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Specification for a Data Collection to Determine Lateral Pathkeeping of Aircraft Flying Low-Altitude Vor-Defined Airways

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16. Abstract

A data collection program is described which would provide much useful information related to lateral pathkeeping performance of aircraft flying low-altitude VOR-defined airways. This data collection would provide specific information which would complement the information previously gained concerning the high-altitude VOR-defined jet route environment. The study would be used to investigate the adequacy of current and proposed domestic and international lateral separation standards.

This proposed data collection would involve data collection at several different Air Route Traffic Control Centers (ARTCC) and data reduction and analysis at the FAA Technical Center. Data to be collected and analyzed would include flight progress strips, air traffic control radar beacon system (ATCRBS) measurements of aircraft position, air traffic control voice communication recordings, real-time observations by trained personnel, status records of ARTCC equipment, results of flight inspection flights, and meteorological reports.

In addition to the data collection plan itself, this document also includes the results of investigations of traffic density and traffic mix shown by flight progress strips collected from selected areas by the New York and Washington Air Route Traffic Control Centers.

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1.0 INTRODUCTION

In response to a November 1976 request from the FAA Associate Administrator for Air Traffic and Airways Facilities to the FAA Associate Administrator for Engineering and Development (reference 1), the FAA Technical Center is conducting a study to provide guidance regarding improved procedures for the establishment of standards for the horizontal separation of aircraft. The first phase of this study addressed procedures for spacing parallel high-altitude VOR-defined jet routes in conterminous United States (CONUS) airspace. This phase would expand the study to consider low-altitude VOR-defined Federal Airways in CONUS airspace.

Potential improvements to the methodology for establishing separation standards between airways will be investigated. Although the primary emphasis will be on minimally spaced parallel airways, various other configurations such as converging routes and en route turns will also be studied. The effort will serve as a companion to the high-altitude VOR-defined jet route study for the dual purposes of collecting data descriptive of the low-altitude environment and of drawing comparisons with and contrasts to the high-altitude environment. If any changes to current airspace planning procedures appear necessary as a result of this study, recommendations will be made at the conclusion of the study. It is important that any proposed changes resulting from this study, in addition to being supported by the best analysis of the data, should be easily applied by operational personnel and easily monitored to ensure their applicability to the Air Traffic Control environment.

As with the study of the jet route structure, the effort contemplated for the Federal Airway system will focus primarily on characterizing the two factors principally affecting the spacing of parallel routes: lateral navigational performance and traffic flows on adjacent routes. Lateral navigational performance will be represented by histograms and calculated statistics from the observed distributions of lateral navigational displacement. Traffic flows will be analyzed by measuring occupancy on adjacent routes.

The data collection program described in this document is intended to satisfy the broad requirement of providing spacing criteria related information on low-altitude operations. The effort has been designed to obtain some initial data at virtually no cost to the Government in either additional resources or personnel beyond that already committed to the study of separation standards. It must be emphasized that the additional staffing, equipment, and contract money necessary to implement the full-scale data collection effort outlined in this plan are neither currently assigned to the Separation Standards program area nor identified as available from other sources at the FAA Technical Center. It is anticipated that equipment, contract, and travel funds will need to be provided if this study is to be undertaken.

Since the completion of the first specification for this study, there have been major changes in the air traffic control system resulting from the air traffic controller strike and the subsequent rebuilding program. In addition, lack of personnel has prevented the air traffic service from being able to support any data collection efforts. As the air traffic control system returns to normal, this data collection will again become feasible. This plan still represents the best methods available for obtaining data on lateral navigational performance, assuming that the required resources are available. If the required resources are not available, it will be necessary to estimate navigational performance from comparisons with the available high-altitude data.

Another study has been proposed to obtain information on traffic flows on adjacent routes in the entire CONUS airspace. This other study will involve building a data base containing information on the structure of the low-altitude Federal airway system and on the traffic densities on each segment of that structure. For comparison purposes, a similar analysis will be conducted for the high-altitude jet route structure. In addition to providing useful information concerning the airway structure and traffic density, the results of this other study would also be used if this large-scale data collection becomes feasible in the future.

1.1 THE VOR-DEFINED AIRWAY SYSTEM

Each VOR-defined airway segment is based on an electronic centerline extending from one VOR or VORTAC navigational facility to another or to an intersection defined by a radial from another VOR or VORTAC facility. As defined in the Federal Aviation Regulations (FAR 71.5, reference 2), each airway includes the airspace within parallel boundary lines four nautical miles on each side of the centerline and, where the VOR changeover point is more than 51 nautical miles from either of the VOR facilities defining that segment, includes the airspace between lines diverging at angles of 4.5 degrees from the centerline at each VOR facility.

Pilots are mandated by regulation to maneuver aircraft on an airway along the centerline of that airway (i. e., the great circle arc connecting the two ground stations defining that airway) unless otherwise authorized by Air Traffic Control (ATC) or unless necessary to pass well clear of other air traffic (FAR 91.123, reference 3). However, because of combined errors from the VOR ground stations, from the airborne receivers, and from pilotage, aircraft may not operate exactly on the centerline.

The VOR-defined airway system is constituted and inter-route spacings are based upon system accuracy criteria given in the United States National Aviation Standard for the VORTAC System (reference 4). The airway system is designed under the assumptions that aircraft would operate within the airway boundaries 95 percent of the time and that this 95 percent containment would lead to safe system operation.

These airways include that airspace extending from 1,200 feet above ground level up to but not including 18,000 feet above mean sea level. In some cases however the floor of the VOR-defined airway is higher than 1200 feet above ground level. The following published altitudes can restrict the usable altitudes on an airway segment (reference 5):

(1) The Minimum En Route IFR Altitude (MEA) is the lowest altitude between VOR fixes which assures acceptable navigational signal coverage and also meets obstacle clearance requirements between those fixes. The minimum obstacle clearance is normally 1000 feet over the highest obstacle within areas not designated as mountainous terrain and 2000 feet over the highest obstacle within areas designated as mountainous terrain (reference 6).

(2) The Minimum Reception Altitude (MRA) is the lowest altitude at which an intersection of two VOR radials can be determined.

(3) The Minimum Obstruction Clearance Altitude (MOCA) is the lowest altitude between VOR fixes which meets obstacle clearance requirements for the entire airway segment and which assures acceptable navigation signal coverage only within twenty-five statute miles of a VOR.

(4) The Minimum Crossing Altitude (MCA) at a fix is the lowest altitude at which an aircraft must cross that fix when proceeding in the direction of a higher minimum en route IFR altitude (MEA).

(5) The Maximum Authorized Altitude (MAA) is the maximum usable altitude or flight level for the airway or jet route. It is the highest altitude on the airway or jet route at which adequate reception of navigation signals is assured.

The VOR-defined Federal Airway system is designed for the use of en route low-altitude traffic and for climbing to and descending from the high-altitude VOR-defined jet route system. Transitioning into and out of the VOR-defined airway system is via published Standard Instrument Departures (SIDs) and Standard Terminal Arrivals (STARs), by radar vectoring by air traffic control, and by direct clears to fixes contained in the airway system. For purposes of this study, an aircraft on a SID or a STAR defined to follow a VOR-defined airway will be considered to be on that airway. An aircraft will not be considered to be on an airway as long as it is being radar vectored or it is operating under a direct clearance to another fix.

1.2 COMPARISONS WITH THE VOR-DEFINED JET ROUTE STUDY

The high-altitude study obtained data on approximately thirteen thousand flights of aircraft on high-altitude VOR-defined jet routes (FL 240 and above) in the Cleveland, Albuquerque, and Memphis Air Route Traffic Control Center (ARTCC) areas between September 1977 and April 1978. Descriptions of the methods used in that study and the results obtained may be found in the study specifications (references 7 and 8), in the reports of flight inspection results (references 9 and 10), and in the preliminary data report (reference 11).

This low-altitude study has been designed so that the collected data will be compatible with the data from the high-altitude study so that direct comparisons among various classes of data may be drawn. However, changes were made where they were necessary because of differences between the high-altitude and low-altitude environments and where they were shown to be desirable based on the results from the previous study.

The low-altitude environment is expected to be more heterogeneous with respect to classification of data relevent to spacing criteria than the high-altitude environment. There are more users, more aircraft types, more differences in navigational equipment, and more differences in pilot experience. In addition to every type of user found in the high-altitude environment, the low-altitude environment contains several additional classes of users, most notably general aviation users. If these various classes exhibit significantly different navigational performance from that shown in the high-altitude study, it may be necessary to estimate probability distributions for each class separately; in this case, each class will require a sample size large enough for a valid statistical description. Since there are expected to be so many more distinct classes than in the high-altitude study, a much larger sample size may be needed in order to meet the goal of a sufficient number of samples for each class.

2.0 OBJECTIVES

The overall intent of this data collection is to provide an accurate description of the low-altitude environment sufficient to support an investigation of the current airspace planning procedures for spacing parallel airways. This should include data on navigational performance for aircraft negotiating a course change as well as for aircraft flying a straight course. This investigation will be based on established collision risk methodology and other factors pertinent to rendering judgements regarding adequate spacing minima. Many similarities exist between the form and substance of the data to be collected for this purpose and data previously collected and analyzed for the high-altitude environment. This study is therefore patterned after the study of the high-altitude VOR-defined jet route structure (reference 11). In principal, representations of lateral navigational performance and traffic flow rates are required. The specifics of their compilation and discrimination differ in some respects from the previous study and are detailed in subsequent sections of this specification. Refinements of the data collection techniques used in the jet route study are made where experience suggests that these refinements are likely to be fruitful. Under this data collection specification, enhancements to the data collection methodology in order to accomodate differing structures in the Federal Airway environment will be suggested.

As with the high-altitude study, the data collection program described in this document is intended to be non-intrusive with respect to the air traffic control environment being observed. That is to say, information gathering will be carried out in such a manner as to avoid drawing attention to the fact that navigational performance and system use are being monitored in any nonstandard way.

Lateral pathkeeping performance on a low-altitude VOR-defined airway will be described in terms of separate distributions of lateral position at various mileposts along the airway. It is necessary to determine an appropriate basic distribution shape, and then to estimate parameters describing the distribution. The exact form of this distribution is not known, and previous studies have shown that the Gaussian (normal) distribution does not provide an accurate statistical description of observed performance. Some distributional parameters which will be estimated are the mean, the standard deviation, the skewness, the kurtosis, the root-mean-square deviation around the geographic airway centerline, the percentage outside of protected airspace, and the boundaries of the central 95 percent of the distribution.

In addition to estimating the general form and parameters of the distribution of lateral deviations, it is necessary to pay special attention to the tails of the distribution. Aircraft collisions are low-probability events, and knowledge of the central part of the probability distribution is not sufficient for estimating collision risk. In particular, two aircraft on adjacent parallel airways cannot have a collision as long as they both remain within their respective airway boundaries (i. e., within the cores of their respective probability distributions); in order for a collision to occur, one or both aircraft must be a larger error (deviating outside protected airspace). A detailed study of the flights with larger errors is thus essential to estimate collision risk.

For a given level of navigational performance, the hazard of a midair collision between aircraft assigned to parallel airways will depend upon the frequency with which aircraft pairs are sufficiently close together along-track so that lateral errors may cause a collision. Estimation of this frequency in various parts of the Federal Airway system is an objective of this study. This frequency will be estimated from this study in two ways. The frequency of aircraft passings will be directly measured. In addition, estimates of aircraft arrival and velocity distributions will be made to allow these frequencies to be estimated from various analytic and simulation models.

3.0 SCOPE OF THE DATA COLLECTION

This study will consider all aircraft with IFR flight plans planning to fly one or more selected airway segments during the time periods selected for data collection. Data collection will be restricted to selected altitudes on the selected airway segments. Because of the design of the data collection equipment, position data can by collected only for secondary (beacon) radar returns; primary radar returns cannot be collected. Because of requirements for the efficient collection of data, the selection of airway segments and time periods will not be random. Data will be collected on all aircraft on these airway segments during these time periods, with the intention that these results be generalized to all airway segments and time periods. Attempts will be made to cover a whole host of airway segments and time periods so that the generalization of these results will be practical under statistically sound procedures.

3.1 AIRCRAFT WITH IFR FLIGHT PLANS

The study will consider only aircraft on IFR flight plans. There is no non-intrusive way to collect data on the intentions of VFR aircraft with which to compare radar position data, and there is no requirement that VFR aircraft attempt to navigate on airway centerline. Therefore, there would be no planned position to compare with the actual position.

3.2 AIRCRAFT WITH OPERATING TRANSPONDERS

Because the method used for data collection utilizes secondary radar returns, position data will be collected only for aircraft with operating transponders. This should not be a significant limitation however. Although transponders are not required for IFR flight on low-altitude Federal Airways (FAR 91.33, reference 3), our experience suggests that there are extremely few aircraft flying on IFR flight plans without operating transponders. A preliminary study of flight progress strips from the New York ARTCC showed no IFR traffic on the selected airway segments without operating transponders (Appendix A). Flight progress strips and real-time observations will be collected for any aircraft without an operating transponder so that the effect of this limitation can be verified.

The data collection will include aircraft both with and without Mode C altimeter reporting capacity. Actual altitudes cannot be determined for the small number of aircraft without Mode C capacity, but these aircraft can be assigned to altitude strata by the use of assigned and reported altitudes recorded on flight progress strips and on observer logs. The altitude data to be collected by this study will not be adequate for an analysis of vertical position keeping, as it has been established that the information from altitude-encoding transponders is not sufficient to support an accurate determination of vertical position. Altitude data is required however to enable the identification of climbing and descending aircraft and to enable the identification of different altitude strata for the analysis of differences in lateral pathkeeping. The recorded altitude information may also be useful for estimating flight technical error in the vertical dimension.

3.3 AIRCRAFT FLYING SELECTED AIRWAY SEGMENTS

This study will consider all aircraft with an IFR flight plan expressing the intention of flying one or more of the selected airway segments. Aircraft will be included which do not necessarily complete an entire airway segment, as long as they fly the segment for a sufficient distance to enable valid data to be collected. The entry and exit points used on each selected airway segment will be analyzed to determine which entry-exit pairs should be used. An example of this analysis for some selected airway segments in the New York ARTCC area is given in Appendix A.

Data will be analyzed only for those portions of a flight in which the pilot is attempting to navigate on the VOR-defined airway. The pilot's intention to follow an airway will be determined from the flight plan as shown on the flight progress strips and from communications between the pilot and the controller as recorded by the observer or, if necessary, as recorded on the voice recordings. Flights with deviations from the airway for traffic management, weather avoidance, or other reasons other than strictly navigational performance will be excluded in their entirety from entry into the data base and the statistics resulting from this study.

Aircraft with ATC interventions (deviation vectors and deviation advisories) will be included in the study. These interventions can be in one of three types:

(1) a deviation vector (such as "ZZ999, I show you ten miles east of centerline, proceed direct Yardley VOR"),

(2) a direct deviation advisory (such as "ZZ999, I show you ten miles east of centerline"), and

(3) an indirect deviation advisory (such as "ZZ999, how do you read Yardley VOR?").

The entire flight for an aircraft with a deviation vector or a deviation advisory will be included in the study regardless of air traffic control functions effected to return the aircraft to the airway centerline, and these flights will also be analyzed separately. These flights require special study for the following two reasons:

(1) These flights usually have larger deviations from centerline, or at least evidence of their likely occurrence, which lead to the deviation vectors or deviation advisories, and flights with larger deviations from centerline are the most significant contributors to collision risk.

