interphone communications to transfer control jurisdiction. The NAS Stage A sector also performs FDP/RDP keyboard and trackball operation to initiate or drop computerized radar tracking. This activity is normally accompanied by an additional FDP operation to input flight data updating information (e.g., departure message, altitude clearance).

Intersector coordinations sometimes accompany silent handoffs when standard control procedures are not strictly followed (e.g., as a result of conflict avoidance instructions). Intersector coordinations generate intrasector consultation between R and D controllers to confirm information

Table A-5

ROUTINE CONTROL EVENT SECTOR TEAM ACTIVITIES, NAS STAGE A

CONTROL JURISDICTION TRANSFER

- Handoff acceptance--FDP/RDP manual operation to acquire jurisdiction for control and computer data file access from another sector or to establish computerized radar tracking of a flight; flight strip marking to record handoff acceptance
  - Flight data update--FDP/RDP manual operation (as required basis) to insert/update the flight progress computer data file
  - Intersector coordination--Interphone oral communication (as required basis) regarding handoff; intrasector team direct voice communication accompanies
  - New flight strip preparation--Flight strip marking (as required basis) to make an entire strip where none has been printed by the FDP system
- Handoff initiation-automatic--Flight strip marking to record occurrence of control and data file jurisdiction transfer to another sector
  - Manual initiation-silent--FDP/RDP manual operation to effect handoff (jurisdiction transfer) to another sector in lieu of automatic handoff initiation by NAS Stage A computerized operation
  - Intersector coordination--Interphone oral communication (as required basis) regarding handoff; intrasector team direct voice communication accompanies

TRAFFIC STRUCTURING

- Initial pilot call-in--A/G communication initiated by a pilot to indicate his presence on the sector team's radio frequency and report altitude; flight strip marking to record call-in occurrence and confirm altitude data
  - Flight data altitude insert--FDP/RDP and flight strip marking manual operations (as required basis) to update altitude data computer files in accordance with the pilot report for non-Mode C equipped aircraft
- Altitude instruction--A/G communication for altitude clearance revision; flight strip marking to record clearance
  - Flight data altitude amendment--FDP/RDP manual operations (as required basis) to update the altitude data computer file
  - Intersector coordination--Interphone oral communication (as required basis) regarding altitude clearance; intrasector team direct voice communication accompanies
- Heading instruction--A/G communication for vector or route clearance/revision; flight strip marking to record vector instruction
  - Flight data amendment--FDP/RDP manual operation (as required basis) to update route data computer file
  - Intersector coordination--Interphone oral communication (as required basis) regarding route/heading instruction; intrasector team direct voice communications accompanies
- Speed instruction--A/G communication for speed clearance/revision; flight strip marking to record speed instruction
  - Intersector coordination--Interphone oral communication (as required basis) regarding speed instruction; intrasector team direct voice communication accompanies
- Altimeter setting instruction--A/G communication to advise pilot of local altimeter setting; flight strip marking to record message issuance
- Runway assignment instruction--A/G communication to advise pilot of expected runway for landing; flight strip marking to record message issuance
- Pilot altitude report--A/G communication to advise controller of current altitude (including controller request); flight strip marking to record altitude reported
  - Flight data altitude amendment--FDP/RDP manual operation (as required basis) to update altitude data computer file for non-Mode C aircraft
- Pilot heading report--A/G communication to advise controller of current heading (including controller request); flight strip marking to record heading reported
- Pilot speed report--A/G communication to advise controller of current speed (including controller request); flight strip marking to record speed reported
- Traffic advisory--A/G communication to inform pilot of other aircraft in his vicinity
- Transponder code assignment--A/G communication to correct/revise aircraft ATCRBS transponder code
  - Flight data code amendment--FDP/RDP manual operation (as required basis) to update code data computer file; flight strip marking to record code revision
- Miscellaneous A/G coordination--Any A/G communications for traffic structuring not described above (including radio failure assistance)
- Frequency change instruction--A/G communication to change an aircraft's radio frequency to that of the sector to which it is being handed; flight strip marking to record instruction occurrence
  - Intersector coordination--Interphone oral communication (as required basis) regarding frequency change issuance; intrasector direct voice communication accompanies

Table A-5 (Concluded)

PILOT REQUEST

- Altitude revision--A/G communication by pilot to revise altitude clearance (including controller reply); flight strip marking to record altitude request
  - Flight data altitude amendment--FDP/RDP manual operation (as required basis) to update altitude data computer file
  - Intersector coordination--Interphone oral communication (as required basis) regarding altitude request; intrasector team direct voice communication accompanies
- Route/heading revision--A/G communication by pilot to revise route or heading clearance (including controller reply); flight strip marking to record heading request
  - Flight data route amendment--FDP/RDP manual operation (as required basis) to update route data computer file
  - Intersector coordination--Interphone oral communication (as required basis) regarding route/heading request; intrasector direct voice communication accompanies
- Speed revision--A/G communication by pilot to revise speed clearance (including controller reply); flight strip marking to record speed request
- Clearance delivery--A/G communication to directly approve a pilot's flight plan routing request; FDP/RDP manual operation to update flight progress data computer file; flight strip marking to record clearance delivery issuance
- Miscellaneous pilot request--All A/G communication for pilot requests not described above (including requests for navigation assistance and weather advisory)

POINTOUT

- Pointout acceptance--Interphone oral communication to acknowledge receipt of forced data block of flight being pointed out and to obtain relevant data; intrasector direct voice communication accompanies
  - Data block suppression--FDP/RDP operation (as required basis) by sector team receiving forced data block to remove the data block display from its PVD
- Pointout initiation--FDP/RDP manual operation to force data block of flight onto adjacent sector's PVD; flight strip marking to record pointout occurrence; interphone oral communication to confirm pointout and issue appropriate flight data (receiving sector has no flight strip for aircraft being pointed out)

GENERAL INTERSECTOR COORDINATION

- Control instruction approval--Interphone oral communication to approve/negotiate traffic structuring and pilot request events of other sector teams
- Planning advisory--Interphone oral communication to request/approve procedural control strategies (including spacing, rerouting, and preferences)
- Aircraft status advisory--Interphone oral communication to request/issue information regarding a specific flight's current altitude, heading, routing, or speed
- Control jurisdiction advisory--Interphone oral communication to request/issue information describing the identity of the sector currently controlling or about to control a specific flight
- Clearance delivery--Interphone oral communication with a terminal facility to approve a flight plan routing request; intrasector direct voice communication accompanies; flight strip marking to record clearance delivery issuance
  - Flight data update--FDP/RDP manual operations (as required basis) to update flight progress data computer file if terminal facility is not FDP equipped

GENERAL SYSTEM OPERATION

- Flight data estimate update--FDP/RDP manual operation to accept flight progress data update (including altitude, route, expected arrival time revision, departure message, and so forth) displayed in D position CRD; flight strip marking to copy updated information onto strips
- Data block/leader line offset--FDP/RDP manual operation to reposition an aircraft's alphanumeric display in the PVD
- Data block forcing/removal--FDP/RDP manual operations to display a data block or to suppress one being displayed
- Miscellaneous data service--FDP/RDP manual operations to obtain supplemental system information from computer files (including weather, altimeter, aircraft holding data) or to perform various system activities (including flight strip printing and removal)
- Flight strip sequencing/removal--Flight strip processing to rearrange flight strips on the flight progress board, or to remove them
- Equipment adjustment--FDP/RDP and related manual operations to maintain surveillance presentation and communication capabilities (including map and range selection, and radio frequency adjustment)

transfers. In cases of an unexpected aircraft pop-up, a paper flight strip for the aircraft is manually prepared by the D controller.

Traffic Structuring--These events include the procedural-based activities routinely required to process an aircraft through a sector. The traffic structuring basic events are all initiated by A/G communications and generally include some manual data updating or recording task. Each A/G communication task entails negotiation or confirmation between pilot and controller. The first traffic structuring event for an aircraft is the pilot's initial flight identity and altitude report call-in, which is manually "checked" on the flight strip. If the aircraft is not equipped with automatic altitude reporting (Mode C) equipment, the reported altitude is manually entered into the FDP data file by keyboard operation and marked on the flight strip. Altitude, heading and speed instructions, and pilot reports are manually recorded on flight strips. When altitude clearances do not conform to current flight plans or when a reported altitude is not from a Mode C equipped aircraft, the FDP flight plan data file is amended or the PVD altitude display is corrected by manual keyboard insertion. Interphone coordinations initiated by a sector team are generally requests to adjacent sector teams to approve and confirm the issuance of nonstandard traffic structuring instructions. Altimeter setting and runway assignment instructions are routinely issued in low altitude sectors to assist climbing and descending aircraft. Traffic advisories describing proximate traffic, transponder code corrections, and miscellaneous A/G coordinations (e.g., radio failure assistance) are performed as needed. A controller-to-pilot instruction to change radio frequency to that of the next sector culminates the traffic structuring activity for an aircraft; it is manually recorded on the aircraft's flight strip at the Los Angeles Center by marking a second circle around the "R" and at the Atlanta Center by marking a cross-line through the "check." (The frequency change instruction is immediately preceded by formal handoff initiation and acceptance of control jurisdiction by the two sector teams.)

Pilot Request--Task requirements generated by pilot requests to revise altitude, route, heading, or speed clearances are essentially similar to those of traffic structuring except that they are initiated by an aircraft crew. All are initiated by A/G communications and, except for miscellaneous requests such as navigation assistance or weather information, entail flight strip processing. FDP/RDP-based data amendments or intersector coordinations are performed as required. In some low sectors, clearance deliveries to approve flight plan routing are issued directly to pilots (rather than a terminal facility) by means of A/G communication.