(2) These deviation vectors and deviation advisories can truncate the distribution of observed lateral deviations by preventing or correcting larger deviations which would otherwise occur. An analysis of these flights is necessary for an estimate of collision risk in a nonradar environment based on data from a radar environment.

There are also cases in which an aircraft deviating from the airway centerline is given a clearance direct to a fix other than the VOR ending that airway segment. In this case, the portion of the flight after the revised clearance cannot be included in the study. However the deviation prior to the revised clearance will be considered, and it will be included in the study if it appears that the intention at that point was to fly the airway.

3.4 AIRCRAFT FLYING SELECTED ALTITUDES

In addition to low-altitude VOR-defined Federal Airways (altitudes up to but not including 18,000 feet above mean sea level), this study will also include the high-altitude VOR-defined jet routes (FL 180 and above) overlying some of these airways. Although the primary purpose of this study is to describe the low-altitude environment, there are several important reasons for also including the high-altitude environment in this study:

(1) Climbing and descending aircraft will be included in the study. Because of the heavier pilot workload, it is possible that these aircraft have a different sort of navigational performace from aircraft in level flight in either the high-altitude or the low-altitude environment. This study will attempt to analyze this important segment of the population.

(2) Inclusion of high-altitude and low-altitude flights in the same study will make possible a direct comparison between the two altitude environments with fewer extraneous influences than if separate studies were used. For example, the flights would be in the same geographic area, would use the same navigational facilities, and would be flown during the same time period. Should sufficient data exist comparisons can be made, and these comparisons ought to assist in determining which conclusions from the previous high-altitude study would be applicable to the low altitude environment.

(3) The previous high-altitude study only included altitudes of FL 240 and above. If this study were to include only the low-altitude environment, then altitudes from FL 180 through FL 230 would not have been studied. These intermediate altitudes are often used for a different kind of traffic than either the higher or lower altitudes, such as mid-range high-performance aircraft. For example, commercial airline shuttle flights between New York and Washington usually use FL 200. Thus it is possible that conclusions from those other altitudes may not be able to be generalized.

For purposes of analysis, the study sample will be divided into various subsamples on the basis of altitude. One of the major purposes of this study is the comparison of navigational performance among these different subsamples for the purpose of estimating navigational performance for the entire population. The altitude subsamples will include the following:

(1) aircraft in level flight on low-altitude airways (up to but not including 18,000 feet above mean sea level),

(2) aircraft climbing and descending on low-altitude airways,

(3) aircraft in level flight on high-altitude jet routes (FL 180 up to but not including FL240),

(4) aircraft climbing from low-altitude airways to high-altitude jet routes, and

(5) aircraft descending from high-altitude jet routes to low-altitude airways.

Data collection will be limited to altitudes below FL 240, and on some airway segments it will be further limited to altitudes below 18,000 feet above mean sea level. However, radar tracking data will also be collected for higher altitudes where it appears useful for the analysis of navigational performance of aircraft climbing from or descending to the altitudes included in this study. Observers will not be assigned specifically to collect data on aircraft at FL 240 and above; however, in some circumstances data will be collected on aircraft at FL 240 and above where it can be done without any additional observers.

3.5 AIRCRAFT FLYING DURING SELECTED TIME INTERVALS

The data collection will be conducted during discrete time intervals of from four to six hours each, depending on the availability of observers and the capacity of the magnetic tapes used to record data. These time intervals will be selected to provide for differing levels of traffic density for data collection and to provide for various mixes of traffic. Different times of day and different days of the week (including weekends as well as weekdays) should be selected. Depending on the availability of observers, data will be collected for all selected airway segments within the ARTCC simultaneously or for different groups of selected airway segments at different times.

Data collection will be conducted over some high-traffic holiday period or periods, such as Thanksgiving or Christmas. Although it is not anticipated that enough data will be collected for definite comparisons among the various subpopulations to be possible specifically for holiday periods, general comparisons between holiday and nonholiday time periods should be possible.

4.0 TYPES OF DATA TO BE COLLECTED

A review of the high-altitude VOR-defined jet route study and a consideration of the differences between high-altitude and low-altitude traffic resulted in the identification of seven types of data to be collected for each Air Route Traffic Control Center (ARTCC):

(1) flight progress strips detailing aircraft flight plans,

(2) Air Traffic Control Radar Beacon System (ATCRBS) measurements of aircraft position,

(3) air traffic control voice communication recordings,

(4) real-time observations of the air traffic control environment,

(5) status records of ARTCC equipment which could affect observed navigational performance,

(6) flight inspection results for the VOR's defining the selected airways, and

(7) meteorological reports along the selected airways.

The seven types of data will furnish three general categories of information:

(1) records identifying aircraft intending to fly the selected airway segments and measuring their achieved navigational performance (types (1) and (2)),

(2) records providing information on flight plan changes and other factors which could assist in explaining the navigational performance observed on a particular flight (types (3) and (4)), and

(3) records providing information on any general or systematic factors which could assist in explaining the navigational performance observed on a number of flights (types (5), (6), and (7)).

An overview of the use of all of these sources of data to obtain results is shown in schematic form in Figure 1. Details of the processing are given in section 6 below.

The first six types of data on the above list were also collected in the high-altitude VOR-defined jet route study. Meteorological data was added to this study because of two potential differences between the high-altitude and low-altitude environments: an expected larger effect of weather conditions on lateral navigational performance in the low-altitude environment and the possible use of ground references as an aid to low-altitude navigation when they are visible. There was also one source of data used in the high-altitude study which is not available for this study. Because of the much larger number of different aircraft in the low-altitude environment, it is not feasible to compile a catalog of navigational equipment on all such aircraft. An attempt will be made to reduce the cost of flight inspections from the high-altitude VOR-defined jet route study by obtaining most of the required flight inspections during routine surveillance or normal en route time at little or no cost.

In order to obtain data as representative of actual navigational performance as possible, no special communications will be initiated with deviating aircraft and no contact will be made with pilots about the data collection. Although such communications might be extremely useful in explaining some deviations from course, the required controller interrogation would alert the pilot of the flight under query and possibly other pilots as well that nonstandard monitoring is operative. Such questioning continued over the entire data collection period might cause the observed navigational performance to be an unrepresentative sample. This policy is a specific instance of the overall intention to conduct a non-intrusive type of data collection.

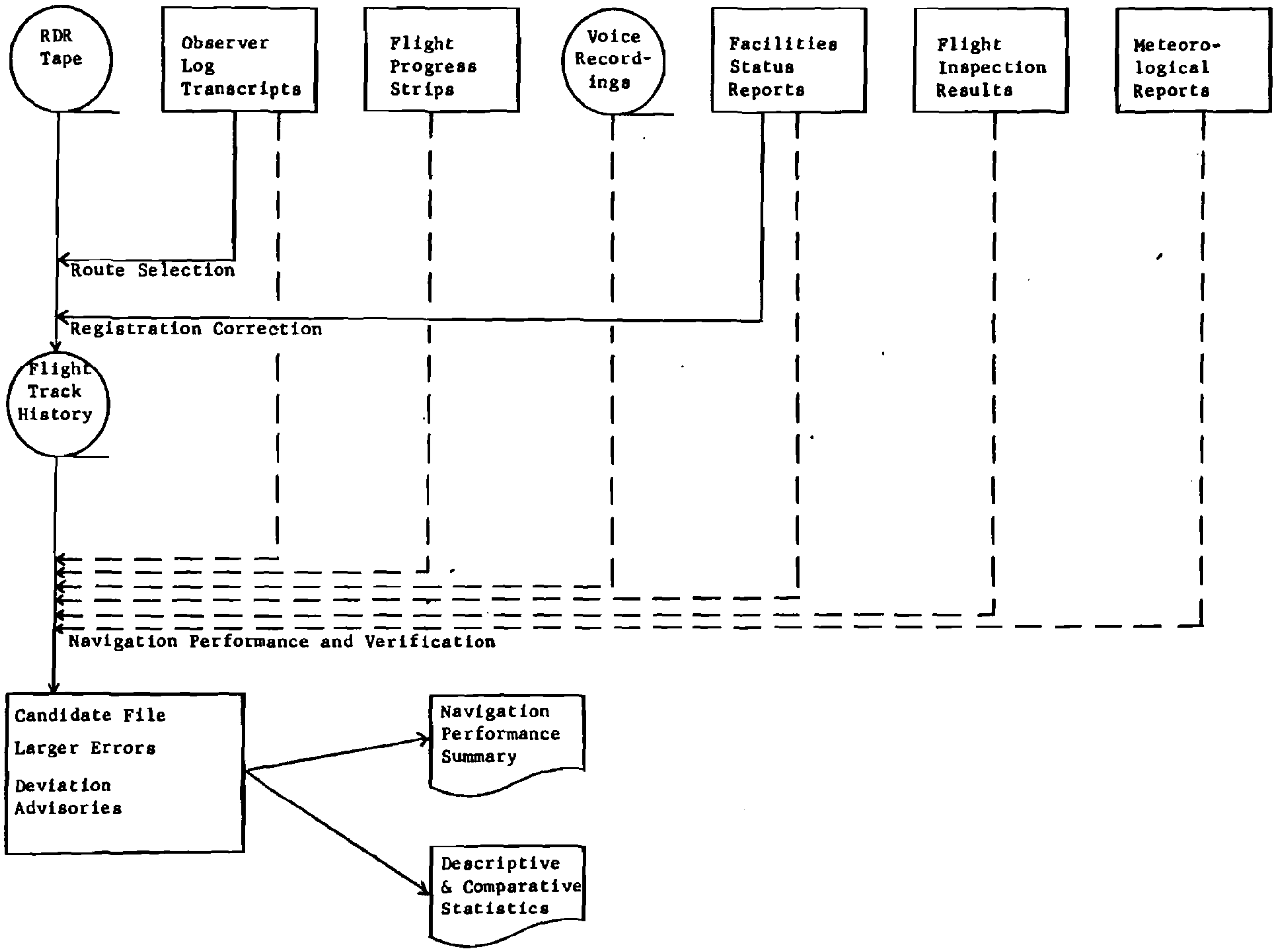


FIGURE 1. USE OF DATA SOURCES

4.1 FLIGHT PROGRESS STRIPS

All flight progress strips for those ARTCC sectors involving the selected airway segments will be segregated and held in a dedicated location in the ARTCC. At the end of the fifteen-day statutory retention period, they will be forwarded to the FAA Technical Center for analysis.

The flight progress strips for selected flights will provide identification data, data reflecting navigational intent, and additional data for analysis. Each flight will be identified by its aircraft identification, its assigned beacon code, and its time of arrival over selected fixes. Navigational intent will be reflected in the filed flight plan and in any revisions annotated by the sector air traffic controllers. Other items which may be used for analysis of differences in navigational performance are user type (derived from aircraft identification), specific user name (derived from aircraft idenfication), aircraft type, aircraft weight class (derived from aircraft type), aircraft type category (derived from aircraft type), filed navigational equipment code, origin and destination of flight, and assigned altitude.

As previously indicated, a preliminary analysis of flight progress strips was undertaken with one week of data from the New York ARTCC. A summary of the results from that analysis is given in Appendix A. Flight progress strips have also been obtained for one week each from the Washington and Albuquerque ARTCC's. These strips are currently being analyzed, and results of this analysis will be reported when it is completed.

4.2 ATCRBS MEASUREMENTS OF AIRCRAFT POSITION

Aircraft position measurements will be obtained using the same methods as used in the high-altitude study. Actual Air Traffic Control Radar Beacon System (ATCRBS) position measurements will be collected on a radar data recorder designed by FAA Technical Center personnel. This device consists of a magnetic tape recorder and the digital processing hardware necessary to read and selectively record ATCRBS target reports from up to three separate radar sites. The radar data recorder is physically located in the ARTCC and collects the ATCRBS target messages in parallel with their transmission from the data receiver group to the systems maintenance monitor console within the ARTCC. Its operation is completely transparent to the National Airspace System (NAS). It should be noted that this method of position data collection uses only secondary radar returns and that no position data is collected on aircraft without operating transponders.

Each secondary radar target report recorded on the radar data recorder tape contains the following information: ATCRBS beacon code, sensor number, range (to one-eighth nautical mile), azimuth (to one azimuth change pulse, equal to 0.088 degree), mode-C altitude (to 100 feet) if available, and time of return (to one-tenth second). Since these target messages are intercepted and recorded before they enter the NAS central computer complex, several processing steps will need to be performed at the FAA Technical Center before the position data can be used. Radar registration corrections will be carried out using correction factors obtained from the ARTCC, and appropriate smoothers will ensure that the position data is as accurate as possible. This position data will then be transformed to a rectangular coordinate system for further processing, using a stereographic projection that closely resembles the one used in the ARTCC.

This data collection and reduction process will be similar to that used in the high-altitude study. All the data reduction computer programs used in the high-altitude study are still available, and they will be usable for this study with modifications.

It is proposed that the preliminary phases of the data collection program concentrate on selected airways within the airspace of the Washington ARTCC. For this preliminary data collection, it will not be necssary to install the radar data recorder physically in the ARTCC. It can be installed at the FAA Technical Center NAS laboratory complex, which receives as a matter of course ATCRBS target reports from the New York (JFK), Trevose, and Washington (Suitland) radars. It was originally proposed that the New York ARTCC be used for this preliminary data collection. However, it appeared unlikely that the New York ARTCC would have sufficient personnel to support this effort. In addition, much of the airspace of interest covered by these radars had been transferred from the New York ARTCC to the Washington ARTCC. These are the only pertinent radars with connections to the FAA Technical Center, and no suitable method of directly transferring ATCRBS returns from other NAS en route radars to the FAA Technical Center has been uncovered; therefore, any further data collection would require that a radar data recorder be installed physically in each relevant ARTCC and that the tapes containing the recorded target reports be shipped from the ARTCC to the FAA Technical Center.

4.3 ATC VOICE COMMUNICATION RECORDINGS

Recordings will be made of all voice communications involving controllers in the selected ARTCC sectors. This will include communications with aircraft under their control and communications with controllers in adjacent sectors (in the same and in contiguous ARTCC's).

These voice communications can be analyzed to identify brief deviations for traffic management, weather avoidance, or other reasons other than navigational performance, to obtain occassional explanatory information regarding navigational errors, and to identify air traffic control interventions initiated because of deviations. Because these recordings can only be replayed at real-time speed, it will not be possible to use them extensively. The recordings will be used only to study deviations and interventions that have been identified by other means, such as by analysis of the achieved navigational performance or by real-time observations. Although experience in the high-altitude study indicates a low rate of resolution of the causes associated with particular larger errors, the voice recordings nonetheless represent an indispensable source of information for verifying the occurrence of these errors and thus are well worth the cost of collection and processing.

These recordings will be made with ARTCC equipment and then shipped to the FAA Technical Center. It is essential that a 152-channel voice recorder be available at the FAA Technical Center throughout this study for playback of these recordings.

4.4 REAL-TIME OBSERVATIONS

Acquisition of on-site observations of the air traffic control and navigation environments within the ARTCC sectors used for data collection will be required in order to insure that important factors affecting planned and achieved navigational performance are not overlooked. The observer will be seated in such a manner that he or she can see the plan video display used by the radar controller and can also listen to any voice communications. An observer will be needed for each sector involved in data collection whenever data is being collected; in some cases, however, it might be possible for one observer to observe two adjacent sectors, should the number of airways and the traffic densities permit.