Such clearance deliveries require FDP/RDP operations to update the flight progress data in the computer file (e.g., departure message, altitude clearance), and flight strip marking to record the issuance of the clearance delivery (any additional flight strip or FDP data revisions that may be required are assumed to occur simultaneously with the A/G communication).

<u>Pointout</u>--Pointout actions are required by a sector team to retain control of aircraft briefly in or near another's airspace. A pointout initiation entails RDP keyboard operations to force an aircraft's alphanumeric data block onto an adjacent sector team's PVD and flight strip marking. Since the sector team receiving the forced data block normally has no flight strip pertaining to the aircraft in question, interphone communications are needed to transmit relevant flight information. The receiving sector may also display pertinent FDP data on its D position CRD, although this normally occurs during the intersector coordination. The receiving sector, by means of manual RDP, keyboard/trackball operations may suppress the forced data block display as desired.

<u>General Intersector Coordination</u>--These events include those informational transfers that are performed by sector teams to maintain mutual cognizance of multisector traffic movement and that are not part of handoff, traffic structuring, pilot request, or pointout. General intersector coordination events almost entirely entail interphone and direct voice communications. Control instruction approvals are issued in response to other sector teams' traffic structuring and pilot request activities. Planning, aircraft status, and control jurisdiction advisories are used to clarify general procedural and individual aircraft situations. Clearance deliveries are negotiations with airport towers to approve flight routings if silent departure procedures are not established and include manual flight strip marking to indicate issuance of the clearance. FDP/RDP keyboard operations are necessary for updating flight progress files (e.g., departure message, altitude clearance) if the tower is not FDP equipped.

<u>General System Operation</u>--In this category are those activities not included in the above descriptions, such as equipment operation and data maintenance. General system operation events are entirely performed by FDP/RDP operation and flight strip processing. Flight-plan update messages (e.g., altitude, route, or beacon code revision; expected position fix time arrival; airport departure confirmation) from incoming flights displayed on the D controller's CRD by the FDP system are manually copied

onto the appropriate proposal flight strips. Using keyboard/trackball operations, the R controller selectively modifies the PVD by offsetting or reorienting alphanumeric data blocks to alleviate display clutter and forcing or removing data block displays. (An aircraft's data block is retained on the PVD of a sector team initiating a handoff for a five-minute period after the handoff has been accepted and is manually forced back onto the PVD as required.) Miscellaneous data services involving FDP system operations include requests for weather and altimeter data displays and flight strip printing, removal of flight plans from the data file and display, removal or modification of PVD tabular listings of inbound, departing, or holding aircraft, and CRD listings of beacon code selections (which define the eligibility of radar target displays) and altitude limits (which define the altitude range over which the PVD displays automatic altitude reports for untracked or intruding aircraft). Arranging and removing the flight strips on the flight progress board is performed by the D controller, while the R controller is responsible for A/G radio frequency and RDP (e.g., map and range selection) adjustments.

Los Angeles Center Versus Atlanta Center Data--Some differences exist between the routine events observed at the Atlanta and the Los Angeles centers. First, automatic handoff initiation events were observed at Atlanta, but not at Los Angeles. Second, flight data altitude amendments for traffic structuring "heading instructions" were observed at Atlanta, but not at Los Angeles. Third, the flight data code amendment was performed, as required, in support of the traffic structuring transponder code assignment event at Atlanta; at Los Angeles it was assumed to be an integral part of the transponder code revision event. Fourth, clearance delivery was issued directly to pilots as part of pilot requests at Atlanta; at Los Angeles, clearance delivery was observed to be issued only to towers as part of general intersector coordination. Both types of clearance deliveries were observed at Atlanta. Fifth, the flight data update event was performed, as required, in support of the clearance delivery to towers at Atlanta; at Los Angeles it was assumed to be an integral part of the clearance delivery event.

These differences are reflected in the routine event structures shown in Table 1 of this report and in Table 1 of Reference 4 (or 5).

We also note that some events observed at Los Angeles were not observed at Atlanta. These include: the flight data update performed on an as-required basis to support handoff acceptance, the traffic structuring runway assignment instruction event, and the miscellaneous pilot request event. To maintain the generality of our routine event descriptions, we chose to include these events in our event structure in Table 1, and to assign them a zero frequency-of-occurrence in Table 2 of this report.

Appendix B

POTENTIAL CONFLICT MODELS AND APPLICATIONS

Appendix B

POTENTIAL CONFLICT MODELS AND APPLICATIONS

This appendix describes mathematical models for estimating the expected frequency of potential conflicts and their applications to the 11 selected sectors of the Atlanta Center.* Potential sector conflicts were examined using techniques based on the RECEP methodology developed during previous SRI research[1-5] and adapted to Atlanta Center operations in accordance with our on-site observations, data collection, and controller interviews.

1. Potential Conflict Frequency Model

Potential conflicts are projected violations of separation minima perceived by controllers. Since this project was concerned with the radar environment, the ATC radar separation minima are the criteria to be maintained. These criteria, based on our observations of the actual separations exercised by controllers, are as follows:

- Aircraft are separated by less than 1000 feet in altitude (2000 feet above FL290).
- Aircraft on arrival routes about to enter terminal airspace are separated by at least five nautical miles.
- All other aircraft are separated by at least ten nautical miles.

The two primary means by which these separation minima can be violated are by the intersection of two aircraft flight paths or by one aircraft overtaking another. The possible events resulting from these two violations are listed in Table B-1. Since there are differences in the difficulty of resolving the potential conflicts resulting from these events, the events should also be classified by type of aircraft involved,

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*The 11 sectors are the 9 sectors included in the ATF study area model and 2 additional sectors that were part of the original data collection effort.

Table B-1

EVENTS RESULTING IN VIOLATION OF RADAR SEPARATION MINIMA

Crossing conflicts	Intersection of two aircraft flight paths at the same altitude. Intersection of a transitioning (climbing or descending) aircraft with a level aircraft at altitude. Intersection of two transitioning aircraft.
Overtaking conflicts	Aircraft at the same altitude. Aircraft transitioning on the same track.

such as nonmilitary versus nonmilitary, military versus nonmilitary, and military versus military. However, during this project, there were not sufficient data to make these distinctions meaningful.

SRI has developed a number of simple mathematical models for predicting the expected number of events. Data acquired in our measurement phase were compared with estimates generated by these models as verification. The development of the model used to predict the expected number of conflicts at two air routes is described in Reference 10. Only the resulting expressions are presented here.

<u>Crossing Conflict Events</u>--The frequency of conflict events at an air route intersection depends on the aircraft flow rate and velocity along each route, the minimum separation requirements, the angle of intersection between the routes, and the number of flight levels at which conflicts would potentially occur. The average frequency of conflicts at an intersection can be found from:

$$E_{c_A} = \sum_i \frac{2 f_{i1} f_{i2} X \sqrt{V_{i1}^2 + V_{i2}^2 - 2V_{i1} V_{i2} \cos \alpha}}{V_{i1} V_{i2} \sin \alpha} \quad (1)$$

where

E_{c_A} = average number of conflicts/hr.

f_{i1} = flow of aircraft at Flight Level i along Route 1 (aircraft/hr).

f_{i2} = flow of aircraft at Flight Level i along Route 2 (aircraft/hr).

X = separation minimum used by controllers (nautical miles).

V_{i1} = average speed of aircraft at Flight Level i along Route 1.

V_{i2} = average speed of aircraft at Flight Level i along Route 2.

α = angle of intersection between the routes.

Σ indicates the summation over all flight levels at which conflicts may occur.

Though this relation is quite suitable for use with a computer, it is somewhat cumbersome to evaluate manually. For this reason a nomograph has been developed[3] that graphically describes this mathematical relationship. Intersections of more than two air routes were treated by finding the sum of the expected number of conflicts between all possible pairs of air routes. The expected number of conflicts was calculated for each flight level considered and summed over all flight levels to determine the total conflict frequency associated with that intersection.

When one of the crossing routes is a transition route, it is necessary to evaluate the additional effects due to the interaction of the transitioning aircraft with air traffic at more than one flight level on the other route. A transitioning aircraft can conflict with air traffic at the actual route crossing altitude, but it can also, because of separation standards, conflict with traffic above and below this flight level. For this reason, the air traffic controller usually provides separation as if transitioning an aircraft "block" more than one altitude at the same time. This concept is equivalent to treating a transition crossing as a number of simultaneous level-level crossings at the "blocked" altitudes. Therefore, the calculation of the expected number of conflicts of this type entails summing the expected number of crossing conflicts at each flight level affected by the transitioning route. The number of altitudes that are affected is a function of climb/descent angle and separation criteria. Procedures developed[3] can be used to determine the vertical distance required (and therefore the number of flight levels affected) by a transitioning aircraft flow while crossing an air route (the data assume a route width of ten nautical miles). Knowing this value and the vertical separation minimum, one can determine which flight levels are affected by this event. The number of potential conflicts resulting between the aircraft flow on each of these flight levels and the flow on the transitioning route can then be determined and summed.

Overtake Conflict Events--The expected frequency of overtakes along a level or transitioning route and between level and transitioning routes in the same direction can be determined from the following relationship:

$$E_o = \sum_{i=1}^{n-1} \frac{(l + 2X)\, f_i}{V_i} \sum_{k=i+1}^{n} \frac{f_k}{V_k} \left|V_i - V_k\right| , \qquad (2)$$

where

E_o = average number of overtakes/hr.

n = number of discrete speed categories along the route.

l = length of air route (nautical miles).

f_i = flow rate of aircraft traveling at the i^{th} speed (aircraft/hr).

V_i = average speed of the i^{th} speed class (knots).

f_k = flow rate of aircraft traveling at the k^{th} speed (aircraft/hr).

V_k = average speed of the k^{th} speed class (knots).

X = separation minimum used by controllers (nautical miles).

$|V_i - V_k|$ = magnitude of the difference in velocities of the two speed categories.

In this relationship, the summation symbol (Σ) indicates that the calculation is performed for each possible pair of speed categories, and these results are then summed to find the total number of potential overtakes. This procedure is followed for each flight level on a level route and for each transition route in a sector.

Again, to reduce the computational effort, another nomograph[3] was used to aid in the evaluation of this expression. The frequency of occurrence of potential overtake conflicts along a route can be determined from this nomograph using aircraft density for each aircraft speed class (in terms of aircraft/nautical mile along a route). Aircraft density is found by dividing the hourly traffic flow of each speed class (in aircraft/hr) by the average velocity of that speed class (in knots), the route length (in nautical miles), and the difference in aircraft speed classes (in knots). This nomograph was used to evaluate the number of potential overtakes caused by more than two speed classes by summing the expected number of overtakes for all possible pairs of speed classes at any given flight level. Then these results were summed for all flight levels and transition routes.

For the occasional interaction of a transitioning aircraft track with a level aircraft route where the aircraft are on opposite headings (meeting head-on), the expected number of such conflicts can be expressed as:

$$E_{o_B} = \sum_j \sum_k \frac{2 f_j f_k X \sqrt{V_j^2 + V_k^2 - 2 V_j V_k \cos\left[\sin^{-1} \frac{V_t}{V_j}\right]}}{V_j V_k \left[\frac{V_t}{V_j}\right]} \qquad (3)$$

where

E_{o_B} = expected number of conflicts/hr.

f_j = flow of aircraft along the j^{th} transitioning track (aircraft/hr).

f_k = flow of aircraft along the route at the k^{th} altitude (aircraft/hr).

X = separation minimum (nautical miles).

V_j = average speed of aircraft along the j^{th} transitioning track (miles/hr).

V_k = average speed of the aircraft along the route at the k^{th} altitude (miles/hr).

V_t = transitioning rate for the transitioning aircraft (miles/hr) (i.e., climb or descent rate for the transitioning aircraft).

j = each transitioning track used in the sector.

k = each altitude level, used for air traffic that intersects j.

This expression was evaluated analytically in the few cases where it applied and was added to the expected overtake workload for the sector.

2. Description of Sector Conflict Modeling

Sector 36--Atlanta Center's Allatoona sector is an ultrahigh altitude sector (FL330 and above) situated directly above the Crossville sector. This sector has mainly level enroute traffic flying between Florida and the Midwest and between the Northeast and South Central regions. The principal routes within this sector are:

- J22: a level, high volume route with northeast traffic in FLs 330, 370, and 410, southwest traffic on FLs 350 and 390, and several northeast-bound flights separating at TYS and using J91.
- J43: for level, enroute northbound and southbound traffic.
- LOU-TYS: for aircraft southeast at FL330 over TYS.
- J46: for level, enroute eastbound and westbound aircraft.
- J89: for level, enroute northbound and southbound aircraft between the Midwest and Florida.
- J118: for eastbound and westbound aircraft.
- J45-73: for northbound and southbound aircraft.

The spatial pattern of crossing conflicts in Sector 36 is similar to that in the lower adjacent Crossville sector, with the exception that most Allatoona crossing conflicts are between level, enroute aircraft, while a significant portion of those in Sector 37 involve aircraft transitioning out of A7L. The major sources of potential crossing conflicts appear to be the intersection of J22 with J89 and the routes that intersect over TYS. Overtaking conflict potential is diminished in this sector by the full use of all flight levels along the several relatively high volume routes, which serves to separate by altitude the largely level, enroute traffic found therein. The Allatoona sector route structure is illustrated in Figure B-1. The conflict equations, based on separations of ten nautical miles, were found to be:

$$C = (4.8 \times 10^{-3})\, N_H^2$$

$$O = (0.9 \times 10^{-3})\, N_H^2 ,$$

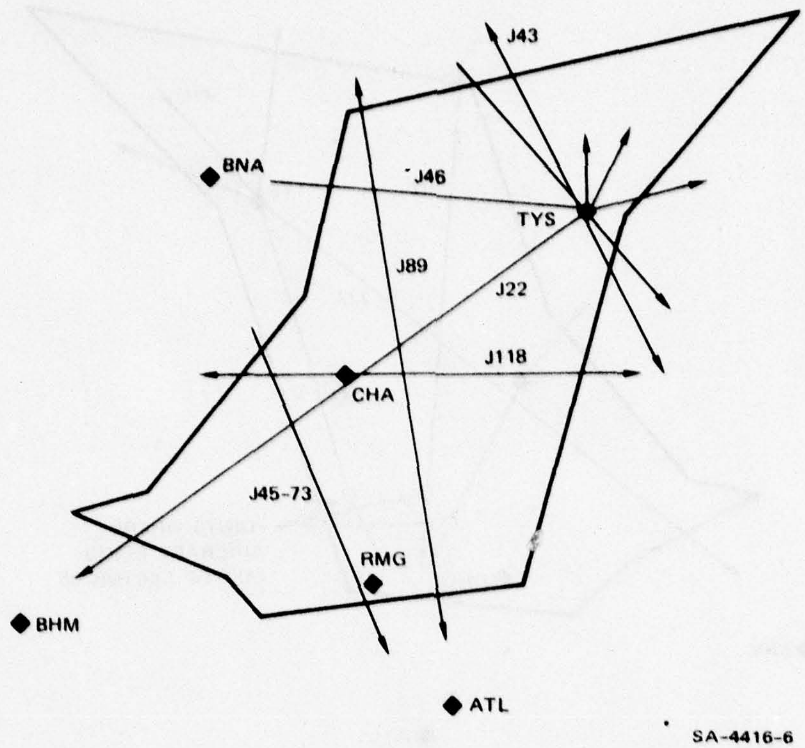

FIGURE B-1 PRIMARY ROUTES IN SECTOR 36

where, for this and each of the sectors evaluated below,

C is the average number of potential crossing conflicts/hr.

O is the average number of potential overtakes/hr.

N_H is the number of aircraft handled/hr.

Sector 37--Atlanta Center's Crossville sector is an intermediate altitude (FL240-FL310) sector north of Atlanta. It is situated above the northern part of Sector 38, and directly west of the Lanier Sector 42. The air traffic is composed of flights originating in Atlanta and climbing out of the North Departure sector, some level enroute flights, and a few transitioning flights at stations such as Chattanooga and Birmingham. The sector's route structure is shown in Figure B-2. The major routes within the sector are:

- J43-91: for flights climbing out of ATL and Sector 38 to TYS and points north (J43) and northeast (J91 and J22).

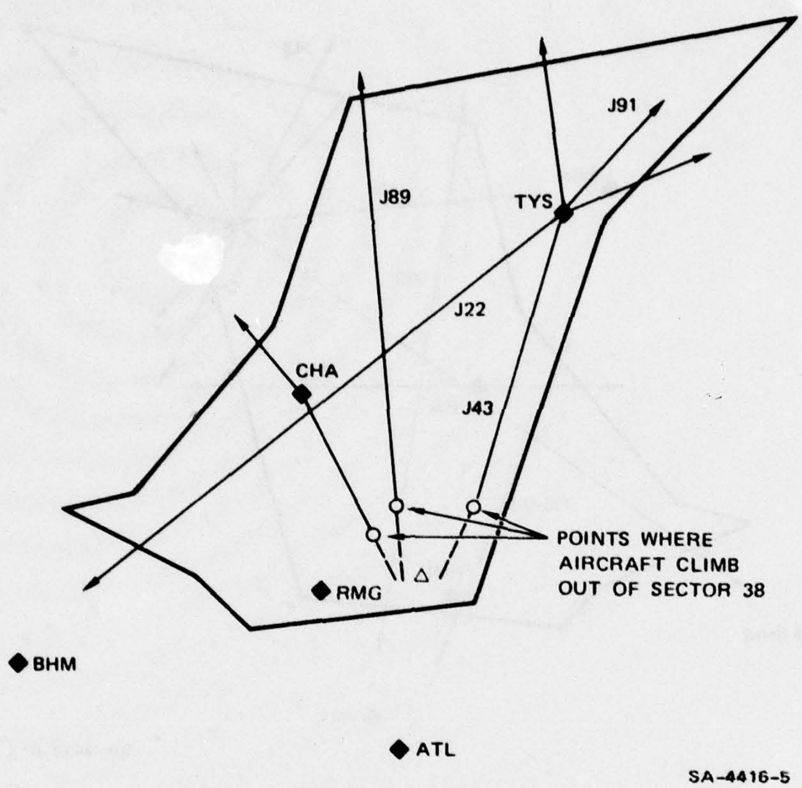

FIGURE B-2 PRIMARY ROUTES IN SECTOR 37

Some level, enroute aircraft at FL270-FL290 can be found on this route.

- J89: for aircraft transitioning north from ATL to the Midwest and for some level, enroute northbound and southbound traffic.
- A transition route over CHA: for aircraft climbing out of ATL and Sector 38 and headed in a northwesterly direction.
- J22: primarily for level, relatively low flying enroute aircraft between Northeast and South Central regions. Some transitioning along this route at Knoxville, Birmingham, and Chattanooga is likely.