The observer must be an individual familiar with air traffic functions within the designated sector. Since the observer is required to quickly and accurately identify deviations outside protected airspace, it is important that each observer be familiar with the boundaries of the designated airways and with the distances between the designated airways and other locations shown on the plan video display. It was originally planned to use area-rated air traffic control specialists as observers, as was done in the high-altitude study. However, it does not appear likely that a sufficient number of air traffic control specialists will be available in the centers to perform this duty. With proper training and supervision, it should be possible to use flight data specialists for making these observations in the centers.

It is extremely important that each observer receive a detailed and uniform briefing on the purposes of this study, the requirements for data collection, and the procedures to be used by the observers. Since the observers will not be area-rated air traffic control specialists, this training will need to be even more extensive than in the high-altitude study. This briefing should be given by an FAA Technical Center air traffic control specialist using a prepared script. The feasibility of preparing a videotape briefing for the observers should be investigated.

The observer will record events of interest on a form. In addition to header information identifying the ARTCC, the sector, the day, and the observer, the following information will be recorded for each flight:

(1) the aircraft identification,

(2) the assigned transponder code or codes,

(3) the time of any change in assigned transponder code,

(4) the airway segment of interest,

(5) the time the aircraft entered the designated airway segment,

(6) the fix at which the aircraft entered the designated airway segment,

(7) the previous airway or radar vector prior to entering the designated airway segment,

(8) the time the aircraft departed the designated airway segment,

(9) the fix at which the aircraft departed the designated airway segment,

(10) the next airway or radar vector after departing the airway segment,

(11) the time and type of any clearance off the planned path for traffic management, weather avoidance, or any other non-navigational reason,

(12) the time and type of any radar vector, deviation advisory, or any other communication from the controller to the aircraft concerning navigational performance,

(13) the assigned altitudes and the times of any changes in assigned altitude,

(14) the reported altitudes and times for any aircraft without Mode C altitude reporting capability,

(15) the time of any excursion outside protected airspace and a description of the surrounding circumstances,

(16) the time of any conflict alert and a description of the surrounding circumstances,

(17) any pilot reports on weather conditions, and

(18) any additional remarks which would be applicable.

The presence of on-site observers was found to be necessary in the high-altitude study. Because of the more diverse low-altitude environment, on-site observers will be even more necessary in this study.

4.5 STATUS RECORDS OF ARTCC EQUIPMENT

Any anomalies, biases, or outages in ARTCC equipment which would influence observed navigational performance should be recorded. The status of ATCRBS units, navigational aids, communications equipment, and data processing facilities will be checked with responsible ARTCC personnel on a daily basis, and this status will be recorded. In addition, NAS central computer complex estimates of the range and azimuth biases of each relevant ATCRBS site will be secured at intervals of no more than three hours during data collection. If any airway segments included in the data collection are covered by only one of the three recorded radars, the range and azimuth biases of that radar should be recorded each hour during the data collection.

4.6 FLIGHT INSPECTION RESULTS

Historical flight inspection results will be obtained for all navigational facilities defining the selected airway segments. This will include Semi-Automatic Flight Inspection (SAFI) results for these facilities and Automatic Flight Inspection System (AFIS) results for these airways. Bearing error reports will be obtained for each VOR utilized in the data collection, and these will be compared with the distributions of observed deviations to determine if any correlations are present.

In addition, at least one flight inspection flight should be flown in each direction on each selected airway segment during the data collecion. This flight inspection can take place at any time during the data collection as long as it occurs during the data collection interval. An attempt should be made to obtain most of the required flight inspections during routine surveillance or normal en route time at little or no cost. However special flight inspections may be required wherever this is not feasible.

4.7 METEOROLOGICAL REPORTS

Meteorological conditions will be much more important in the low-altitude environment than they would be in the high-altitude environment, and hourly reports on these conditions will be collected at ground stations along the selected airways. During the data collection, weather reports from selected reporting stations will be collected either from the National Weather Service office at the appropriate ARTCC or from the National Weather Service office at the FAA Technical Center, depending on the availability and location of personnel. The following data will be collected:

(1) wind aloft direction and velocity,

(2) reports of storms and turbulence,

(3) ceiling and cloud cover, and

(4) visibility.

In addition, the observers will record any pilot reports of weather conditions along the selected airways.

Wind and turbulence data will be used to aid in analyzing deviations from course. The availability of ground references to the IFR pilot will be estimated based on ceiling and visibility data and on the altitude of the aircraft, and the data will be analyzed to test for any differences in navigational performance based on the availability of ground references.

5.0 SELECTION OF AIRWAY SEGMENTS

Data should be collected on many different airway segments having characteristics as representative of the entire population as possible. Since low-altitude traffic can be expected to be less homogeneous than high-altitude traffic in user class, in aircraft type, and in navigational equipment, it will be necessary to collect data on more airway segments than in the high-altitude study. Collecting data to estimate the interactions of more variables should result in a larger data collection than the high-altitude study.

Selection of airway segments should be based on the following state variables:

(1) Both long and short airway segments should be selected. In particular, some airway segments should be selected with a VOR facility to VOR change-over point distance as long as possible, so that data can be collected at various distances from the VOR.

(2) Airway segments should be selected with and without en route turns at the VOR change-over point. In particular, several routes with course changes of 15 to 50 degrees should be included in the study.

(3) In several cases, consecutive airway segments should be selected with various gradations of degree of turn about the VOR between the two segments. Several routes with course changes of 15 to 50 degrees should be included in the data collection.

(4) Airway segments should be selected with close parallel airways, since this is the environment in which navigational performance is most critical. As a control, some airway segments with no nearby airways should also be selected. Also some airway segments should be selected close to special use airspace and/or to terrain features (such as mountains) at the altitudes of interest if this can be done without interfering with the primary objective of investigating parallel airways.

(5) Airways on some preferred IFR low-altitude routes should be selected. Preferred routes are published routes recommended by ATC for particular origin-destination pairs, and pilots requesting preferred routes are given priority by ATC.

(6) Airway segments should be selected from different sections of the country and over different terrain types. In particular, some airway segments should be selected over mountainous terrain, some segments should be selected over flat terrain, and some segments should be selected over water.

(7) Airway segments should be selected with various levels of traffic density. Both density on the particular airway and total density for the applicable sectors should be considered. Peak density should be considered as well as average density.

(8) Airway segments should be selected with various mixes of traffic. Consideration should be given to differences in user type (air carrier, air taxi, general aviation, or military), to differences in aircraft type, and to differences in aircraft velocity.

(9) Some airway segments should be selected which use all altitudes of interest. Consideration should be given to Minimum Enroute Altitudes and to Minimum Reception Altitudes, as well as to the actual mix of altitude usage on the particular airway segments. Also airway segments should be selected with various mixes of level, climbing, and descending traffic.

(10) Both unidirectional and bidirectional airway segments should be selected.

(11) Some airway segments should be selected using VOR radials with various levels of conformance to nominal performance (all within applicable tolerances), based on historical flight inspection results. In particular, some segments should be selected which use VOR radials with close to nominal performance and others should be selected which use VOR radials which are barely within legal tolerances.

Flexibility in selecting airway segments to satisfy the above conditions is limited by several data collection considerations. The following factors should be considered in an effort to minimize the cost of data collection:

(1) Only a limited number of different ARTCC's can be included in the study. Data can only be collected at various ARTCC's subject to hardware and manpower limitations. The availability of personnel in the selected ARTCC's to act as observers will impose substantial constraints on the selection of the ARTCC's for the data collection program.

(2) No airway segment which crosses an ARTCC boundary should be selected. Otherwise, it would be necessary to collect data at more than one ARTCC simultaneously.

(3) Airway segments should be selected which use a minimum number of different ARTCC sectors in order to minimize the number of observers required during the data collection.

(4) All selected airway segments must be entirely contained within radar coverage. All airway segments selected in a single ARTCC should be covered by a total of not more than three different radars, so that a single radar data recorder can be used. In particular, all airway segments selected in the Washington ARTCC for the preliminary phases of the data collection program should be covered by the specific radars available at the FAA Technical Center, so that it may not be necessary to install the radar data recorder physically at that ARTCC.

It is currently planned to conduct the initial data collections at the Washington ARTCC and at the Albuquerque ARTCC, for exploratory purposes. These two centers appear to cover a large number of different values for the required state variables for the study. Washington and Albuquerque centers were selected primarily because they were among the most likely to have sufficient personnel to be able to support a data collection. The Washington ARTCC was selected because of the availability of direct radar connections between there and the FAA Technical Center. Selection of the Albuquerque ARTCC provides for data collection on some of the same routes used in the high-altitude study, and this should facilitate direct comparisons between the results of the two studies.

Flight progress strips from the Washington ARTCC have been analyzed, and results of this analysis are included in Appendix B. Information about traffic density and composition from this study will be used to prepare a list of proposed airway segments for the data collection. In addition, a data base curretly under development to contain information on the aircraft structure and on traffic density will be used to refine the design of this study in the future.

6.0 METHODS OF ANALYSIS

The methods of analysis will be very similar to those used in the high-altitude VOR-defined jet route study (reference 11) in order to insure that the data is comparable and in order to take advantage of computer programs already written. However additional analyses will be conducted where they appear useful. Direct comparisons will be made between the results of this study and the results of the high-altitude study wherever possible.

The computer programs used in the high-altitude study are considered adequate for most of the data reduction and analysis, after necessary modifications. These programs will need to be translated for use on a different computer and modified for analysis of different route segments and altitudes. In particular, changes will be required to account for the expected larger number of transponder code changes in the low-altitude environment. Changes to the radar data smoothing routines to improve velocity estimation will also be implemented. It is not expected that these changes will materially affect the ability to compare the results with those from the previous data collection.

The processing scheme for data reduction and analysis is designed to accomplish the following:

(1) to ensure the proper characterization of the navigational performance of each aircraft flying a selected airway segment during the data collection period,

(2) to investigate and explain the circumstances surrounding those aircraft exhibiting large deviations from airway centerline,

(3) to provide summary descriptions of achieved navigational performance, and

(4) to provide for comparisons of navigational performance among different subsamples of this study and between this study and the high-altitude study.

The data flow for position information processing (described in paragraph 6.1 below) is presented in schematic form in Figure 6.1. The continuation of the data reduction and analysis procedures (described in paragraphs 6.2 and 6.3 below) is presented in schematic form in Figure 6.2. This processing is done for one day's data from a single ARTCC at a time.

6.1 DATA REDUCTION

The proper characterization of navigational performance for a particular aircraft requires two things: accurate position measurements for the aircraft's location with respect to the geographical centerline of the airway and assurance that the aircraft is being piloted with the intent to fly that centerline. The processing scheme is designed to satisfy these two requirements, producing a candidate file of flights navigating a given airway segment.

The Radar Data Recorder (RDR) tape is the primary source of position information for this study. It is produced by the FAA Technical Center radar data recorders installed at each ARTCC, and it records secondary radar target reports (ATCRBS data) for up to three radars in real time as they are received from the Common Digitizer. Each secondary radar target report recorded on the RDR tape contains the following information: ATCRBS beacon code, sensor number, range (to one-eighth nautical mile), azimuth (to 1 Azimuth Change Pulse(ACP) = 0.088 degree), mode-C altitude (to 100 feet), and time of return (to one-tenth second). These target messages are intercepted and recorded by the recorder before they enter the NAS mainframe computer, and so require several processing steps designed to emulate NAS processing and produce useful position estimates. The first of these steps is radar registration, i.e., the correction of radar returns for electronic misalignment of the sensors. In the NAS system, this function is performed by Real Time Quality Control (RTQC) of radars (reference 12). Software which emulates the RTQC function is available at the FAA Technical Center. Although RTQC uses data from all radar pairs with overlapping coverage, the stability of the estimated radar biases is poor because of certain compromises made to allow operation in real time. An extension of RTQC yielding more precise estimates of radar biases will be implemented for recorded radars with overlapping coverage. No estimation of bias is possible for a recorded radar whose area of coverage does not overlap the area of coverage of any other recorded radar. In this case, the biases computed by the NAS computer and recorded during the data collection must be used.

In processing the recorder data to obtain location data, filters and smoothers are used to remove outliers and noise in order to ensure that the position information is as accurate as possible. The filtering process is part of the computer program named VORKL1, which decodes the target messages ordered in real time and recorded on the RDR tape into the All Aircraft Target Report File (AATRF), which is ordered by aircraft trace. The data smoother routines are part of the VORKL2 computer program, which collates position information on the AATRF with other data sources. The smoothing routines to be used are tailored to the noise structure of ATCRBS radar data, and they provide robust estimates of aircraft location and velocity. These routines replace the non-linear smoothing algorithms first used in the Central East Pacific Separation Study (reference 13) and modified for use in the CONUS high-altitude study (reference 11). These previous non-linear smoothers were found to provide good estimates of aircraft position but inconsistent estimates of aircraft velocity.

The VORKL2 program also selects those traces which correspond to aircraft flying airway segments of interest to the study. This is accomplished by matching beacon codes supplied by the on-site observer logs, thus assigning aircraft to the airway segments they were actually flying. Then the trace from the best radar for the airway segment under consideration (predetermined for each airway segment by examination of NAS-supplied radar coverage data) is selected as the basis for the aircraft's track. The radar returns (corrected for radar registration) are projected from the rho-theta-altitude coordinate system of each radar to a stereographic plane tangent to the surface of the earth. The nonlinear data smoothers are applied to both the rho-theta and the projected X-Y information to yield a smooth track. The smoothed trace is translated to a preselected base VOR for the airway segment and rotated to align with the airway segment. The resulting track is thus aligned so that the X coordinates of the returns represent the distance from the base VOR for the airway segment under consideration, and the Y coordinate the distance perpendicular to the airway centerline.

The Flight Track History File consists of one record for each aircraft selected as flying an airway segment of interest. This record contains a series of X-Y points detailing position along the airway segment and deviation from the airway geographic centerline and also all information, except written comments, present on the observer forms. A flight's navigational performance on an airway segment of interest is summarized by storing its estimated lateral deviation, crosstrack velocity, and along-track velocity at specific positions (or mileposts) located at five nautical mile intervals from each end of the VOR-defined airway segment to the VOR changeover point. Estimation of cross-track and along-track velocities is accomplished by the application of a least squares quadratic fit to a set of 17 points centered about the milepost and the evaluation of the first derivatives of this curve. Only information for those mileposts contained within the monitored route segment is retained in the flight's navigation summary.

6.2 CANDIDATE SELECTION AND TREATMENT OF SPECIAL CASES

To this point in the data processing, "candidate flights" (aircraft attempting to navigate a VOR-defined airway segment of interest) have been selected only on the basis of the beacon code noted on the on-site observer log. In consonance with the objective of the proper characterization of navigational performance, the aircraft so selected undergo a series of checks to ascertain that they are indeed "candidates" in the above sense of the word. This segment of the data processing scheme serves not only to ensure that those flights which finally enter the candidate file are not exhibiting deviations from airway centerline due to some ATC approved directive, but also to thoroughly investigate and document the circumstances surrounding certain special occurrences (the issuance of an ATC deviation advisory or vector, the generation of a Conflict Alert warning, or the exhibition of a large deviation from route centerline unaccounted for by normal ATC procedures).