In Figure B-2, several random, single aircraft flight tracks have been deleted for clarity. The traffic structure of the Crossville sector resembles that of the Pulaski sector, with a scattering of relatively low volume routes that tend to create crossing conflict workloads of more significance than overtaking workloads. Sector 37 does, of course, contain more transitioning aircraft than the Pulaski sector. The major intersections in the sector are those of J22 traffic with the three, largely transition tracks out of ATL. The conflict equations, using separations of ten nautical miles, were found to be:

$$C = (4.4 \times 10^{-3})\ N_H^2$$

$$O = (0.5 \times 10^{-3})\ N_H^2 \quad .$$

Sector 38--Atlanta Center's North Departure sector is a relatively low altitude (FL120-FL230) transition sector that handles aircraft climbing out of the Atlanta TRACON and headed for destinations in the Northeast and Midwest. The departing stream of aircraft enters the sector south of the 2QC fix and is separated at 2QC into three streams according to destination. Most aircraft climb out of the sector into the adjacent higher sectors within 50 nautical miles of the demerge point, as shown in Figure B-3. As a result, there are generally no intersection crossing conflicts within the sector. At separations of five nautical miles at the entry point (TRACON boundary) with transition to separations of ten nautical miles at sector exits, the overtake conflict processing load is light, but significant, and can be found from the expression

$$O = (0.7 \times 10^{-3})\ N_H^2 \quad .$$

Sector 39--Atlanta Center's Chattanooga sector is a rather small, "flat" (FL230-FL270) sector used primarily by aircraft enroute to ATL from the north and west. The three major operational routes, as shown in Figure B-4, are:

- J45-73: for ATL arrivals from the Midwest.
- J66: for arrivals from Memphis and points west.
- J22: for relatively low level enroute traffic and transitioning traffic at CHA.

The overall conflict processing workload is relatively light, with some potential crossing conflicts at the intersections of J22 with the arrival routes and some potential overtaking conflicts on the relatively short

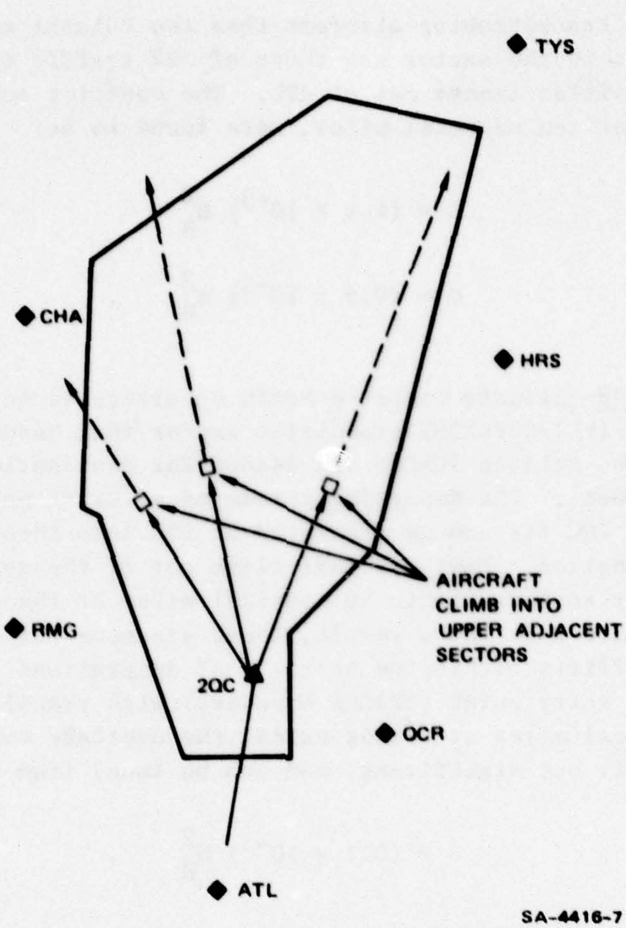

FIGURE B-3 PRIMARY ROUTES IN SECTOR 38

arrival routes. Sector conflicts, using separations of ten nautical miles, can be estimated from:

$$C = (1.7 \times 10^{-3})\ N_H^2$$

$$O = (1.0 \times 10^{-3})\ N_H^2 \quad .$$

Sector 40--Atlanta Center's Dallas sector is a low-to-intermediate level (FL120-FL270) arrival sector situated "downstream" of Sector 39. Its operating characteristics are similar to those of the Norcross sector, since it is responsible for merging and sequencing streams of arrival traffic to the Atlanta airport. Traffic descending into ATL is sequenced

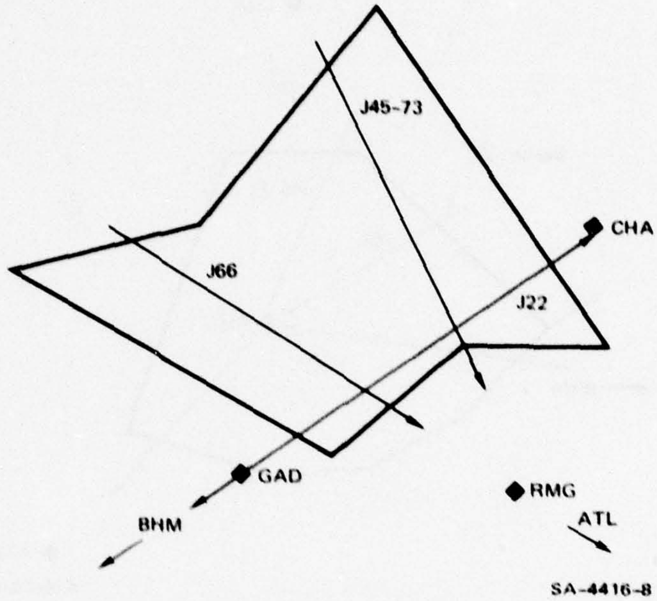

FIGURE B-4 PRIMARY ROUTES IN SECTOR 39

along one of the three routes shown in Figure B-5--J66 from the west, J45-73 from the northwest, and a route from BHM to the southwest--and merged at the RMG VORTAC for transfer to Atlanta approach control. Aircraft crossing the arrival routes are routinely vectored under or over the inbound streams.

The merging workload at RMG contributes significantly to the potential crossing conflicts in the sector, while the sequencing of the arrival traffic contributes to potential overtake conflicts. Because of the prevailing, westerly wind patterns in the area, inbound speeds and speed differences of eastbound aircraft are significantly greater than for southbound and westbound aircraft using Sector 41, which contributes somewhat to the sector's overtake workload. For this reason, separations of ten nautical miles were assumed to hold throughout the sector. The conflict equations, similar to those of the Norcross sector, are:

$$C = (2.7 \times 10^{-3})\ N_H^2$$

$$O = (5.8 \times 10^{-3})\ N_H^2 \quad .$$

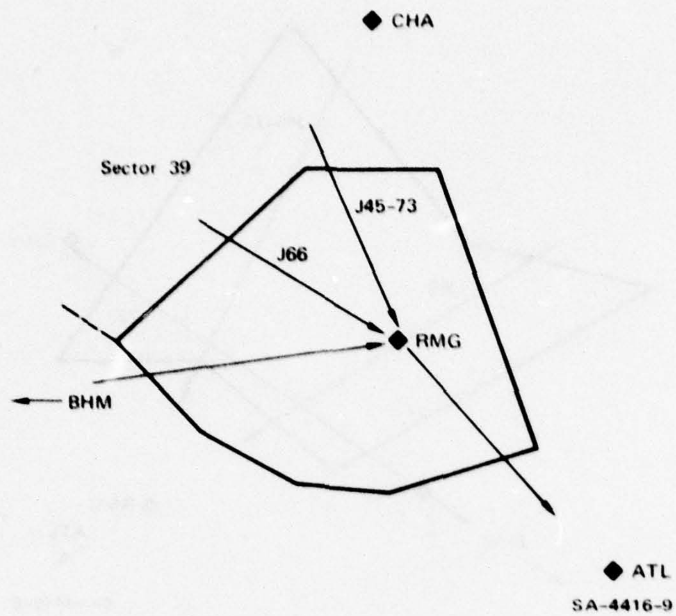

FIGURE B-5 PRIMARY ROUTES IN SECTOR 40

Sector 41--Atlanta Center's Norcross sector is a relatively low altitude (FL120-FL230) arrival sector to the north and east of Atlanta over the Norcross, Georgia, VORTAC (See Figure B-6). Sector 41 has two primary arrival routes that merge at an inbound fix to the Atlanta TRACON at FL120. The sector controllers are therefore responsible for merging and sequencing the traffic from these routes before transferring control of the aircraft to Atlanta approach control.

In modeling this sector, separations of five nautical miles were assumed to hold at the OCR merge point; separations of ten nautical miles were used elsewhere. The relationships for crossing and overtake conflicts in the current Sector 41 configuration are expressed by:

$$C = (2.7 \times 10^{-3})\ N_H^2$$

$$O = (6.4 \times 10^{-3})\ N_H^2 \quad .$$

Most of the crossing conflict processing entails the merging at OCR and 2LI of aircraft in the two arrival streams crossing the TYS and TOC VORTACs. Some random crossing traffic occasionally intersects the two routes on east-west headings, but usually at altitudes well above or below the high volume inbound routes. When potential crossing conflicts

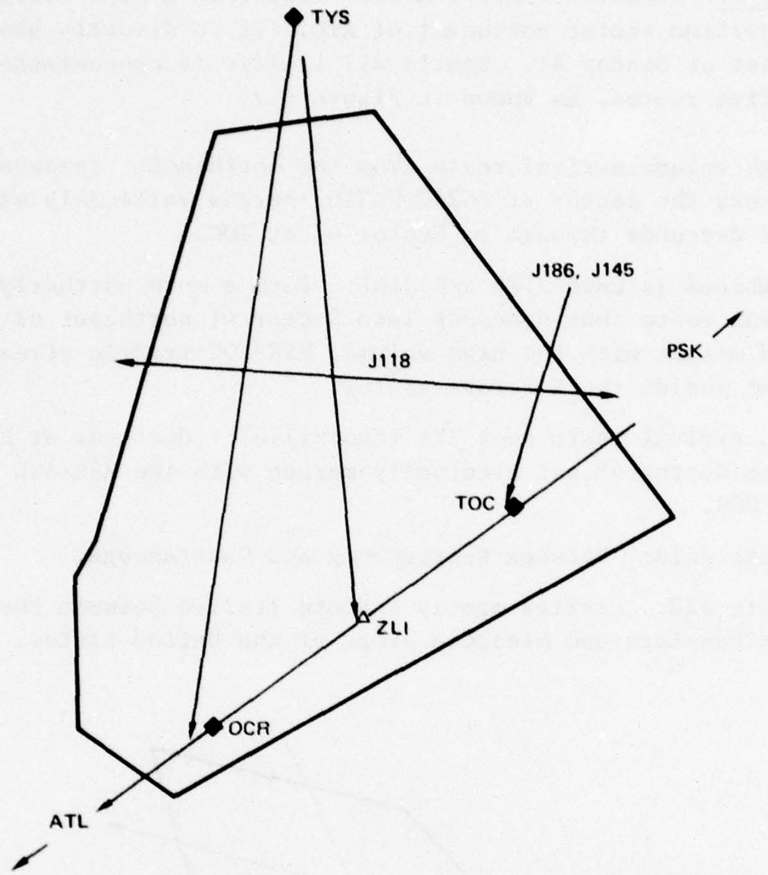

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FIGURE B-6 PRIMARY ROUTES OF SECTOR 41

between these aircraft and the inbound streams do occur, routine "tunneling" or "climbing" directives are issued to the aircraft involved.

The sequencing of aircraft on the inbound streams entails significant overtake conflict processing work. For aircraft transitions into Atlanta, controllers generally allow the use of "pilot discretion" to maintain passenger comfort in descending to FL120 and slowing to 250 knots to enter the terminal airspace. The resulting, unique deceleration and descent profiles of each inbound aircraft are characteristic of these kinds of sectors and contribute greatly to the relatively high overtaking workloads associated with most low altitude approach sectors.

Sector 42--Atlanta Center's Lanier sector is a high altitude (FL240-FL310) transition sector northeast of ATL. It is directly above and to the northeast of Sector 41. Nearly all traffic is concentrated on the following five routes, as shown in Figure B-7:

- High volume arrival route from the northeast: crosses PSK, enters the sector at FL240-FL310, merges vertically at F240, and descends through to Sector 41 at TOC.
- Combined jetways J186 and J145: form a more northerly arrival route that descends into Sector 41 northeast of TOC and merges with the high volume, PSK-TOC traffic stream just inside the Norcross sector.
- ATL arrival route over TYS (Knoxville): descends at FL240 into Sector 41 and eventually merges with the PSK-ATL route at OCR.
- Route J118: between Spartanburg and Chattanooga.
- Route J22: carries mostly enroute traffic between the northeastern and midsouth areas of the United States.

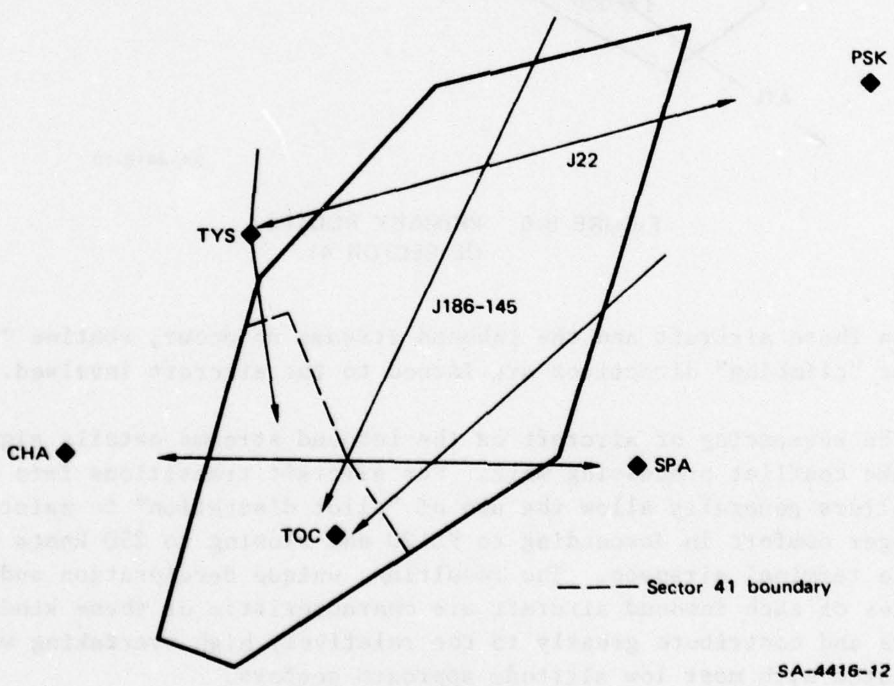

FIGURE B-7 PRIMARY ROUTES OF SECTOR 42

Sector 42 aids the metering and spacing of aircraft descending into Atlanta by ensuring that the altitude differences of flights entering the sector are eliminated so that aircraft can be handed off to Sector 41 at the same spatial location on each arrival route. Altitude merging and in-trail sequencing on the PSK-TOC route, in particular, contribute significantly to the overtake conflict processing workload in this sector. Crossing conflicts occur at the intersection of J186-145 with J22 and, to a limited extent, at the intersections of J118 with J186-145 and the TYS arrival route. Generally, the level enroute traffic on J118 crosses below the major PSK-TOC transition flow, thereby minimizing potential crossing conflicts. Some preliminary merging conflict processing is assumed for J186-145 and the PSK-TOC arrival routes, although actual intersection is in Sector 41. Evaluation of these operational procedures, using separations of ten nautical miles, led to the following conflict relationships:

$$C = (3.5 \times 10^{-3})\ N_H^2$$

$$O = (5.8 \times 10^{-3})\ N_H^2 \quad .$$

<u>Sector 43</u>--Atlanta Center's Pulaski sector is a high altitude enroute sector adjacent to Sector 42 in the northeast corner of the Atlanta Center jurisdictional area. Figure B-8 *shows the major operational routes*

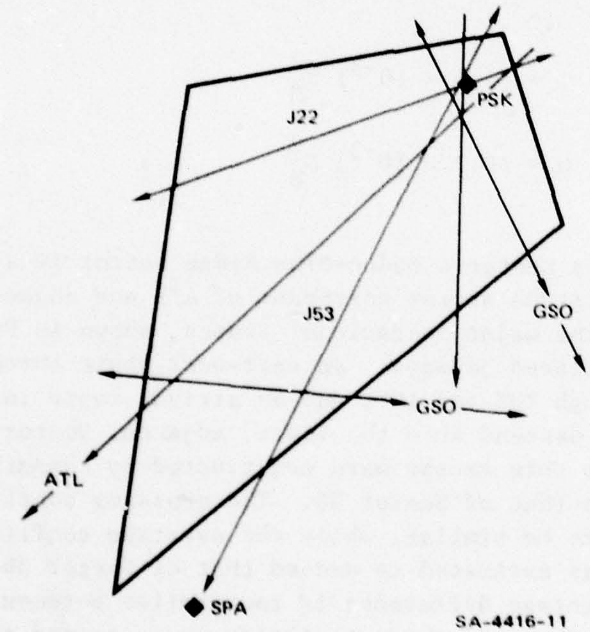

FIGURE B-8 PRIMARY ROUTES IN SECTOR 43

of the sector, which consist mainly of a series of low volume, highly scattered flight tracks in which aircraft are in level flight or are initiating descent/climb maneuvers. These routes are:

- J22: for level, enroute aircraft and for traffic entering and leaving Knoxville.
- PSK-ATL: for aircraft enroute to ATL and flying under FL310.
- J53: for enroute, level aircraft between SPA and PSK.
- PSK-GSO: for level enroute aircraft.
- PSK-south: for southbound traffic through Pulaski.
- An east-west level, enroute track out of GSO.