Flights receiving deviation advisories are the first flights to be segregated from the data. The issuance of a deviation advisory will have been noted in the on-site observer's log. "Deviation advisory" is here used in a sense which covers a number of different occurrences. The first is the issuance of a vector by ATC for the expressed purpose of correcting a flight's poor navigational performance. The second is the issuance of an advisory by ATC without vectoring the flight, which implies ATC acknowledgment of poor navigational performance. Advisories themselves are segregated into two types: direct and indirect. A direct advisory is one in which the controller makes overt reference to the aircraft's position with respect to airway centerline. An indirect advisory consists of a comment in which the controller does not make specific reference to the aircraft's position with respect to its intended course, but implies that the pilot may be navigating poorly. In recognition of the fact that ATC intervention in the case of poor navigation will have significant impact on the characterization of systemic risk calculation, all available information pertaining to a flight which receives such an advisory is carefully analyzed by an operations research analyst and by an Air Traffic Control Specialist (ATCS). The ATCS examines the available information, especially the voice communication transcription, and ensures that a deviation advisory had indeed been issued and has been categorized correctly. Having passed this scrutiny, the Flight Track History record enters the candidate file, but marked as a flight having received a deviation advisory. If an aircraft were vectored off of the route for traffic management purposes, then the flight track would not enter the candidate file and the flight would no longer be considered for evaluation.

The next flights to receive special attention are those exhibiting a deviation outside protected airspace for the airway. As in the case of deviation advisories, these flights are carefully analyzed. The analyst inspects the aircraft track to ensure that the large value for the deviation is not the result of an error in position data processing, and then the ATCS relies on his operational experience to ascertain that the large deviation from airway centerline has not occurred as a result of some standard operating procedure in the ATC control loop in general, or in that particular ARTCC. Circumstances which would indicate that the large deviation recorded was not a result of poor navigation would include ATC vectors for weather or traffic or direct clears to some point other than the endpoint VOR of the route segment. Detection of circumstances such as these would result in the flight being excluded from the candidate file. If no exculpatory circumstances are noted, the ATCS examines the voice communications transcript to determine if a deviation advisory had been issued. This is a backup designed to detect those deviation advisories which were not recorded by the on-site observer. If a deviation advisory is discovered, the Flight History record for this aircraft is so marked, and included in the deviation advisory section of the candidate file. If no deviation advisory was issued, the flight is certified to be a "large error", so marked, and included in the large error section of the candidate file.

A third class of flights to be examined is based on the magnitude of the cross-track velocity. If this quantity exceeds 150 knots at any point along the airway segment, the flight is selected from the candidate file for further examination. If the flight has not already been examined in detail as a flight receiving a deviation advisory or as a flight with a deviation outside protected airspace, the analyst plots the aircraft's trace for examination and then examines the plot for the cause of a large lateral velocity. If poor position data processing is evident, the flight is rejected. The shape of the trace may show the cause of a large lateral velocity to be within the bounds of normal procedures, in which case the flight is returned to the candidate file. The most common occurrence of this type of behavior arises when an aircraft makes a poor turn onto a new airway segment, overshoots the airway (hence the large lateral velocity), and corrects the course after completion of the turn. If the analyst believes that the aircraft's trace exhibits "suspicious" behavior (i.e., that the trace indicates the issuance of a deviation advisory), the voice communications pertaining to that flight are transcribed, and an ATCS determines if any deviation advisories were issued or if some action was taken (with the controller's cognizance) which could invalidate the flight as a bona fide VOR-to-VOR navigator. In the first instance the Flight History Record is placed into the candidate file marked as a deviation advisory; in the second instance the flight is rejected for inclusion into the candidate file.

Records will be retained in a separate file for all flights rejected for inclusion into the candidate file. Although data from these flights will not be used for describing achieved navigational performance, this data is essential for describing occupancy on the routes of interest.

6.3 SUMMARY DATA AND ANALYSIS

Various statistics and summary tables will be generated for the purpose of describing the achieved navigation performance exhibited by the flights recorded in the candidate file for each ARTCC. Statistics are computed from a histogram-generation computer program, which is run first on daily ARTCC data (the Flight Track History records of the candidate file for each ARTCC). The histograms generated from the daily data are then combined to provide a basis for summmary descriptions of each ARTCC.

The histogram program produces the following outputs from an ARTCC's candidate file: histograms of lateral deviation (distance from airway centerline), histograms of along-track speed (the component of velocity parallel to the airway centerline), and a bivariate histogram of lateral deviation and lateral velocity (the component of velocity perpendicular to the airway centerline). Histograms of lateral deviations are generated for each airway segment and each five nautical mile milepost within the area of interest. This segment of the histogram program also computes the sample size, mean, standard deviation, skewness, and standardized kurtosis of the signed lateral deviations recorded in the histogram. The lateral deviation histograms are also collapsed over all mileposts for a particular half route segment (i.e., data for every milepost from the VOR to the VOR changeover point is entered into one histogram), combined for each milepost over all half route segments, and combined for the ARTCC as a whole.

The second portion of the program produces a histogram of along-track speeds for each airway segment. The entries are the absolute values of each aircraft's average along-track velocities computed from the first and last points recorded on that particular airway segment. Sample size, mean, standard deviation, skewness, and standardized kurtosis are computed. The final output of this program is a bivariate histogram of lateral velocity and lateral deviation. These histograms are produced for each milepost of all half-route segments, for each milepost combined over all half-route segments, and for the combination of all mileposts and all route segments.

The Navigation Performance Summary is a table designed to characterize the achieved navigational performance of a group of flights within the candidate file. The tables are generated from the appropriate histogram of all candidate flights at an ARTCC using a particular half-route segment, and for all ARTCC flights in the aggregate. Entries are presented for each milepost on the half-route segment so that effects dependent on distance from the VOR may be easily noted. The statistics presented on the Navigation Performance Summary Form address several aspects of the data for each milepost. The first is the shape of the distribution of lateral deviations recorded at the milepost in question. The sample size, mean, standard deviation, skewness, kurtosis, and midpoints of the modal and median cells are presented as the pertinent statistics. The lateral (cross-course) velocities are represented by the sample mean and standard deviation; the range of the deviations recorded for that milepost is shown by exhibition of the largest deviation on each side of the airway centerline. To produce the 95 percent core sample, 2.5 percent of the data is trimmed from the extreme values of lateral deviation on each side of the airway centerline. The mean of this core data is computed and displayed, as are the extreme values of this 95 percent core sample on each side of the airway centerline. Plots of this data are also displayed.

In addition to the above methods of analysis, used in the high-altitude VOR-defined jet route study, some additional methods of analysis will be used for this study. The Statistical Package for the Social Sciences (SPSS) computer program (references 14 and 15) will be used to calculate various descriptive and comparative statistics for the various subsamples of the data base. Comparisons will also be made with the results of the high-altitude study.

Statistics on all flights, including flights rejected for inclusion into the candidate file, will be analyzed to estimate occupancy on all selected routes.

Occupancy on each route will be analyzed on a time-dependent basis for each identified subpopulation of aircraft. Time-dependent distributions of aircraft interarrival times and of aircraft velocities will be derived from the data for use in modeling occupancy.

7.0 SAMPLE SIZE CONSIDERATIONS

Under the assumption that the same level of description is required for the low-altitude environment as was deemed necessary for the high-altitude environment, this study will require a sample size at least as large as that used in the VOR-defined jet route study; that is, data collection on approximately 15,000 flights in order to achieve a sample of 10,000 flights.

For the follwing two reasons, it is possible that more data will be required than in the high-altitude study:

(1) The low-altitude environment is expected to be much less homogeneous than the high-altitude environment. This will result in more distinct subsamples which will need to be evaluated separately.

(2) There are expected to be more deviations for non-navigational reasons in the low-altitude environment than were observed in the jet route structure.

Thus the same final sample size would require a larger data collection effort in order to allow for the potential of a larger number of flights being excluded from the study.

Differences in navigational performance can be expected in the low-altitude environment for different user types, for different aircraft types, and for different altitude levels. It is not possible to determine a priori which of these differences will significantly affect the distributions of lateral deviation. It is expected that there will be significantly greater differences in aircraft types in the low-altitude environment than in the high-altitude environment. In addition, it is likely that completely different aircraft and pilot populations will be found in the lower altitudes of the low-altitude environment than in the higher altitudes of the low-altitude environment; this would contrast with a relative homogeneity over different flight levels in the high-altitude environment. The possible differences and mixes of avionics components, aircraft performance, and pilot experience will range over a wider region than in previous studies; and the resulting profile by strata will be analyzed.

The above reasons are countered to some extent by the following differences between the low-altitude and high-altitude environments which could lead to a smaller required sample size.

(1) The generally slower velocities encountered in the low-altitude environment may give the pilot more time to discover and correct a deviation before it becomes large.

(2) The slower velocities may make it possible to analyze data at mileposts located closer together while retaining the same level of independence. This would make possible a larger statistical sample size with the same number of distinct flights.

If the study objective were restricted to a broad comparison with the results from the high-altitude study, a much smaller sample size would be adequate. However the study would then provide only general comparisons with the high-altitude study; it would not provide enough data for stable estimates of low-altitude population parameters, and it might not be useful for descriptive results.

The required sample size will be continually evaluated during the study based on analysis of available data. Analysis of data from the first ARTCC should be sufficient to establish a specific required sample size. For example, if analysis of early data were to show no significant differences among various subsamples, a smaller sample size would be adequate. On the other hand, if each subsample must be treated as representing a separate and different population, a larger sample size would be required.

8.0 SCHEDULE FOR DATA COLLECTION AND ANALYSIS

In order to minimize the cost of data collection and to obtain data in an incremental fashion as resources are augmented, the study will consist of a series of steps which will be completed sequentially. Major findings resulting from the data collection and analysis will be documented as they become available. Certain initial steps have been completed in the sequence of events necessary to finalize a data base for the study of spacing criteria applicable to the Federal Airways structure. The following phases constitute the proposed serial progression of efforts which, when completed, will result in the desired data base:

(1) All flight progress strips for a one-week period have been obtained from the New York ARTCC. These have been analyzed to evaluate the density and mix of traffic on some selected airway segments, and this analysis has been used in the preparation of this plan. A report on the results of this analysis is given in Appendix A. It was originally planned to use these airway segments for the initial data collection, but the projected unavailability of personnel support in the New York ARTCC has forced these plans to be changed.

(2) All flight progress strips for a one-week period have also been obtained from the Washington ARTCC. These have been analyzed to evaluate the density and mix of traffic over some selected navigational facilities, and this analysis has also been used in the preparation of this plan. A report on this analysis is given in Appendix B.

(3) A small test data collection will be conducted for a few airway segments in the Washington ARTCC in order to verify data collection and reduction procedures. Specific airway segments will be selected based upon the

preliminary analysis of flight progress strips. This data collection should last approximately three months after all data collection and data reduction procedures are determined. All phases of the data collection and evaluation task will be covered, but real-time observers will not be used. This test data collection will be used to refine the plan and procedures as necessary.

(4) Once the procedures have been refined, data collection with observers can commence. The initial data collection is planned for the Washington ARTCC. This data collection will use ATCRBS reports from NAS radars, some of which transmit information both to the FAA Technical Center and to the Washington ARTCC and some of which transmit data only to the Washington ARTCC. Data reduction and analysis will commence as soon as data have been collected. Figure 2 is the time-line schedule and serves as a model for data collection at an ARTCC with the use of observers. The modification of analytical tools will have already been accomplished for the Washington ARTCC, but it will be required at each additional Center. While there exists an estimate of the duration of the data collection event, it will actually last as long as is necessary in order to accumulate sufficient samples. It should be emphasized that sufficient sample size is the object of the data collection -- not necessarily an epoch in time. These schedules will remain extremely tentative until commitments are obtained for the availability of personnel and funding.

(5) Data collection will be conducted at additional ARTCC's either in parallel or in series depending upon the level of funding and other resources allotted. In any case, data from multiple ARTCC's are required for proper execution of the plan. The Albuquerque ARTCC has been proposed as a possible candidate for this phase of the data collection to encompass the state variables not adequately covered by the Washington ARTCC. This data collection will also follow the time-line schedule given in Figure 2. Once again an approximation to the duration of the data collection is shown; it must be emphasized that the effort will be complete only when major design objectives have been satisfied and that the length of the data collection will vary according to variables specific to each Center.

(6) It is not possible to determine whether a third ARTCC will be necessary to cover all of the desired state variables until after some preliminary analysis of the data collected at the first two centers. This analysis will be necessary to determine if a sufficient amount of data for estimation purposes has been obtained for each discrete value of each of the state variables.

9.0 RESOURCE REQUIREMENTS

There are some fixed support requirements which are independent of the size of the study. Additional requirements vary with the amount of data collected and with the number of days of data collection (which is dependent both on the required sample size and on the traffic density on the selected airway segments). Table 1 is a schedule of equipment and services necessary for the implementation of the data collection plan. Costs are based upon similar events previously conducted in the jet route environment, and they do not include payroll costs borne by FAA parent organizations. The required

SCHEDULE STATUS

Figure 2. ARTCC Data Collection Time-Line Schedule
PROGRAM ________________________

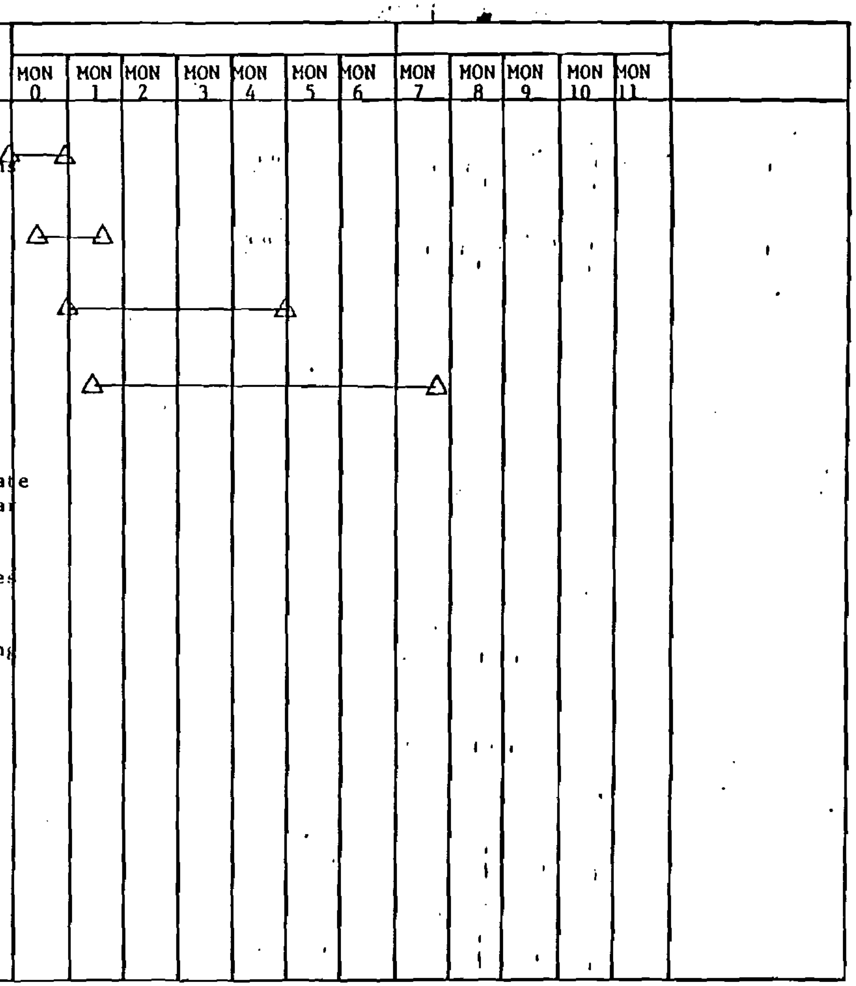
EVENTS/ACTIVITIES

Coordination of Facility and Data Collection Means

Modification of Analytical Tools

Collection of Data (with observers) *

Data Reduction and Analysis @*



* the duration of this event is approximate and based upon the duration of a similar data collection in the jet route environment. the data collection will be complete when major design objectives have been satisfied.