Several of these routes are aggregations of closely spaced flight tracks that do not lie along existing jetways. No route was found to process more than four aircraft during the hour(s) of observation. As a result, the primary conflict workload entailed the numerous route crossings at or near the PSK VORTAC and at the several intersections in the western part of the sector, while overtaking conflicts along the low volume routes were minimized. The conflict relationships were estimated in part from traffic statistics prepared for the Crossville and Hinch Mountain sectors. They are based on separations of ten nautical miles and can be formulated as follows:

$$C = (4.6 \times 10^{-3})\ N_H^2$$

$$O = (0.7 \times 10^{-3})\ N_H^2 \quad .$$

Sector 44--Atlanta Center's Baden-Blue Ridge sector is a large, wide-ranging, ultrahigh altitude sector northeast of ATL and adjacent to Sector 36 on the east. The major operational routes, shown in Figure B-9, are basically the published jetways: an east-west route through TOC and SPA, a route through TUS and AGS, and an arrival route into ATL from PSK on which aircraft descend into the lower, adjacent Sector 42. The conflict equations for this sector were constructed by comparing its traffic structure with that of Sector 36. The crossing conflict workloads were estimated to be similar, while the overtake conflict workload at Baden-Blue Ridge was estimated to exceed that of Sector 36 by approximately the fixed percentage difference in route-miles between the two sectors. Aircraft performance characteristics were assumed to be the

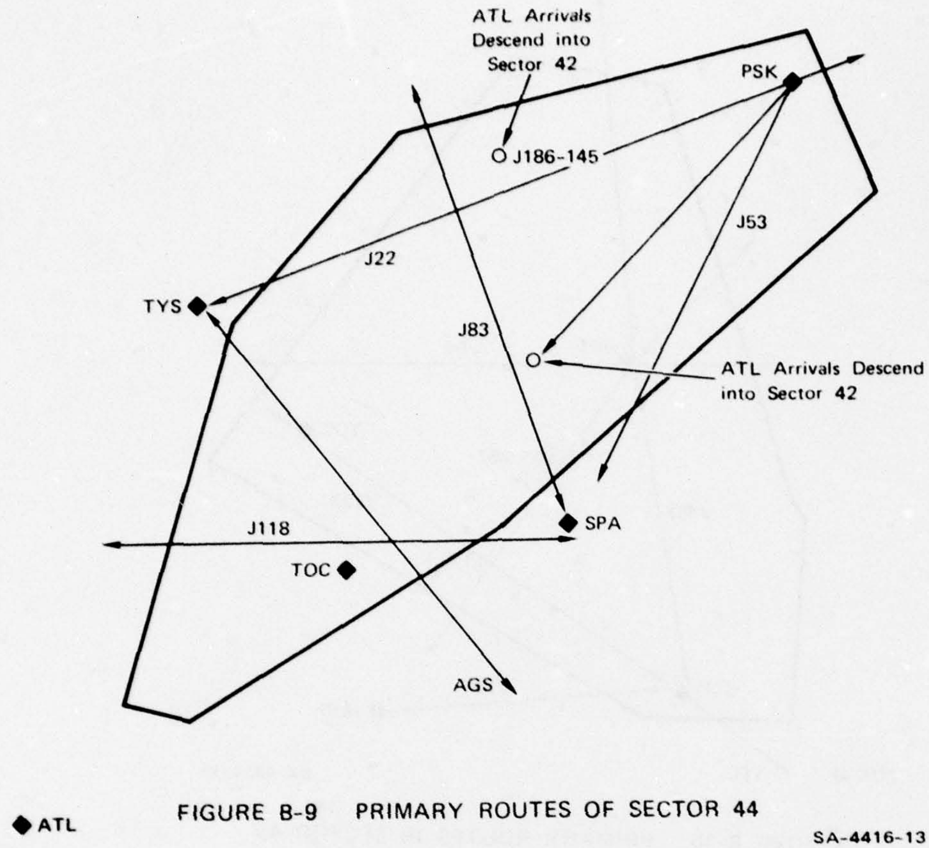

FIGURE B-9 PRIMARY ROUTES OF SECTOR 44

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same for both sectors. Accordingly, the conflict relationships, using separations of ten nautical miles, are:

$$C = (4.8 \times 10^{-3})\ N_H^2$$

$$O = (1.5 \times 10^{-3})\ N_H^2 \quad .$$

Sector 46--Atlanta Center's Commerce sector is a low altitude (surface to FL110) sector underneath Sector 41 to the north and east of ATL. The major published operational routes within Sector 46, depicted in Figure B-10 are:

- V463: from TYS to OCR, used by low level, general aviation aircraft arriving in the ATL area from the north.
- V222: from TOC to OCR for aircraft enroute to the Atlanta area airports from the northeast.
- V235: from TOC to OCR for Atlanta area arrivals from AHN and points east.

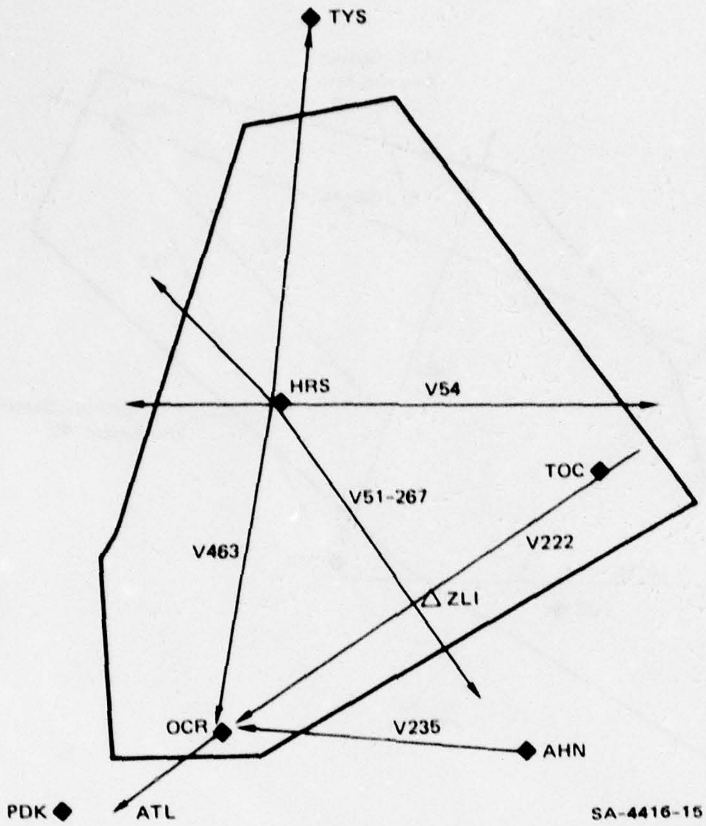

FIGURE B-10 PRIMARY ROUTES IN SECTOR 46

- An arrival route into the Atlanta TRACON area: from OCR, where V463, V222, and V235 merge.
- V54: for eastbound and westbound traffic over HRS.
- V51-267: between HRS and AHN.

Sector traffic is mostly general aviation aircraft that are enroute to one of the airports in the Atlanta area through the OCR arrival fix or are distributed more or less uniformly among the remaining Victor Airways and origin-destination tracks through the area. Some commercial aircraft transitioning into and out of TYS will use a small portion of sector airspace via V267. The major crossing conflict point is, of course, at the OCR VORTAC, where a significant amount of merging takes place. A small overtaking conflict workload will be associated with the ATL arrival streams. The expected number or crossing and overtake conflicts, at separations of ten nautical miles, can be found from the expressions:

$$C = (6.6 \times 10^{-3})\ N_H^2$$

$$O = (0.7 \times 10^{-3})\ N_H^2 \quad .$$

Sector 52--Atlanta Center's Hinch Mountain sector is a low (surface to FL230), primarily enroute sector located below Sector 37. This is adjacent to the Indianapolis and Memphis ARTCCs in an area north of Chattanooga and west of Knoxville, Tennessee. Sector traffic is mainly low altitude, general aviation aircraft (under FL100), some intermediate and high altitude general aviation aircraft, and a few, regularly scheduled commercial aircraft. The traffic is mostly of the level, enroute variety, with some general aviation traffic transitioning out of the smaller airfields in the area, and some commercial and general aviation flights approaching and departing CHA and TYS. The route structure in Sector 52 is not well-defined because of the scattered origin-destination characteristics of the heavy general aviation traffic through the sector. The few identifiable primary routes, shown in Figure B-11, include:

- A route connecting BNA and TYS (J46): for eastbound and westbound level and transitioning traffic.
- J22 between TYS and CHA: for low, enroute general aviation and traffic transitioning at TYS and CHA.
- A route roughly parallel to and south of J46: for level, enroute traffic between Nashville and points east.

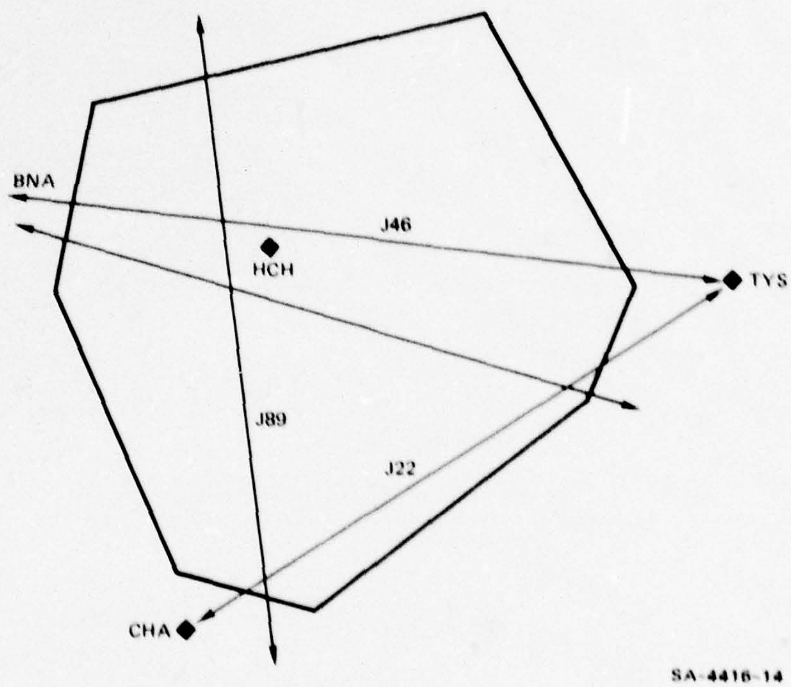

FIGURE B-11 PRIMARY ROUTES IN SECTOR 52

- J89: for northbound and southbound traffic and transitions at CHA.