@ there is a fifteen day statutory waiting period until some of the required data may be released.

LEGEND

△ SCHEDULED EVENT
▲ COMPLETED ON SCHEDULE
▽ SLIPPAGE (PROJECTED)
▼ LATE COMPLETION (ACTUAL DATE)

Next Major Milestone Outside 12-Month Window
(Should be last event/activity listed)

TIME NOW

FIGURE 2. ARTCC DATA COLLECTION TIME-LINE SCHEDULE

equipment, contract, and travel funds will need to be provided prior to the beginning of the data collection. Details about these items will be developed in the actual data collection plan rather than this specification of that plan.

Table 1
REQUIRED EQUIPMENT AND SERVICES

Contract services (data reduction)	$150,000
Purchase of new equipment (152-channel voice recorder)	$100,000
Modification of radar data recorders	$ 10,000
Flight inspection	$ 70,000
Travel (FAA Technical Center personnel)	$ 35,000

Note: Cost estimates are in 1983 dollars.

9.1 FAA TECHNICAL CENTER PERSONNEL

If the data is collected at only one ARTCC at a time, the following FAA Techical Center personnel will be required:

(1) Air Traffic Control Specialists: 2 full-time.

(2) Operations Research Analysts: 2 full-time and 1 half-time.

(3) Computer Programmer: 1 full-time (co-operative education student, if available).

(4) Electronic Technician: 1 half-time

(5) Statistical Assistants: 2 full-time.

If data is collected at more than one ARTCC at the same time, the following additional FAA Technical Center personnel will be required for each additional ARTCC:

(1) Air Traffic Control Specialist: 1 full-time.

(2) Operations Research Analyst: 1 full-time.

(3) Statistical Assistants: 1 full-time.

The above personnel requirements are the minimum required for an efficient study to be conducted. If more personnel are available, the length of time required for data reduction and analysis can be reduced.

9.2 TRAVEL COSTS

It will be necessary for this study to fund travel costs for FAA Technical Center personnel.

9.3 CONTRACT SERVICES

It will be necessary to use contract personnel for much of the data reduction. It is estimated that from four to six people will be needed for more than one year. These people need to be experienced in reading, interpreting, and recording data from FAA flight progress strips and in using time-share computer terminals for direct data entry. They are required to be familiar with both written and spoken air traffic control terminology. Experience is also required with interactive graphics devices used for the display of radar position information. These personnel are also required to have an extensive in-depth knowledge of ATC voice recordings and their transcription to permanent records.

If sufficient ARTCC personnel are not available to act as observers, it will be necessary to use contract personnel for real-time observations. The numbers and qualifications of these observers will be the same whether government or contract personnel are used (see paragraph 9.4).

9.4 ARTCC PERSONNEL

Observers will need to be furnished by the Air Traffic Service through the support of operating organizations. One observer will be required for each data collection sector whenever data is being collected. Each observer should be either an air traffic control specialist or a specially trained flight data specialist. Each observer will also be required to undergo training prior to the data collection. This training will be administered by a FAA Technical Center air traffic control specialist.

If the individual sector observers are not area-rated air traffic control specialists, it will be necessary to have one area-rated air traffic control specialist to serve as a real-time observer supervisor for each data collection area. The number of sector observers per area supervisor will have to be determined separately in each center based upon the characteristics of the center organization and the training of the observers.

Each ARTCC will also need to furnish one person (half-time) to coordinate its data collection effort.

9.5 RADAR DATA RECORDERS

One radar data recorder will be required at each ARTCC during data collection. The FAA Technical Center can supply two of these recorders (used in the jet route data collection) without a major procurement effort. In addition, enough magnetic tapes will be required to record all data to be collected.

9.6 COMPUTER PROCESSING

A substantial amount of computer processing will be required at the FAA Technical Center. Initial data reduction is estimated to require approximately four hours of computer time for each day of data collection at each ARTCC, and subsequent data reduction and analysis will require additional computer time. Since the data reduction for the high-altitude study used a different computer system, exact computer usage requirements are not available. The current Honeywell general purpose computer system should have adequate resources. These requirements will need advance coordination within the FAA Technical Center to assure scheduling of adequate computer resources.

Data analysis will require the continued availability of the Statistical Package for the Social Sciences (SPSS) computer program currently on the general purpose computer system.

9.7 VOICE RECORDER

One 152-channel voice recorder is needed at the FAA Technical Center for playback of ARTCC voice recordings. In addition, enough recording tapes will be required to replace those tapes taken from the ARTCC's.

9.8 FLIGHT INSPECTION

Each VOR radial defining an airway segment used in the study should be flight inspected one time in each direction sometime during the study. It should be possible to obtain most of these flight inspections during routine surveillance or normal en route time at little or no cost. However special flight inspections will be required wherever this is not feasible. These requirements will need to be coordinated with the Aviation Standards National Field Office.

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APPENDIX A

REPORT OF STUDY OF NEW YORK ARTCC FLIGHT PROGRESS STRIPS

As the first step in the investigation of the low-altitude environment, a study was conducted of flight progress strips for some airway segments of possible interest. All flight progress strips for the week of February 1 through February 7, 1981, were obtained from the New York Air Route Traffic Control Center (ARTCC) after the fifteen-day mandatory retention period had expired. Information was taken from the flight progress strips for a selected group of airway segments, and this information was analyzed using the SPSS computer program (references 14 and 15).

This flight progress strip study was designed to obtain data on the density and mix of aircraft on selected airway segments. The information on aircraft density and mix will be used in the selection of airway segments for the main data collection, and the information on density will also be used to estimate the amount of data which can be collected on each day of data collection.

The following airway segments were included in this analysis of flight progress strips:

(1) V433 and V433E between New Castle VORTAC (EWT) and Yardley VORTAC (ARD), V123-213 between Woodstown VORTAC (OOD) and Robbinsville VORTAC (RBV), and V157 between New Castle VORTAC (EWT) and Robbinsville VORTAC (RBV): These parallel airways are the primary northbound approaches into the New York area. They are the preferred low-altitude routes from Baltimore, Washington, and Dulles to LaGuardia, Newark, and Westchester County. These airways are used by the Standard Terminal Arrivals Proud One (V123-213 and V157) and Harry One (V433) into the New York area.

(2) V3 between Modena VORTAC (MXE) and Solberg VORTAC (SBJ): This is a unidirectional southbound airway. It is the preferred low-altitude route from LaGuardia, Newark, and Westchester County to Baltimore and Washington.

(3) V139-308 between Sea Isle VORTAC (SIE) and Hampton VORTAC (HTO): This airway segment is one of the longest low-altitude airway segments available; it has a total length of 159 nautical miles from VORTAC to VORTAC (with distances of 76 nautical miles and 83 nautical miles from the VORTAC's to the changeover point). This airway is located over water along the east coast, and it is a major bidirectional north-south airway. Although there is only a small en route turn at the changeover point, there is a large amount of turning traffic entering and leaving the airway within this segment. This airway is located adjacent to Warning Areas W-106B and W-107A, and New York ARTCC personnel have a significant problem with aircraft deviating from this airway into the Warning Areas (reference 16).

(4) V232 between Milton VORTAC (MIP) and Broadway VOR/DME (BWZ): This airway is the preferred low-altitude route from Pittsburgh to LaGuardia and Kennedy. It is primarily used, however, by eastbound aircraft descending from high-altitude routes for an approach to the New York area.

(5) V6-30 between Philipsburg VORTAC (PSB) and Selinsgrove VORTAC (SEG), V6 between Selinsgrove VORTAC (SEG) and Allentown VORTAC (ABE), and V30 between Selinsgrove VORTAC (SEG) and East Texas VORTAC (ETX): This airway pair carries low-altitude bidirectional traffic. V30 is the preferred low-altitude route from LaGuardia and Newark to Pittsburgh.

Flight progress strips were analyzed for flights which included any part of the selected low-altitude airway segments. The total number of flights on each airway segment for each day of the data collection is given in Table A-1.

Table A-1
NUMBER OF FLIGHTS PER DAY OF DATA COLLECTION
(February 1 - 7, 1981)

Airway	Segment	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Total
V433	EWT-ARD	72	133	122	138	132	130	79	806
V433E	EWT-ARD	0	0	0	1	0	1	1	3
V123-213	OOD-RBV	74	103	96	102	99	100	75	649
V157	EWT-RBV	45	46	57	58	59	59	48	372
V3	MXE-SBJ	22	70	56	63	63	67	20	361
V139-308	SIE-HTO	46	64	57	57	47	76	39	386
V232	MIP-BWZ	62	113	135	129	189	75	64	767
V6	PSB-ABE	6	9	14	15	21	9	8	82
V30	PSB-ETX	7	5	8	20	18	5	1	64
Totals		334	543	545	583	628	522	335	3490

This study includes, in addition to flights within the low-altitude environment, flights climbing from and descending into the low-altitude environment. A breakdown of flights by maximum altitude is given in Table A-2. The maximum altitudes are grouped into the following three classes: (1) Low (up to but not including 18,000 feet MSL), (2) Medium (FL 180 up to but not including FL 240), and (3) High (FL 240 and above). It should be noted that these maximum altitudes are not always completely accurate for the selected airway segment; in some cases, this maximum represents an altitude achieved either before or after the selected segment. Note that only flights with a minimum altitude below 18,000 feet MSL are included in this study.

Table A-2
NUMBER OF FLIGHTS BY MAXIMUM ALTITUDE

Airway	Segment	Low	Medium	High	Total
V433	EWT-ARD	163	92	551	806
V433E	EWT-ARD	3	0	0	3
V123-213	OOD-RBV	46	270	333	649
V157	EWT-RBV	7	16	349	372
V3	MXE-SBJ	315	46	0	361
V139-308	SIE-HTO	216	54	116	386
V232	MIP-BWZ	95	6	666	767
V6	PSB-ABE	35	8	39	82
V30	PSB-ETX	35	20	9	64
Totals		915	512	2063	3490

This study included unidirectional and bidirectional north-south and east-west airways. A breakdown of the number of flights by direction of flight is given in Table A-3.

Table A-3
NUMBER OF FLIGHTS BY DIRECTION OF FLIGHT

Airway	Segment	North	South	Total
V433	EWT-ARD	806	0	806
V433E	EWT-ARD	3	0	3
V123-213	OOD-RBV	649	0	649
V157	EWT-RBV	372	0	372
V3	MXE-SBJ	2	359	361
V139-308	SIE-HTO	112	274	386

Airway	Segment	East	West	Total
V232	MIP-BWZ	707	60	767
V6	PSB-ABE	74	8	82
V30	PSB-ETX	6	58	64

All of the flights on V433, V433E, and V157 flew the entire selected airway segment. All flights except one on V123-213 flew the entire selected airway segment; that one northbound flight entered the segment at Cobus intersection.

There were 58 flights out of a total of 361 on V3 which did not fly the entire selected airway segment; 57 southbound flights left the segment at Mazie intersection and one southbound flight entered the segment at Mazie intersection.

Only 28 of the 386 flights on V139-308 flew the entire selected airway segment between SIE and HTO. The distribution of segment entry and exit points, along with the distances flown on the selected airway segment, is given in Table A-4. The mean distance flown on the selected airway segment was 87.88 nautical miles, and the median distance was 88 nautical miles.

Table A-4
NUMBER OF FLIGHTS BY SEGMENT ENTRY AND EXIT
(V139-308 between SIE and HTO)

Entry	Exit	Direction	Distance	Number
SIE	Sardi	North	127 nm	10
SIE	HTO	North	159 nm	10
Avalo	Sardi	North	109 nm	10
Avalo	HTO	North	141 nm	8
Brigs	Drift	North	29 nm	1
Brigs	Manta	North	37 nm	1
Brigs	Sardi	North	88 nm	6
Brigs	HTO	North	120 nm	10
VCN101	Sardi	North	86 nm	2
VCN101	HTO	North	118 nm	3
Harbo	SIE	South	48 nm	1
Harbo	Sardi	North	79 nm	7
Harbo	HTO	North	111 nm	9
Drift	Sardi	North	59 nm	3
Drift	HTO	North	91 nm	1
Manta	Avalo	South	58 nm	3
Manta	Drift	South	8 nm	1
Manta	JFK142	North	27 mm	4
Manta	Sardi	North	51 nm	6
Manta	HTO	North	83 nm	15
Plume	SIE	South	94 nm	3
Plume	Drift	South	26 nm	2
Plume	Sardi	North	33 nm	1
Plume	HTO	North	65 nm	3
Sardi	SIE	South	127 nm	8
Sardi	Avalo	South	109 nm	16
Sardi	Harbo	South	79 nm	4
Sardi	Drift	South	59 nm	125
Sardi	Manta	South	51 nm	3

Table A-4 (Continued)
NUMBER OF FLIGHTS BY SEGMENT ENTRY AND EXIT
(V139-308 between SIE and HTO)

Entry	Exit	Direction	Distance	Number
Sardi	HTO	North	32 nm	2
HTO	SIE	South	159 nm	18
HTO	Avalo	South	141 nm	10
HTO	Brigs	South	120 nm	4
HTO	Drift	South	91 nm	72
HTO	Manta	South	83 nm	3
HTO	Sardi	South	32 nm	1

There were 669 out of a total of 767 flights on V232 which flew the entire selected airway segment between MIP and BWZ. The distribution of segment entry and exit points, along with the distances flown on the selected airway segment, is given in Table A-5. The mean distance flown on the selected airway segment was 81.32 nautical miles, and the median distance was 85 nautical miles.

Table A-5
NUMBER OF FLIGHTS BY SEGMENT ENTRY AND EXIT
(V232 between MIP and BWZ)

Entry	Exit	Direction	Distance	Number
MIP	Frebe	East	37 nm	1
MIP	BWZ	East	85 nm	649
V106	BWZ	East	68 nm	9
V164	BWZ	East	63 nm	41
Frebe	BWZ	East	48 nm	4
V29-147	BWZ	East	40 nm	1
Beers	MIP	West	55 nm	1
Beers	V106	West	38 nm	2
Beers	Frebe	West	18 nm	2
V162	Frebe	West	26 nm	1
V162	BWZ	East	22 nm	1
ABE069	BWZ	East	18 nm	1
BWZ	MIP	West	85 nm	20
BWZ	V106	West	68 nm	9
BWZ	V164	West	63 nm	8

Table A-5 (Continued)
NUMBER OF FLIGHTS BY SEGMENT ENTRY AND EXIT
(V232 between MIP and BWZ)

Entry	Exit	Direction	Distance	Number
BWZ	Frebe	West	48 nm	12
BWZ	Beers	West	30 nm	1
BWZ	V162	West	22 nm	4

Only 9 of the 82 flights on V6 flew both of the selected airway segments between PSB and ABE, and 38 of the 64 flights on V30 flew both of the selected airway segments between PSB and ETX. There were 4 flights on V6 and 3 flights on V30 which flew the segment between PSB and SEG only, 69 flights on V6 which flew the segment between SEG and ABE only (including 27 flights entering and 4 flights exiting at the Snowy intersection), and 23 flights on V30 which flew the segment between SEG and ETX only.

The user identifications from the flight progress strips were used to classify the flights into distinct user classes. The seven user classes used were (1) air carrier airlines, (2) commuter airlines, (3) air taxi (4) general aviation (N-number), (5) military, (6) foreign, and (7) other (for example, FAA flight inspection and other civilian US Government aircraft). A breakdown of user class by airway segment is given in Table A-6.