The conflict equations, based on separations of ten nautical miles, are:

$$C = (5.3 \times 10^{-3})\, N_H^2$$

$$O = (4.3 \times 10^{-3})\, N_H^2 \quad .$$

The relatively high crossing conflict coefficient can be attributed to a large number of single, pairwise interactions at nearly as many longitude-latitude fixes. Overtaking conflict workload will be high because of the head-on interaction of aircraft transitioning on the same route, which occurs on J22 between TYS and CHA, and on the route south of J46 between BNA and Spartanburg, South Carolina. Sector controllers are also hampered by "holes" in the radar coverage of some lower altitude regions in the Hinch Mountain airspace.

Appendix C

ROUTINE WORKLOAD WEIGHTING SUMMARIES

Table C-1

SUMMARY OF ROUTINE WORKLOAD WEIGHTINGS FOR SYSTEM 1A--NAS STAGE A BASE

Sector			Sector Team (R,D) and R Controller* Routine Workload Weighting (man-sec/aircraft)					
Type	Identity Number	Name	A/G Communication	FDP/RDP Operation	Flight Strip Processing	Interphone Communication	Direct Voice Communication	Total
High enroute	36	Allatoona	19.19(19.19)	11.93(4.30)	13.94 (5.74)	2.62(0)	3.02 (1.51)	50.70(30.74)
Departure transition	37	Crossville	21.67(21.67)	12.01(4.69)	16.51 (7.72)	6.39(0)	7.56 (3.78)	64.14(37.86)
Departure	38	North Departure	22.07(22.07)	11.62(4.30)	18.63 (7.75)	11.58(0)	12.70 (6.35)	76.60(40.47)
Arrival	41	Norcross	35.55(35.55)	13.04(4.30)	22.18(12.94)	10.21(0)	11.40 (5.70)	92.38(58.49)
Arrival transition	42	Lanier	23.70(23.70)	10.30(4.45)	18.30 (8.50)	6.25(0)	7.40 (3.70)	65.95(40.35)
Low arrival	46	Commerce	21.79(21.79)	14.60(4.30)	18.05 (7.44)	15.75(0)	15.04 (7.52)	81.23(41.05)
Low enroute	52	Hinch Mountain	24.56(24.56)	14.62(4.30)	20.59 (8.25)	23.07(0)	20.46(10.23)	103.30(47.34)

*R controller work is indicated in parentheses.

Table C-2

SUMMARY OF R CONTROLLER ROUTINE WORKLOAD WEIGHTINGS
FOR SYSTEM 1A--NAS STAGE A BASE

Event/Task Description	R Controller Routine Workload Weighting by Sector (man-sec/aircraft)						
	36	37	38	41	42	46	52
Total A/G communications	19.19	21.67	22.07	35.55	23.70	21.79	24.56
Traffic structuring--flight strip processing	5.50	7.38	7.75	12.46	8.30	7.10	7.89
Pilot request--flight strip processing	0.24	0.34	0	0.48	0.20	0.34	0.36
Pointout acceptance--data block suppression	0	0.39	0	0	0.15	0	0
Data block/leader line offset	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Data block forcing/removal	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Equipment adjustment	0.30	0.30	0.30	0.30	0.30	0.30	0.30
One-half total direct voice communications	1.51	3.78	6.35	5.70	3.70	7.52	10.23
Total	30.74	37.86	40.47	58.49	40.35	41.05	47.34

Table C-3

SUMMARY OF ROUTINE WORKLOAD WEIGHTINGS FOR SYSTEM 1B--NAS STAGE A

Sector			Sector Team (R,T) and R Controller* Routine Workload Weighting (man-sec/aircraft)					
Type	Identity Number	Name	A/G Communication	FDP/RDP Operation	Flight Strip Processing	Interphone Communication	Direct Voice Communication	Total
High enroute	36	Allatoona	19.19(19.19)	11.64(1.30)	7.07 (3.66)	0.28(0)	3.02 (1.51)	41.20(25.66)
Departure transition	37	Crossville	21.67(21.67)	11.53(1.30)	9.07 (4.76)	0.63(0)	7.56 (3.78)	50.46(31.51)
Departure	38	North Departure	22.07(22.07)	10.62(1.30)	9.63 (5.37)	4.41(0)	12.70 (6.35)	59.43(35.09)
Arrival	41	Norcross	35.55(35.55)	12.51(1.30)	14.59(10.00)	1.68(0)	11.40 (5.70)	75.73(52.55)
Arrival transition	42	Lanier	23.70(23.70)	9.60(1.30)	10.20 (4.60)	1.05(0)	7.40 (3.70)	51.95(33.30)
Low arrival	46	Commerce	21.79(21.79)	10.10(1.30)	8.69 (5.28)	4.06(0)	15.04 (7.52)	59.68(35.89)
Low enroute	52	Hinch Mountain	24.56(24.56)	12.90(1.30)	9.79 (5.89)	5.11(0)	20.46(10.23)	72.82(41.98)

*R controller work is indicated in parentheses.

Table C-4

SUMMARY OF R CONTROLLER ROUTINE WORKLOAD WEIGHTINGS
FOR SYSTEM 1B--NAS STAGE A

Event/Task Description	R Controller Routine Workload Weighting, by Sector (man-sec/aircraft)						
	36	37	38	41	42	46	52
Total A/G communications	19.19	21.67	22.07	35.55	23.70	21.79	24.56
Traffic structuring--flight strip processing*	3.42	4.42	5.37	9.52	4.40	4.94	5.53
Pilot request--flight strip processing	0.24	0.34	0	0.48	0.20	0.34	0.36
Pointout acceptance--data block suppression	0†	0†	0†	0†	0†	0†	0†
Data block/leader line offset	0†	0†	0†	0†	0†	0†	0†
Data block forcing/removal	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Equipment adjustment	0.30	0.30	0.30	0.30	0.30	0.30	0.30
One-half total direct voice communications	1.51	3.78	6.35	5.70	3.70	7.52	10.23
Total	25.66	31.51	35.09	52.55	33.30	35.89	41.98

*R controller flight strip processing excludes flight strip markings for altitude instruction and transponder code assignment events.

†Indicated event is performed by T controller.

Table C-5

SUMMARY OF ROUTINE WORKLOAD WEIGHTINGS FOR SYSTEMS 2, 3, 4, AND 5--
INCLUDING AUTOMATED DATA HANDLING

Sector			Sector Team (R,D) and R Controller* Routine Workload Weighting (man-sec/aircraft)					
Type	Identity Number	Name	A/G Communication	FDP/RDP Operation	Flight Strip Processing†	Interphone Communication	Direct Voice Communication	Total
High enroute	36	Allatoona	19.19(19.19)	13.92(0.30)	0(0)	2.34(0)	2.70(1.35)	38.15(20.84)
Departure transition	37	Crossville	21.67(21.67)	16.66(0.69)	0(0)	4.85(0)	5.80(2.90)	48.98(25.26)
Departure	38	North Departure	22.07(22.07)	16.30(0.30)	0(0)	8.08(0)	8.70(4.35)	55.15(26.72)
Arrival	41	Norcross	35.55(35.55)	22.38(0.30)	0(0)	8.95(0)	9.96(4.98)	76.84(40.83)
Arrival transition	42	Lanier	23.70(23.70)	16.55(0.45)	0(0)	4.85(0)	5.80(2.90)	50.90(27.05)
Low arrival	46	Commerce	21.79(21.79)	16.82(0.30)	0(0)	15.19(0)	14.40(7.20)	68.20(29.29)
Low enroute	52	Hinch Mountain	24.56(24.56)	19.68(0.30)	0(0)	21.81(0)	19.02(9.51)	85.07(34.37)

*R controller work is indicated in parentheses.

†Flight strip processing is not performed.

Table C-6

SUMMARY OF R CONTROLLER ROUTINE WORKLOAD WEIGHTINGS
FOR SYSTEMS 2, 3, 4, and 5--INCLUDING AUTOMATED DATA HANDLING

Event/Task Description	R Controller Routine Workload Weighting, by Sector (man-sec/aircraft)						
	36	37	38	41	42	46	52
Total A/G communications	19.19	21.67	22.07	35.55	23.70	21.79	24.56
Traffic structuring--flight strip processing	0*	0*	0*	0*	0*	0*	0*
Pilot request--flight strip processing	0*	0*	0*	0*	0*	0*	0*
Pointout acceptance--data block suppression	0	0.39	0	0	0.15	0	0
Data block/leader line offset	0†	0†	0†	0†	0†	0†	0†
Data block forcing/removal	0†	0†	0†	0†	0†	0†	0†
Equipment adjustment	0.30	0.30	0.30	0.30	0.30	0.30	0.30
One-half total direct voice communications	1.35	2.90	4.35	4.98	2.90	7.20	9.51
Total	20.84	25.26	26.72	40.83	27.05	29.29	34.37

*Flight strip processing is not performed.

†Indicated event is performed automatically.