Table A-6
NUMBER OF FLIGHTS BY USER TYPE

Airway	Segment	Air Carr	Commuter	Air Taxi	Gen Avn	Military	Foreign	Other	Total
V433	EWT-ARD	444	70	24	255	8	5	0	806
V433E	EWT-ARD	0	1	0	2	0	0	0	3
V123-213	OOD-RBV	516	69	2	57	2	3	0	649
V157	EWT-RBV	342	0	0	30	0	0	0	372
V3	MXE-SBJ	84	106	11	151	9	0	0	361
V139-308	SIE-HTO	155	65	10	102	40	10	4	386
V232	MIP-BWZ	585	35	14	129	1	3	0	767
V6	PSB-ABE	44	5	7	26	0	0	0	82
V30	PSB-ETX	23	0	0	39	2	0	0	64
Totals		2193	351	68	791	62	21	4	3490

Aircraft types were classified into the aircraft categories that are programmed into the National Airspace System (NAS) Enroute Stage A system (reference 17). The eight categories are (1) single-engine piston, (2) multi-engine piston, (3) single-engine turboprop, (4) multi-engine turboprop, (5) civilian turbojet, (6) military fighter type turbojet, (7) military cargo/bomber type turbojet, and (8) special performance turbojet. A breakdown of these aircraft categories by airway segment is given in Table A-7.

Table A-7
NUMBER OF FLIGHTS BY AIRCRAFT CATEGORY

Airway	Segment	Single Engine Piston	Multi-Engine Piston	Single Engine Turbo	Multi-Engine Turbo	Civ Jet	Mil Cargo/ Bomber	Spec Perf	Total
V433	EWT-ARD	7	31	2	95	559	20	92	806
V433E	EWT-ARD	1	0	0	2	0	0	0	3
V123-213	OOD-RBV	0	2	1	19	563	39	25	649
V157	EWT-RBV	0	3	0	9	350	1	9	372
V3	MXE-SBJ	10	61	1	121	132	0	36	361
V139-308	SIE-HTO	10	69	2	111	175	11	8	386
V232	MIP-BWZ	24	44	1	30	652	0	16	767
V6	PSB-ABE	8	12	1	10	51	0	0	82
V30	PSB-ETX	4	17	1	13	27	0	2	64
Totals		64	239	9	410	2509	71	188	3490

Aircraft types were also classified into weight classes representing maximum takeoff weights (reference 17). The three weight classes are small (12,500 pounds or less), large (more than 12,500 pounds but less than 300,000 pounds), and heavy (300,000 pounds or more). The number of aircraft in each weight class is given by airway segment in Table A-8.

On these selected airway segments, the two most common aircraft types (Boeing Model 727 and McDonnell-Douglas DC-9) accounted for over one half of the 3490 flights recorded and the seven most common aircraft types accounted for over two thirds. The seven most common aircraft types recorded on these airway segments were Boeing Model 727 (B727), McDonnell-Douglas DC-9 (DC9), Boeing Model 737 (B737), Nord Super Broussard (ND26), Lockheed Tri-Star (L101), British Aircraft BAC 11 (BA11), and Piper Navajo (PA31). The distribution of the seven most common aircraft types recorded is given in Table A-9.

Table A-8
NUMBER OF FLIGHTS BY WEIGHT CLASS

Airway	Segment	Small	Large	Heavy	Total
V433	EWT-ARD	90	604	112	806
V433E	EWT-ARD	2	1	0	3
V123-213	OOD-RBV	18	574	57	649
V157	EWT-RBV	13	348	11	372
V3	MXE-SBJ	122	239	0	361
V139-308	SIE-HTO	126	229	31	386
V232	MIP-BWZ	96	654	17	767
V6	PSB-ABE	22	60	0	82
V30	PSB-ETX	32	32	0	64
Totals		521	2741	228	3490

Table A-9
NUMBER OF FLIGHTS BY AIRCRAFT TYPE
(Seven Most Common Aircraft Types)

Airway	Segment	B727	B737	BA11	DC9	L101	ND26	PA31
V433	EWT-ARD	254	54	2	28	38	39	15
V433E	EWT-ARD	0	0	0	0	0	0	0
V123-213	OOD-RBV	343	45	8	132	17	0	1
V157	EWT-RBV	247	37	0	47	10	0	0
V3	MXE-SBJ	63	1	10	14	0	49	30
V139-308	SIE-HTO	62	0	17	59	7	19	15
V232	MIP-BWZ	436	24	27	108	17	0	4
V6	PSB-ABE	20	0	6	22	0	5	1
V30	PSB-ETX	6	0	3	14	0	0	4
Totals		1431	161	73	424	89	112	70

The navigational equipment codes filed by the pilots are broken down by type of navigational equipment in Table A-10.

Table A-10

NUMBER OF FLIGHTS BY FILED NAVIGATIONAL EQUIPMENT CODE

Airway	Segment	RNAV	VOR/ DME	VOR Only	TACAN Only	Total
V433	EWT-ARD	269	534	3	0	806
V433E	EWT-ARD	0	2	1	0	3
V123-213	OOD-RBV	112	537	0	0	649
V157	EWT-RBV	36	335	1	0	372
V3	MXE-SBJ	92	262	7	0	361
V139-308	SIE-HTO	41	327	15	3	386
V232	MIP-BWZ	60	703	4	0	767
V6	PSB-ABE	9	71	2	0	82
V30	PSB-ETX	15	48	1	0	64
Totals		634	2819	34	3	3490

The filed navigational equipment codes are also used to determine the type of transponder used by the aircraft. All of the aircraft in the study had codes indicating that they were using 4096-code transponders. The distribution of aircraft with and without Mode C altitude reporting capability is given in Table A-11.

Table A-11

NUMBER OF FLIGHTS BY FILED TRANSPONDER CODE

Airway	Segment	Transponder with Mode C	Transponder without Mode C	Total
V433	EWT-ARD	803	3	806
V433E	EWT-ARD	2	1	3
V123-213	OOD-RBV	649	0	649
V157	EWT-RBV	371	1	372
V3	MXE-SBJ	355	6	361
V139-308	SIE-HTO	372	14	386
V232	MIP-BWZ	760	7	767
V6	PSB-ABE	80	2	82
V30	PSB-ETX	64	0	64
Totals		3456	34	3490

APPENDIX B

REPORT OF STUDY OF WASHINGTON ARTCC FLIGHT PROGRESS STRIPS

An additional study of flight progress strips was conducted to collect data after the air traffic controller strike and the initial rebuilding program. All flight progress strips for the week of March 16 through March 22, 1982, were obtained from the Washington Air Route Traffic Control Center (ARTCC) after the fifteen-day mandatory retention period had expired. Information was taken from the flight progress strips for a selected group of airway fixes, and this information was analyzed using the SPSS computer program (references 14 and 15).

This flight progress strip study was designed to obtain data on the density and mix of aircraft at selected airway fixes and on selected airway segments. The information on aircraft density and mix will be used in the selection of airway segments for the main data collection, and the information on density will also be used to estimate the amount of data which can be collected on each day of data collection.

Flight progress strips were analyzed if they included any of ten selected VORTAC facilities as the Current Fix on the flight progress strip. This should include all IFR flights on airways and jet routes overflying these facilities. A list of these ten VORTAC facilities, along with the low-altitude airways and high-altitude jet routes overflying these facilities, is given in table B-1.

Table B-1
VORTAC FACILITIES USED BY THE DATA COLLECTION

VORTAC	Name and Location	Airways (Low) and Jet Routes (High)
CVI	Cofield VORTAC Cofield, NC	Low: V1, V194, V260 High: None
EKN	Elkins VORTAC Elkins, WV	Low: V4, V37, V38, V103, V174, V286, V469 High: None
FAK	Flat Rock VORTAC Flat Rock, VA	Low: V3, V16, V155, V223, V260, V290 High: J55
GVE	Gordonsville VORTAC Gordonsville, VA	Low: V3, V38, V39, V373, V375 High: J22, J37, J75, J77, J109, J147, J150
ISO	Kinston VORTAC Kinston, NC	Low: V1, V45, V157, V472 High: None

Table B-1 (Continued)
VORTAC FACILITIES USED BY THE DATA COLLECTION

VORTAC	Name and Location	Airways (Low) and Jet Routes (High)
LYH	Lynchburg VORTAC	Low: V16, V143, V222, V260, V469
	Lynchburg, VA	High: None
RDU	Raleigh-Durham VORTAC	Low: V3, V45, V66, V136, V155, V194, V310
	Raleigh/Durham, NC	High: J51, J52, J55
RIC	Richmond VORTAC	Low: V16, V20, V38, V157, V260, V376
	Richmond, VA	High: J14, J24, J40, J52, J165
SBV	South Boston VORTAC	Low: V20, V39, V136, V266
	South Boston, VA	High: None
TYI	Tar River VORTAC	Low: V157, V189, V194, V213, V310
	Rocky Mount, NC	High: None

The total number of flights overflying each VORTAC facility for each day of the data collection is given in table B-2. It should be noted that this includes flights at all altitudes. The number of low-altitude flights (up to but not including 18,000 feet above mean sea level) overflying each VORTAC facility for each day of the data collection is given in table B-3.

Table B-2
NUMBER OF FLIGHTS PER DAY OF DATA COLLECTION
(March 16 - 22, 1982)

Date	Day	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
16	Tue	96	50	110	416	30	62	76	457	74	33	1404
17	Wed	118	77	104	335	9	42	173	420	85	66	1429
18	Thu	122	81	127	422	40	70	211	526	89	37	1725
19	Fri	127	82	106	451	52	27	210	341	81	65	1542
20	Sat	86	35	86	337	39	37	168	422	28	21	1259
21	Sun	110	44	80	383	46	22	176	288	49	31	1229
22	Mon	91	52	108	317	37	57	188	453	64	32	1399
Total		750	421	721	2661	253	317	1202	2907	470	285	9987

Table B-3
NUMBER OF FLIGHTS PER DAY OF DATA COLLECTION
(March 16 - 22, 1982)
(Low Altitude Only)

Date	Day	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
16	Tue	56	27	22	44	21	35	37	31	43	21	337
17	Wed	62	57	18	73	7	33	57	44	57	47	455
18	Thu	67	57	20	63	24	49	25	49	64	25	443
19	Fri	72	62	15	76	39	19	26	37	54	51	451
20	Sat	53	28	9	26	30	24	4	24	10	15	223
21	Sun	66	30	12	43	33	14	21	36	27	26	308
22	Mon	47	38	16	37	26	39	12	23	34	18	290
Total		423	299	112	362	180	213	182	244	289	203	2507

This study includes flights at all altitudes over the selected VORTAC facilities. A breakdown of flights by altitude is given in table B-4. This breakdown is summarized in table B-5 by dividing the altitudes into three separate altitude strata: (1) Low (up to but not including 18,000 feet above mean sea level), (2) Medium (FL180 up to but not including FL240), and (3) High (FL240 and above). Note that only the last one of these strata (FL240 and above) was considered in the previous high-altitude jet route data collection (reference 11). In addition, the altitudes were divided between the predominantly eastbound altitudes and the predominantly westbound altitudes according the hemispheric rule, and a breakdown of flights into the eastbound altitudes and the westbound altitudes is given in table B-6 for all flights and in table B-7 for low-altitude flights only.

Table B-4
NUMBER OF FLIGHTS BY ALTITUDE

Altitude	Nominal Direction	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
2000 ft	Westbound	4	0	0	1	0	0	0	0	0	1	6
3000 ft	Eastbound	11	0	0	2	0	1	0	0	2	8	24
4000 ft	Westbound	23	0	0	10	0	1	0	0	22	11	67
5000 ft	Eastbound	55	2	0	13	0	15	0	1	13	20	119
6000 ft	Westbound	36	8	0	50	2	25	0	1	60	37	219
7000 ft	Eastbound	62	21	1	34	42	27	16	3	40	24	270

Table B-4 (Continued)
NUMBER OF FLIGHTS BY ALTITUDE

Altitude	Nominal Direction	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
8000 ft	Westbound	13	72	18	58	39	26	12	40	47	17	342
9000 ft	Eastbound	51	64	17	43	26	23	15	54	33	26	352
10000 ft	Westbound	2	24	9	7	10	14	19	22	15	5	127
11000 ft	Eastbound	26	27	23	19	11	19	29	19	8	8	189
12000 ft	Westbound	14	14	2	25	4	8	11	14	9	6	107
13000 ft	Eastbound	11	10	20	13	4	12	2	6	5	9	92
14000 ft	Westbound	8	17	3	9	4	11	10	9	13	4	88
15000 ft	Eastbound	43	11	9	38	15	7	15	22	7	4	171
16000 ft	Westbound	22	16	8	11	11	8	36	28	10	8	158
17000 ft	Eastbound	42	13	2	29	12	16	17	25	5	15	176
FL 180	Westbound	2	14	10	25	6	6	19	19	5	3	109
FL 190	Eastbound	19	4	3	28	5	11	32	38	7	5	152
FL 200	Westbound	3	13	13	29	4	3	24	33	5	3	130
FL 210	Eastbound	38	13	4	33	7	6	19	51	7	8	186
FL 220	Westbound	3	22	15	10	1	11	23	21	22	10	138
FL 230	Eastbound	35	35	2	38	3	21	31	68	14	19	266
FL 240	Westbound	3	1	29	28	3	0	32	27	10	4	137
FL 250	Eastbound	70	1	4	37	7	3	63	55	17	10	267
FL 260	Westbound	1	0	39	7	6	1	60	52	6	11	183
FL 270	Eastbound	10	0	5	53	2	9	13	47	0	0	139
FL 280	Westbound	2	1	58	28	7	1	25	80	0	0	202
FL 290	Eastbound	25	3	12	82	1	7	47	122	2	2	303
FL 310	Westbound	4	7	117	160	2	2	86	283	15	1	677
FL 330	Eastbound	81	2	22	712	9	19	241	669	25	2	1782
FL 350	Westbound	1	1	218	330	3	0	157	603	35	1	1349
FL 370	Eastbound	24	3	14	501	5	4	100	323	7	1	982
FL 390	Westbound	1	1	31	70	0	0	25	98	1	1	228
FL 410	Eastbound	5	1	10	112	2	0	19	60	3	1	213
FL 430	Westbound	0	0	3	9	0	0	4	9	0	0	25
FL 450	Eastbound	0	0	0	5	0	0	0	4	0	0	9
FL 470	Westbound	0	0	0	2	0	0	0	0	0	0	2
FL 490	Eastbound	0	0	0	0	0	0	0	1	0	0	1
Total		750	421	721	2661	253	317	1202	2907	470	285	9987

Table B-5
NUMBER OF FLIGHTS BY ALTITUDE STRATUM

Stratum	Altitudes	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
Low	2-170	423	299	112	362	180	213	182	244	289	203	2507
Medium	180-230	100	101	47	163	26	58	148	230	60	48	981
High	240-490	227	21	562	2136	47	46	872	2433	121	34	6499
Total		750	421	721	2661	253	317	1202	2907	470	285	9987

Table B-6
NUMBER OF FLIGHTS BY DIRECTION OF FLIGHT
(Nominal Direction from Altitude)

Nominal Direction	Altitudes	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
Eastbound	Odd *	608	210	148	1792	151	200	659	1568	195	162	5693
Westbound	Even #	142	211	573	869	102	117	543	1339	275	123	4294
Total		750	421	721	2661	253	317	1202	2907	470	285	9987

* Odd altitude include FL 290, FL 330, FL 370, FL 410, FL 450, and FL 490.
# Even altitudes include FL 310, FL 350, FL 390, FL 430, and FL 470.

Table B-7
NUMBER OF FLIGHTS BY DIRECTION OF FLIGHT
(Nominal Direction from Altitude)
(Low Altitude Only)

Nominal Direction	Altitudes	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
Eastbound	Odd	301	148	72	191	110	120	94	130	113	114	1393
Westbound	Even	122	151	40	171	70	93	88	114	176	89	1114
Total		423	299	112	362	180	213	182	244	289	203	2507

The user identifications from the flight progress strips were used to classify the flights into distinct user classes. The seven user classes used were (1) air carrier airlines, (2) commuter airlines, (3) air taxi, (4) general aviation (N-number), (5) military, (6) foreign, and (7) other (for example, FAA flight inspection and other civilian US Government aircraft). A breakdown of user class by VORTAC is given in table B-8 for all flights and in table B-9 for low-altitude flights only. It should be noted that, although air carrier airlines predominate in the overall population, general aviation predominates in the low-altitude subpopulation.

Table B-8
NUMBER OF FLIGHTS BY USER TYPE

User Type	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
Air Carrier	176	47	365	1334	23	74	593	1787	142	64	4605
Commuter	7	4	42	105	13	42	48	224	7	13	505
Air Taxi	13	30	14	70	3	15	7	35	34	7	228
Gen Aviation	229	253	169	761	125	177	215	517	258	121	2825
Military	308	38	115	197	85	8	300	292	22	73	1438
Foreign	7	49	10	194	4	1	23	32	7	3	330
Other	10	0	6	0	0	0	16	20	0	4	56
Total	750	421	721	2661	253	317	1202	2907	470	285	9987

Table B-9
NUMBER OF FLIGHTS BY USER TYPE
(Low Altitude Only)

User Type	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
Air Carrier	24	2	12	38	5	22	37	14	9	22	185
Commuter	7	3	21	26	12	42	2	8	7	13	141
Air Taxi	10	29	11	37	2	14	3	8	30	6	150
Gen Aviation	207	200	53	229	117	127	82	152	217	104	1488
Military	166	23	12	23	41	7	55	57	19	55	458
Foreign	4	42	3	9	3	1	3	4	7	2	78
Other	5	0	0	0	0	0	0	1	0	1	7
Total	423	299	112	362	180	213	182	244	289	203	2507

All aircraft were classified by type as either (1) fixed-wing land aircraft, (2) rotary-wing aircraft (helicopters), or (3) firxed-wing amphibian aircraft. A breakdown of these aircraft type classifications by VORTAC is given in table B-10 for all flights and in table B-11 for low-altitude flights only. Only 43 helicopters and one amphibian were found during this data collection, and they were all in the low-altitude subpopulation.

Table B-10
NUMBER OF FLIGHTS BY AIRCRAFT TYPE CLASSIFICATION

Aircraft Type	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
Land	718	420	721	2658	253	317	1202	2907	470	277	9943
Helicopter	32	0	0	3	0	0	0	0	0	8	43
Amphibian	0	1	0	0	0	0	0	0	0	0	1
Total	750	421	721	2661	253	317	1202	2907	470	285	9987

Table B-11
NUMBER OF FLIGHTS BY AIRCRAFT TYPE CLASSIFICATION
(Low Altitude Only)

Aircraft Type	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
Land	391	298	112	359	180	213	182	244	289	195	2463
Helicopter	32	0	0	3	0	0	0	0	0	8	43
Amphibian	0	1	0	0	0	0	0	0	0	0	1
Total	423	299	112	362	180	213	182	244	289	203	2507

Aircraft types were classified into the aircraft categories that are programmed into the National Airspace System (NAS) Enroute Stage A system (reference 17). The eight categories are (1) single-engine piston, (2) multi-engine piston, (3) single-engine turboprop, (4) multi-engine turboprop, (5) civilian turbojet, (6) military fighter type turbojet, (7) military cargo/bomber type turbojet, and (8) special performance turbojet. A breakdown of these aircraft categories by VORTAC is given in table B-12 for all flights and in table B-13 for low-altitude flights only. Although jet aircraft predominate in the overall population, piston and turboprop aircraft predominate in the low-altitude subpopulation.

Table B-12
NUMBER OF FLIGHTS BY AIRCRAFT CATEGORY

Aircraft Category	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
Single-Engine Piston	106	94	13	111	51	48	18	49	99	56	645
Multi-Engine Piston	111	156	33	142	68	81	58	89	141	67	946
Single-Engine Turbo	3	0	0	2	0	0	0	0	0	1	6
Multi-Engine Turbo	190	96	116	282	62	90	188	307	63	68	1462
Civilian Jet	176	63	444	1821	24	93	689	2062	162	67	5601
Military Fighter	48	6	10	26	14	1	67	58	0	8	238
Military Cargo/Bomber	53	2	66	100	19	0	94	188	1	4	527
Special Performance	63	4	39	177	15	4	88	154	4	14	562
Total	750	421	721	2661	253	317	1202	2907	470	285	9987

Table B-13
NUMBER OF FLIGHTS BY AIRCRAFT CATEGORY
(Low Altitude Only)

Aircraft Category	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
Single-Engine Piston	105	93	13	109	51	48	17	47	98	55	636
Multi-Engine Piston	106	148	31	122	67	77	52	76	136	64	879
Single-Engine Turbo	3	0	0	2	0	0	0	0	0	1	6
Multi-Engine Turbo	116	50	53	81	43	63	53	82	44	48	633
Civilian Jet	26	2	13	42	5	24	38	18	8	22	198
Military Fighter	24	6	0	2	5	0	3	8	0	3	51
Military Cargo/Bomber	9	0	0	2	3	0	6	0	0	1	21
Special Performance	34	0	2	2	6	1	13	13	3	9	83
Total	423	299	112	362	180	213	182	244	289	203	2507

Aircraft types were also classified into weight classes representing maximum takeoff weights (reference 17). The three weight classes are small (12,500 pounds or less), large (more than 12,500 pounds but less than 300,000 pounds), and heavy (300,000 pounds or more). The number of aircraft in each weight class is given by VORTAC in table B-14 for all flights and in table B-15 for low-altitude flights only. Although the overall population is composed primarily of large aircraft, the low-altitude subpopulation is composed primarily of small aircraft. Also there are almost no heavy aircraft in the low-altitude population.

Table B-14
NUMBER OF FLIGHTS BY WEIGHT CLASS

Weight	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
Small	324	309	181	535	173	208	254	383	285	167	2819
Large	417	109	517	1766	78	109	870	2175	185	116	6342
Heavy	9	3	23	360	2	0	78	349	0	2	826
Total	750	421	721	2661	253	317	1202	2907	470	285	9987

Table B-15
NUMBER OF FLIGHTS BY WEIGHT CLASS
(Low Altitude Only)

Weight	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
Small	262	258	88	284	158	182	112	182	251	149	1926
Large	161	41	24	78	22	31	68	62	38	54	579
Heavy	0	0	0	0	0	0	2	0	0	0	2
Total	423	299	112	362	180	213	182	244	289	203	2507

At these selected VORTAC facilities, the three most common aircraft types (Boeing Model 727, Boeing Model 737, and McDonnell-Douglas DC-9) accounted for 43.7 percent of the 9,987 flights recorded, and the fourteen most common aircraft types accounted for 63.1 percent. The fourteen most common aircraft types in the overall population are given in table B-16. The low-altitude subpopulation contained a much more heterogenous collection of aircraft types. In the low-altitude subpopulation, the three most common aircraft types (Beech Super King Air 90, Boeing Model 737, and Piper Navajo) accounted for only 16.1 percent of the 2,507 flights recorded, and the fourteen most common aircraft types accounted for 47.9 percent. The fourteen most common aircraft types in the low-altitude subpopulation are given in table B-17.

Table B-16
NUMBER OF FLIGHTS BY AIRCRAFT TYPE
(Fourteen Most Common Aircraft Types)

	Aircraft Type	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
B727	Boeing 727	77	4	163	681	0	6	268	871	53	5	2128
B737	Boeing 737	67	21	125	266	22	38	161	329	31	57	1117
DC9	DC-9	50	22	81	281	18	31	153	420	57	2	1115
BE20	Super King Air	49	20	20	60	21	6	46	43	13	7	285
N265	Sabreliner	20	2	53	93	1	0	50	51	1	2	273
L101	Tri-Star	0	1	1	107	0	0	9	152	0	0	270
BE90	King Air 90	14	15	16	38	8	15	26	34	17	16	199
L382	Hercules (130)	18	11	10	27	4	0	39	51	1	6	167
FA28	Fellowship	0	0	13	0	0	0	37	92	0	0	142
DC8	DC-8	0	1	5	96	0	0	13	20	0	0	135
PA31	Piper Navajo	15	24	1	15	10	12	10	16	18	8	129
A300	Airbus	0	0	1	20	0	0	10	96	0	0	127
DC10	DC-10	0	0	2	71	0	0	6	30	0	0	109
C500	Cessna Citation	0	7	9	38	0	2	11	26	11	1	105

Table B-17
NUMBER OF FLIGHTS BY AIRCRAFT TYPE
(Fourteen Most Common Aircraft Types)
(Low Altitude Only)

	Aircraft Type	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
BE90	Super King Air	13	10	12	21	6	11	15	23	16	13	140
B737	Boeing 737	10	1	12	36	5	23	21	1	6	20	135
PA31	Piper Navajo	15	23	1	15	10	12	10	16	18	8	128
BE20	Super King Air	25	3	5	8	15	0	12	9	6	4	87
BE58	Beech Baron 58	7	7	4	18	5	13	5	3	19	6	87
SW4	Swearingen Metro	0	1	21	20	0	39	0	0	0	0	81
C182	Cessna Skylane	6	7	3	22	4	3	1	5	16	8	75
PA28	Piper Cherokee	16	16	0	13	5	2	1	0	12	8	73
PAZT	Piper Aztec	18	9	4	8	7	10	1	4	6	1	68
C310	Cessna 310	5	14	2	5	6	5	3	9	16	2	67
PA32	Piper Cherokee	3	8	2	18	5	7	2	3	13	6	67
BE55	Beech Baron 55	15	2	3	7	11	5	2	7	5	9	66
M020	Mooney Mark 20	8	7	1	9	7	5	4	8	12	4	65
A6	Intruder	29	0	2	0	5	1	6	7	3	8	61

The navigational equipment codes filed by the pilots were used to determine the type of navigational equipment available in each aircraft. The distribution of navigational equipment types is given in table B-18 for all flights and in table B-19 for low-altitude flights only. The low-altitude subpopulation is relatively similar to the overall population; however, it has a much higher proportion of aircraft without distance measuring equipment (DME) capability.

Table B-18
NUMBER OF FLIGHTS BY FILED NAVIGATIONAL EQUIPMENT CODE

Navigational Equipment	Filed Codes	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
RNAV	F,C,W	126	108	177	783	65	101	231	873	103	54	2621
VOR/DME	A,B,D	423	263	528	1794	143	191	864	1958	321	185	6670
VOR	U,T,X	55	44	2	49	24	23	7	8	41	24	277
TACAN only	P,N,M	146	6	14	35	21	2	100	68	5	22	419
Total		750	421	721	2661	253	317	1202	2907	470	285	9987

Table B-19
NUMBER OF FLIGHTS BY FILED NAVIGATIONAL EQUIPMENT CODE
(Low Altitude Only)

Navigational Equipment	Filed Codes	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
RNAV	F,C,W	66	74	27	68	40	61	44	82	60	36	558
VOR/DME	A,B,D	207	175	81	250	109	128	120	136	183	126	1515
VOR	U,T,X	55	44	2	42	24	23	6	7	41	24	268
TACAN only	P,N,M	95	6	2	2	7	1	12	19	5	17	166
Total		423	299	112	362	180	213	182	244	289	203	2507

The filed navigational equipment codes were also used to determine the type of transponder used by the aircraft. All except five aircraft had codes indicating that they were using 4096-code transponders, and most of the aircraft had Mode C altitude reporting capability. The distribution of transponder types is given in table B-20 for all flights and in table B-21 for low-altitude flights only. Like the overall population, the low-altitude subpopulation is composed primarily of aircraft with Mode C altitude reporting capability; however, nearly all of the aircraft without Mode C capability are in the low-altitude subpopulation.

Table B-20
NUMBER OF FLIGHTS BY FILED TRANSPONDER CODE

Transponder	Filed Codes	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
Mode C	F,A,U,P	727	388	721	2632	242	307	1197	2897	446	271	9828
Mode A	C,B,T,N	23	32	0	28	10	10	5	9	24	13	154
None	W,D,X,M	0	1	0	1	1	0	0	1	0	1	5
Total		750	421	721	2661	253	317	1202	2907	470	285	9987

Table B-21
NUMBER OF FLIGHTS BY FILED TRANSPONDER CODE
(Low Altitude Only)

Transponder	Filed Codes	CVI	EKN	FAK	GVE	ISO	LYH	RDU	RIC	SBV	TYI	Total
Mode C	F,A,U,P	401	267	112	336	170	203	179	236	265	189	2358
Mode A	C,B,T,N	22	31	0	25	9	10	3	7	24	13	144
None	W,D,X,M	0	1	0	1	1	0	0	1	0	1	5
Total		423	299	112	362	180	213	182	244	289	203	2507

All low-altitude flights (up to but not including 18,000 feet above mean sea level) overflying these ten VORTAC facilities were identified by the airway segments flown before and after passing over the selected VORTAC facilities. This analysis gave two airway segments for each flight at each VORTAC facility, one before and one after the facility. After analyzing all of the airway segments flown, thirty low-altitude airway segments were selected for further analysis.

Information about traffic on these thirty selected airway segments is given in tables B-22 through B-27. Each airway segment on these tables is identified by airway name and by the names of navigational facilities defining the segment end points. These segments are further identified (on tables B-22 and B23 only) by the VORTAC facility (from the list in table B-1) and the radial from that facility that was used to identify that segment. In addition, the length of each selected airway segment (in nautical miles between end points) and the total number of low-altitude flights on each segment are given on these tables.

The flights on these thirty selected low-altitude airway segments were analyzed by direction of flight. For each flight, the actual direction of flight over the airway segment was recorded. In addition, the normal direction of flight for the aircraft's recorded altitude was determined from the hemispheric rule. A breakdown of flights on these selected segments by direction of flight is given in table B-22. For each airway segment, the total number of flights is broken down by actual directions of flight and by the nominal directions determined from the altitudes used. In addition, the number of flights at a nonstandard altitude for the actual direction is calculated.