Table C-7

SUMMARY OF ROUTINE WORKLOAD WEIGHTINGS FOR SYSTEM 6A--100% DATA LINK AVIONICS

Sector			Sector Team (R,D) and R Controller* Routine Workload Weighting (man-sec/aircraft)					
Type	Identity Number	Name	A/G Communication	FDP/RDP Operation†	Flight Strip Processing‡	Interphone Communication	Direct Voice Communication	Total
High enroute	36	Allatoona	8.69 (8.69)	11.22 (6.92)	0(0)	2.34(0)	2.70(1.35)	24.95(16.96)
Departure transition	37	Crossville	10.00(10.00)	15.41 (9.08)	0(0)	4.85(0)	5.80(2.90)	36.03(21.98)
Departure	38	North Departure	6.55 (6.55)	16.09 (9.80)	0(0)	8.08(0)	8.70(4.35)	39.42(20.70)
Arrival	41	Norcross	15.37(15.37)	22.18(12.17)	0(0)	8.95(0)	9.96(4.98)	56.46(32.52)
Arrival transition	42	Lanier	10.65(10.65)	16.65 (9.95)	0(0)	4.85(0)	5.80(2.90)	37.90(23.50)
Low arrival	46	Commerce	12.87(12.87)	16.18 (6.05)	0(0)	15.19(0)	14.40(7.20)	58.64(26.12)
Low enroute	52	Hinch Mountain	15.30(15.30)	21.29 (6.65)	0(0)	21.81(0)	19.02(9.51)	77.42(31.46)

*R controller work is indicated in parentheses.

†Indicated values include manual data entry/display operations and data link message cognizance.

‡Flight strip processing is not performed.

Table C-8

SUMMARY OF R CONTROLLER ROUTINE WORKLOAD WEIGHTINGS
FOR SYSTEM 6A--100% DATA LINK AVIONICS

Event/Task Description	R Controller Routine Workload Weighting, by Sector (man-sec/aircraft)						
	36	37	38	41	42	46	52
Total A/G communications	8.69	10.00	6.55	15.37	10.65	12.87	15.30
Traffic structuring--flight strip processing	0*	0*	0*	0*	0*	0*	0*
Pilot request--flight strip processing	0*	0*	0*	0*	0*	0*	0*
Pointout acceptance--data block suppression	0	0.39	0	0	0.15	0	0
Data block/leader line offset	0†	0†	0†	0†	0†	0†	0†
Data block forcing/removal	0†	0†	0†	0†	0†	0†	0†
Equipment adjustment	0.30	0.30	0.30	0.30	0.30	0.30	0.30
One-half total direct voice communication	1.35	2.90	4.35	4.98	2.90	7.20	9.51
Subtotal	10.34	13.59	11.20	20.65	14.00	20.37	25.11
Traffic structuring message cognizance							
Altitude instruction	3.12	4.44	3.57	4.41	5.85	3.24	3.00
Heading instruction	1.50	1.95	3.93	2.46	0.90	0.51	1.35
Speed instruction	0	0	0	3.00	0.75	0	0
Frequency change instruction	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Subtotal	6.62	8.39	9.50	11.87	9.50	5.75	6.35
Total	16.96	21.98	20.70	32.52	23.50	26.12	31.46

*Flight strip processing is not performed.

†Indicated event is performed automatically.

Table C-9

SUMMARY OF R CONTROLLER ROUTINE WORKLOAD WEIGHTINGS FOR SYSTEM 6B--100% DATA LINK AVIONICS

Sector			R Controller* Routine Workload Weighting (man-sec/aircraft)					
Type	Identity Number	Name	A/G Communication	FDP/RDP Operation†	Flight Strip Processing‡	Interphone Communication	Direct Voice Communication§	Total
High enroute	36	Allatoona	8.69	11.22	0	2.34	0	22.25
Departure transition	37	Crossville	10.00	15.41	0	4.85	0	30.26
Departure	38	North Departure	6.55	16.09	0	8.08	0	30.72
Arrival	41	Norcross	15.37	22.18	0	8.95	0	46.50
Arrival transition	42	Lanier	10.65	16.60	0	4.85	0	32.10
Low arrival	46	Commerce	12.87	16.18	0	15.19	0	44.24
Low enroute	52	Hinch Mountain	15.30	21.29	0	21.81	0	58.40

*One-man sector team; R controller performs all control events.

†Indicated value includes data input/output and data link message cognizance.

‡Flight strip processing is not performed.

§Intrasector direct voice communication is not performed.

Appendix D

WORKLOAD MODELING DATA

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Table D-1

SUMMARY OF SECTOR TEAM ROUTINE WORKLOAD WEIGHTINGS

Enhancement System	Equipped Aircraft		Team Workload Weighting, by Sector (man-sec/aircraft)						
	RNAV (%)	Data Link (%)	36,44	37	38	39,42,43	40,41	46	52
1A. NAS Stage A Base	0%	0%	51	64	77	66	92	81	103
1B. NAS Stage A (three-man sectors)	0	0	41	50	59	52	76	60	73
2. + Automated data handling	0	0	38	49	55	51	77	68	85
3. + Automated local flow control	0	0	38	49	55	51	77	68	85
4. + Sector conflict probe	0	0	38	49	55	51	77	68	85
5. + RNAV	0-100	0	38	49	55	51	77	68	85
6A. + Data link (two-man sectors)	100	0	38	49	55	51	77	68	85
	100	50	31.5	42.5	47	44.5	66.5	63.5	81
	100	100	25	36	39	38	56	59	77
6B. + Data link (one-man sector)	100	0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	100	50	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	100	100	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

n.a. = not applicable

Table D-2

SUMMARY OF SECTOR R CONTROLLER ROUTINE WORKLOAD WEIGHTINGS

Enhancement System	Equipped Aircraft		R Controller Workload Weighting, by Sector (man-sec/aircraft)						
	RNAV (%)	Data Link (%)	36,44	37	38	39,42,43	40,41	46	52
1A. NAS Stage A Base	0%	0%	31	38	41	40	58	41	47
1B. NAS Stage A (three-man sectors)	0	0	26	32	35	33	53	36	42
2. + Automated data handling	0	0	21	25	27	27	41	29	34
3. + Automated local flow control	0	0	21	25	27	27	41	29	34
4. + Sector conflict probe	0	0	21	25	27	27	41	29	34
5. + RNAV	0-100	0	21	25	27	27	41	29	34
6A. + Data link (two-man sectors)	100	0	21	25	27	27	41	29	34
	100	50	19	23.5	24	25.5	37	27.5	32.5
	100	100	17	22	21	24	33	26	31
6B. + Data link (one-man sectors)	100	0	35	43	46	45	67	54	66
	100	50	28.5	36.5	38.5	38.5	57	49	62
	100	100	22	30	31	32	47	44	58

Table D-3

SUMMARY OF CONFLICT PERFORMANCE TIMES

Enhancement System	Equipped Aircraft		Crossing Conflict Task Times (sec)			Overtaking Conflict Task Times (sec)		
	RNAV (%)	Data Link (%)	Detection and Assessment	Resolution	Total	Detection and Assessment	Resolution	Total
1A and 1B. NAS Stage A Base	0%	0%	20	40	60	20	20	40
2. + Automated data handling	0	0	20	40	60	20	20	40
3. + Automated local flow control	0	0	20	40	60	20	20	40
4. + Sector conflict probe	0	0	5	40	45	5	20	25
5. + RNAV	0-100	0	5	40	45	5	20	25
6A and 6B. + Data link (one- or two-man sectors)	100	0	5	40	45	5	20	25
	100	50	5	30	35	5	15	25
	100	100	5	20	25	5	10	15

Table D-4

SUMMARY OF SECTOR CONFLICT EVENT FREQUENCY AND TRANSIT TIMES

Enhancement System	Sector										
	36	37	38	39	40	41	42	43	44	46	52
	Average Sector Transit Time* (min)										
1A,1B,2,3,4, 5,6A and 6B	20	21	12	14	12	19	18	14	21	21	14
	Crossing Conflicts [(conflicts/hr)/(aircraft/hr)^2]										
1A,1B,2,3,4, 5,6A and 6B	4.8×10^{-3}	4.4×10^{-3}	0	1.7×10^{-3}	2.7×10^{-3}	2.7×10^{-3}	3.5×10^{-3}	4.6×10^{-3}	4.8×10^{-3}	6.6×10^{-3}	5.3×10^{-3}
	Overtaking Conflicts [(conflicts/hr)/(aircraft/hr)2]										
1A,1B,2,3,4	0.9×10^{-3}	0.5×10^{-3}	0.7×10^{-3}	1.0×10^{-3}	5.8×10^{-3}	6.4×10^{-3}	5.8×10^{-3}	0.7×10^{-3}	1.5×10^{-3}	0.7×10^{-3}	4.3×10^{-3}
5,6A and 6B: 0% RNAV	0.9×10^{-3}	0.5×10^{-3}	0.7×10^{-3}	1.0×10^{-3}	5.8×10^{-3}	6.4×10^{-3}	5.8×10^{-3}	0.7×10^{-3}	1.5×10^{-3}	0.7×10^{-3}	4.3×10^{-3}
50% RNAV	0.45×10^{-3}	0.25×10^{-3}	0.35×10^{-3}	0.5×10^{-3}	2.9×10^{-3}	3.2×10^{-3}	2.9×10^{-3}	0.35×10^{-3}	0.75×10^{-3}	0.35×10^{-3}	2.15×10^{-3}
100% RNAV	0	0	0	0	0	0	0	0	0	0	0

*Sector R controller surveillance workload weighting (man-sec/aircraft) = 1.25 (man-sec/aircraft-min) X average sector transit time (min).

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