Table B-22

NUMBER OF FLIGHTS BY DIRECTION OF FLIGHT

(Thirty Selected Low Altitude Airway Segments)

Airway	Segment	Fix	Radial	Length (NM)	Total Flights	Direction (Actual)		Direction (Altitude)		Non-Stand Dir
						East	West	East	West	
V1	CVI-ORF	CVI	052	45	274	242	32	216	58	26
V1	ISO-CVI	CVI	215	69	185	131	54	128	57	3
V20	GSO-SBV	SBV	236	60	112	42	70	41	71	1
V1	CRE-ISO	ISO	219	110	102	63	39	61	41	2
V37	PSK-EKN	EKN	199	113	101	36	65	48	53	12
V16-157	RIC-PXT	RIC	045	65	95	33	62	29	66	4
V39	SBV-GVE	SBV	032	90	90	35	55	35	55	0
V157	LVL-RIC	RIC	220	50	87	44	43	48	39	4
V37-103	CKB-EKN	EKN	343	22	86	64	22	46	40	18
V38	GVE-RIC	GVE	133	50	82	25	57	23	59	2
V20	SBV-RIC	SBV	063	95	77	38	39	38	39	0
V16-260	ROA-LYH	LYH	283	40	76	47	29	45	31	2
V39E	GVE-CSN	GVE	026	40	71	25	46	23	48	2
V3-39	GVE-LDN	GVE	003	50	67	21	46	21	46	0
V38	EKN-GVE	GVE	307	106	65	20	45	24	41	4
V260	FKN-CVI	CVI	348	22	58	45	13	16	42	29
V4	CRW-EKN	EKN	251	86	58	23	35	23	35	0
V375	ROA-GVE	GVE	253	100	57	45	12	45	12	0
V16-260	LYH-FAK	LYH	081	69	56	48	8	48	8	0
V469	EKN-MGW	EKN	020	40	55	39	16	33	22	6
V39	SDZ-SBV	SBV	203	92	54	20	34	20	34	0
V4	EKN-ESL	EKN	074	55	52	20	32	18	34	2
V222N	LYH-GVE	GVE	235	69	50	36	14	37	13	1
V16-260	FAK-RIC	FAK	100	24	48	45	3	44	4	1
V194	TYI-CVI	TYI	064	47	47	43	4	41	6	2
V213	ILM-TYI	TYI	196	99	47	24	23	27	20	3
V143	GSO-LYH	LYH	211	81	46	24	22	25	21	1
V213	TYI-HPW	TYI	024	86	45	18	27	16	29	2
V194-310	RDU-TYI	TYI	269	43	42	32	10	34	8	2
V136	SBV-RDU	SBV	172	49	40	16	24	20	20	4

Further analysis was done on the flights on these thirty selected low-altitude airway segments. A breakdown of these flights by day of the data collection (March 16 through 22, 1982) is given in table B-23.

Table B-23
NUMBER OF FLIGHTS PER DAY OF DATA COLLECTION
(Thirty Selected Low Altitude Airway Segments)

Airway	Segment	Fix	Radial	Length (NM)	Total Flights	Mar 16 Tue	Mar 17 Wed	Mar 18 Thu	Mar 19 Fri	Mar 20 Sat	Mar 21 Sun	Mar 22 Mon
V1	CVI-ORF	CVI	052	45	274	42	38	37	50	34	35	38
V1	ISO-CVI	CVI	215	69	185	22	22	20	31	30	35	25
V20	GSO-SBV	SBV	236	60	112	16	30	27	14	4	8	13
V1	CRE-ISO	ISO	219	110	102	13	2	11	24	15	27	10
V37	PSK-EKN	EKN	199	113	101	9	15	22	24	11	8	12
V16-157	RIC-PXT	RIC	045	65	95	18	12	15	12	12	15	11
V39	SBV-GVE	SBV	032	90	90	10	18	18	20	5	13	6
V157	LVL-RIC	RIC	220	50	87	10	11	9	16	11	17	13
V37-103	CKB-EKN	EKN	343	22	86	8	13	21	19	9	6	10
V38	GVE-RIC	GVE	133	50	82	10	19	16	16	6	7	8
V20	SBV-RIC	SBV	063	95	77	17	15	20	10	3	2	10
V16-260	ROA-LYH	LYH	283	40	76	13	10	21	13	2	2	15
V39E	GVE-CSN	GVE	026	40	71	4	16	15	16	9	7	4
V3-39	GVE-LDN	GVE	003	50	67	6	13	14	14	4	10	6
V38	EKN-GVE	GVE	307	106	65	8	11	15	11	5	7	8
V260	FKN-CVI	CVI	348	22	58	8	9	11	12	9	4	5
V4	CRW-EKN	EKN	251	86	58	5	11	13	15	8	3	3
V375	ROA-GVE	GVE	253	100	57	7	12	11	14	5	4	4
V16-260	LYH-FAK	LYH	081	69	56	12	10	13	8	1	2	10
V469	EKN-MGW	EKN	020	40	55	5	11	14	7	3	7	8
V39	SDZ-SBV	SBV	203	92	54	7	6	12	12	1	11	5
V4	EKN-ESL	EKN	074	55	52	5	12	11	10	8	2	4
V222N	LYH-GVE	GVE	235	69	50	7	10	8	9	4	7	5
V16-260	FAK-RIC	FAK	100	24	48	11	7	9	2	3	5	11
V194	TYI-CVI	TYI	064	47	47	6	11	7	7	6	6	4
V213	ILM-TYI	TYI	196	99	47	5	7	4	14	3	11	3
V143	GSO-LYH	LYH	211	81	46	8	7	11	1	4	4	11
V213	TYI-HPW	TYI	024	86	45	3	12	3	12	4	6	5
V194-310	RDU-TYI	TYI	269	43	42	4	8	5	13	4	4	4
V136	SBV-RDU	SBV	172	49	40	7	4	10	9	3	5	2

The number of flights on these selected airway segments is given by user type (air carrier airlines, commuter airlines, air taxi, general aviation, military, foreign, and other) in table B-24.

Table B-24
NUMBER OF FLIGHTS BY USER TYPE
(Thirty Selected Low Altitude Airway Segments)

Airway	Segment	Length (NM)	Total Flights	Air Carr	Commuter	Air Taxi	Gen Avn	Military	Foreign	Other
V1	CVI-ORF	45	274	24	6	10	126	100	3	5
V1	ISO-CVI	69	185	1	0	2	134	47	1	0
V20	GSO-SBV	60	112	8	1	22	75	5	1	0
V1	CRE-ISO	110	102	2	0	1	88	10	1	0
V37	PSK-EKN	113	101	0	0	0	57	5	39	0
V16-157	RIC-PXT	65	95	1	1	2	83	7	1	0
V39	SBV-GVE	90	90	0	1	3	75	6	5	0
V157	LVL-RIC	50	87	1	1	0	62	22	1	0
V37-103	CKB-EKN	22	86	0	2	3	47	3	31	0
V38	GVE-RIC	50	82	7	8	27	34	4	2	0
V20	SBV-RIC	95	77	2	4	7	59	5	0	0
V16-260	ROA-LYH	40	76	7	34	8	24	2	1	0
V39E	GVE-CSN	40	71	0	0	4	61	4	2	0
V3-39	GVE-LDN	50	67	0	0	0	60	3	4	0
V38	EKN-GVE	106	65	8	6	20	28	3	0	0
V260	FKN-CVI	22	58	0	0	0	35	22	1	0
V4	CRW-EKN	86	58	0	0	3	49	6	0	0
V375	ROA-GVE	100	57	20	6	0	28	2	1	0
V16-260	LYH-FAK	69	56	3	19	10	21	2	1	0
V469	EKN-MGW	40	55	3	0	2	47	2	1	0
V39	SDZ-SBV	92	54	0	1	0	47	4	2	0
V4	EKN-ESL	55	52	0	0	3	41	8	0	0
V222N	LYH-GVE	69	50	6	11	3	28	2	0	0
V16-260	FAK-RIC	24	48	11	18	3	14	2	0	0
V194	TYI-CVI	47	47	9	0	0	17	21	0	0
V213	ILM-TYI	99	47	0	0	0	36	10	0	1
V143	GSO-LYH	81	46	0	0	0	45	1	0	0
V213	TYI-HPW	86	45	0	0	0	34	10	1	0
V194-310	RDU-TYI	43	42	1	0	2	24	14	1	0
V136	SBV-RDU	49	40	0	0	1	31	4	4	0

Breakdowns by aircraft type classification (land, helicopter, and amphibian) and by aircraft weight class (small, large, and heavy) for flights on these selected airway segments are given in table B-25.

Table B-25
NUMBER OF FLIGHTS BY AIRCRAFT TYPE AND WEIGHT CLASSIFICATIONS
(Thirty Selected Low Altitude Airway Segments)

		Length	Total	Aircraft Type			Weight Class		
Airway	Segment	(NM)	Flights	Land	Copter	Amphib	Small	Large	Heavy
V1	CVI-ORF	45	274	249	25	0	166	108	0
V1	ISO-CVI	69	185	162	23	0	151	34	0
V20	GSO-SBV	60	112	112	0	0	88	24	0
V1	CRE-ISO	110	102	102	0	0	96	6	0
V37	PSK-EKN	113	101	100	0	1	93	8	0
V16-157	RIC-PXT	65	95	95	0	0	86	9	0
V39	SBV-GVE	90	90	90	0	0	88	2	0
V157	LVL-RIC	50	87	87	0	0	80	7	0
V37-103	CKB-EKN	22	86	86	0	0	78	8	0
V38	GVE-RIC	50	82	81	1	0	48	34	0
V20	SBV-RIC	95	77	77	0	0	67	10	0
V16-260	ROA-LYH	40	76	76	0	0	66	10	0
V39E	GVE-CSN	40	71	70	1	0	70	1	0
V3-39	GVE-LDN	50	67	67	0	0	65	2	0
V38	EKN-GVE	106	65	65	0	0	40	25	0
V260	FKN-CVI	22	58	50	8	0	44	14	0
V4	CRW-EKN	86	58	58	0	0	49	9	0
V375	ROA-GVE	100	57	56	1	0	36	21	0
V16-260	LYH-FAK	69	56	56	0	0	50	6	0
V469	EKN-MGW	40	55	55	0	0	51	4	0
V39	SDZ-SBV	92	54	54	0	0	53	1	0
V4	EKN-ESL	55	52	52	0	0	43	9	0
V222N	LYH-GVE	69	50	49	1	0	41	9	0
V16-260	FAK-RIC	24	48	48	0	0	34	14	0
V194	TYI-CVI	47	47	46	1	0	25	22	0
V213	ILM-TYI	99	47	47	0	0	44	3	0
V143	GSO-LYH	81	46	46	0	0	44	2	0
V213	TYI-HPW	86	45	44	1	0	43	2	0
V194-310	RDU-TYI	43	42	41	1	0	30	12	0
V136	SBV-RDU	49	40	40	0	0	39	1	0

The flights on these thirty selected airway segments are broken down by aircraft category (single-engine piston, multi-engine piston, single-engine turboprop, multi-engine turboprop, civilian turbojet, military fighter type turbojet, military cargo/bomber type turbojet, and special performance turbojet) in table B-26.

Table B-26
NUMBER OF FLIGHTS BY AIRCRAFT CATEGORY
(Thirty Selected Low Altitude Airway Segments)

Airway	Segment	Length (NM)	Total Flights	Sing Eng Pist	Mult Eng Pist	Sing Eng Turb	Mult Eng Turb	Civ Jet	Mil Fght Jet	Mil Carg Bomb	Spec Perm Jet
V1	CVI-ORF	45	274	58	72	3	92	26	6	8	9
V1	ISO-CVI	69	185	75	61	1	41	1	1	3	2
V20	GSO-SBV	60	112	23	62	0	21	6	0	0	0
V1	CRE-ISO	110	102	39	51	0	10	2	0	0	0
V37	PSK-EKN	113	101	34	58	0	8	0	1	0	0
V16-157	RIC-PXT	65	95	30	29	0	35	1	0	0	0
V39	SBV-GVE	90	90	46	38	0	5	1	0	0	0
V157	LVL-RIC	50	87	29	23	0	33	1	0	0	1
V37-103	CKB-EKN	22	86	33	46	0	7	0	0	0	0
V38	GVE-RIC	50	82	15	33	0	26	8	0	0	0
V20	SBV-RIC	95	77	18	42	0	15	2	0	0	0
V16-260	ROA-LYH	40	76	8	21	0	38	9	0	0	0
V39E	GVE-CSN	40	71	34	30	1	6	0	0	0	0
V3-39	GVE-LDN	50	67	37	27	0	3	0	0	0	0
V38	EKN-GVE	106	65	12	32	0	12	8	1	0	0
V260	FKN-CVI	22	58	22	14	0	19	0	0	0	3
V4	CRW-EKN	86	58	19	18	0	21	0	0	0	0
V375	ROA-GVE	100	57	10	10	1	16	20	0	0	0
V16-260	LYH-FAK	69	56	8	19	0	24	5	0	0	0
V469	EKN-MGW	40	55	18	29	0	5	3	0	0	0
V39	SDZ-SBV	92	54	35	15	0	3	1	0	0	0
V4	EKN-ESL	55	52	16	16	0	18	0	2	0	0
V222N	LYH-GVE	69	50	9	16	0	16	8	0	0	1
V16-260	FAK-RIC	24	48	1	9	0	25	12	0	0	1
V194	TYI-CVI	47	47	6	19	0	12	8	0	1	1
V213	ILM-TYI	99	47	17	17	0	11	0	0	0	2
V143	GSO-LYH	81	46	18	18	0	10	0	0	0	0
V213	TYI-HPW	86	45	15	19	0	10	0	1	0	0
V194-310	RDU-TYI	43	42	17	14	1	6	1	0	1	2
V136	SBV-RDU	49	40	12	23	0	4	0	0	0	1

Breakdowns of flights on these selected segments by filed navigational equipment code (RNAV, VOR/DME, VOR, and TACAN only) and by filed transponder code (Mode C with altitude reporting, Mode A without altitude reporting, and no transponder) are given in table B-27.

Table B-27
NUMBER OF FLIGHTS BY FILED NAVIGATIONAL EQUIPMENT AND TRANSPONDER CODES
(Thirty Selected Low Altitude Airway Segments)

				Navigational Equipment				Transponder		
Airway	Segment	Length (NM)	Total Flights	RNAV	VOR DME	VOR	TACAN Only	Mode C Alt	Mode A No Alt	None
V1	CVI-ORF	45	274	45	154	31	44	262	12	0
V1	ISO-CVI	69	185	35	90	31	29	173	12	0
V20	GSO-SBV	60	112	15	85	11	1	107	5	0
V1	CRE-ISO	110	102	22	60	19	1	95	7	0
V37	PSK-EKN	113	101	17	64	19	1	87	14	0
V16-157	RIC-PXT	65	95	40	50	5	0	89	6	0
V39	SBV-GVE	90	90	9	66	15	0	84	6	0
V157	LVL-RIC	50	87	27	56	3	1	85	2	0
V37-103	CKB-EKN	22	86	18	53	15	0	75	11	0
V38	GVE-RIC	50	82	9	65	8	0	78	4	0
V20	SBV-RIC	95	77	18	48	11	0	73	4	0
V16-260	ROA-LYH	40	76	12	60	4	0	76	0	0
V39E	GVE-CSN	40	71	15	44	12	0	64	7	0
V3-39	GVE-LDN	50	67	14	42	11	0	62	4	1
V38	EKN-GVE	106	65	6	50	8	1	60	5	0
V260	FKN-CVI	22	58	9	22	14	13	51	7	0
V4	CRW-EKN	86	58	16	39	3	0	55	3	0
V375	ROA-GVE	100	57	10	44	3	0	52	5	0
V16-260	LYH-FAK	69	56	12	39	5	0	56	0	0
V469	EKN-MGW	40	55	19	27	9	0	48	6	1
V39	SDZ-SBV	92	54	7	35	12	0	50	4	0
V4	EKN-ESL	55	52	14	33	3	2	49	3	0
V222N	LYH-GVE	69	50	14	30	5	1	47	3	0
V16-260	FAK-RIC	24	48	8	38	1	1	48	0	0
V194	TYI-CVI	47	47	5	35	4	3	45	2	0
V213	ILM-TYI	99	47	15	23	7	2	43	3	1
V143	GSO-LYH	81	46	18	20	8	0	38	8	0
V213	TYI-HPW	86	45	12	25	7	1	43	2	0
V194-310	RDU-TYI	43	42	4	28	7	3	38	4	0
V136	SBV-RDU	49	40	16	17	5	2	36	4	0