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TE-45

AN AIRSPACE UTILIZATION MODEL FOR V/STOL TERMINAL OPERATIONS

by

Dorian Albert De Maio

January 1971

N71 23186
(ACCESSION NUMBER) (THRU)
95
(PAGES) (CODE)
CR-117887 11
(NASA CR OR TMX OR AD NUMBER) (CATEGORY)
FACILITY FORM 602

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B.S., University of Maryland
(1968)

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF SCIENCE
AND THE DEGREE OF ENGINEER IN
AERONAUTICS AND ASTRONAUTICS

at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
January 1971

Signature of Author Dorian A. DeMaio
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January 1971

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Submitted to the Department of Aeronautics and Astronautics on January 22, 1971, in partial fulfillment of the requirements for the degrees of Master of Science and Engineer in Aeronautics and Astronautics.

ABSTRACT

A computer graphics display program is developed for use in terminal area studies and V/STOL approach and departure path synthesis. The computer processes inputs describing the terminal area and accompanying constraints and displays on a cathode ray tube the airspace utilization model, a three dimensional image representation of the constraints at a given altitude. Extensive machine/operator interaction is provided to select various constraint criteria, to plan approaches and departures and to check the results through viewing and teletype output. The program is general and may be applied to a number of terminal areas.

The programs' applicability and usefulness is demonstrated in the analyses of several proposed VTOL port sites in the Northeast Corridor. Approach and departure paths are developed for each site and observations are made regarding flight path characteristics. The computer display leads to drastic reductions in time and effort over a comparable manual task in terminal area studies.

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ACKNOWLEDGEMENTS

The author wishes to express his appreciation to his thesis supervisor, Professor Walter Hollister, for his guidance and encouragement during the course of this study.

Thanks are also extended to Mr. R. Anderson of the M.I.T. Man Vehicle Laboratory and Mr. R. Rausch of the M.I.T. Electronic Systems Laboratory for their time and suggestions in the development of the computer program. Many thanks to Mrs. Ann Preston and Mrs. Jennifer Kelley who prepared the illustrations and manuscript for publication.

Special appreciation goes to my wife, Chris, for her continual patience and encouragement throughout this work.

This research was supported in part through NASA Contract NAS 12-2081 and NASA Grant NGR 22-009-010 and in part through Department of Transportation Contract DOT TSC-5.

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Chapter I

Introduction

V/STOL aircraft promise considerable reductions in door-to-door travel time for short interurban trips provided that safe and efficient all weather operation can be conducted near metropolitan areas. Conventional aircraft have proven inadequate for this purpose due to congestion and lack of convenient locations for large airports. The effective use of V/STOL aircraft is dependent upon its unique performance capabilities, particularly low speed maneuverability, which will allow safe operation in restricted areas through efficient utilization of the terminal airspace. The city center environment, however, imposes severe constraints upon the short-haul flight transportation system which will have a significant influence on aircraft design and operation. The problem is to determine how to conduct V/STOL terminal operations subject to constraints established by considerations of safety, noise, traffic and economy. This problem is complex, requiring the consideration and control of all the elements of the operation. A system approach is needed.

The major objective of terminal operation analyses is to determine the approach and departure paths for the area of interest. Recent studies [1,2,3] have established optimum V/STOL flight paths by minimizing costs associated with fuel and time. Although the results provide fundamental information regarding flight path characteristics and fuel and time penalties, their application to actual IFR terminal operations is limited because of the overriding influence of constraints imposed by the specific area in study. The path determination problem, which is difficult in itself, is further complicated by the continual evolution and definition of V/STOL system requirements and by a lack of well-defined constraint criteria (such as community response to noise). A flexible approach is desired that is compatible with the V/STOL system concept presently undergoing the iterative design processes characteristic of the planning stage. Clearly, an integrated information system is required which can handle variable constraint inputs and various terminal areas with specific characteristics and considerations. In this thesis, a computer generated display is developed to study the terminal area environment and synthesize V/STOL approach and departure paths.

In a previous study[4] V/STOL flight paths were established for three sites in the Boston metropolitan region. Specific constraints were determined and used to generate airspace utilization maps at several altitude levels indicating the airspace not available for aircraft operation. Approach and departure paths were then chosen using the remaining airspace. The manual task performed in that study was both arduous and time consuming, and motivated the development of the computer program/graphics display. Since Reference 4 provides the basis for this work, it should be regarded as a companion study.

The graphics display leads to drastic reductions in time and effort over the manual task while providing far greater flexibility in the selection of constraint criteria and viewing modes. The design program consists of two phases. First, the computer processes inputs describing the terminal area and attendant constraints and displays on a cathode ray tube a three dimensional image representation of the constraints at a selected altitude level. The resulting image, referred to as the airspace utilization model, illustrates the location of the noise sensitive areas, noise restricted airspace, obstacle restrictions and CTOL traffic. The airspace available for V/STOL operations is subsequently identified. Throughout program execution, extensive real time man/machine interation is provided to allow the operator to control image viewing and in the next phase to determine unconstrained flight paths. The paths are defined by selected waypoints which are later output by the teletype unit. All fixed map data is stored in external files resulting in a general program which may be applied to any locality.

Since the entire development progresses from a consideration of the system constraints, the thesis first presents a review of the major constraints in the terminal area. This is followed by a description of the computer generated display, its operational modes and application to terminal area studies using the Boston region as a demonstration model. Afterwards, the display program is utilized in the analysis of several sites of general interest in the Northeast Corridor. The Appendices contain a detailed program guide and program listing.

Chapter II

The Constraints

2.1 General

City center vertiports will impose certain constraints upon the short-haul flight transportation system which will have a significant influence on aircraft design and operation. The purpose of this chapter is to identify and define these constraints and discuss their impact on terminal operation. Constraint criteria will be specified whenever appropriate since this is a significant input to the computer display system described in the next chapter.

2.2 The Noise Constraint

2.2.1 Noise Problem/Community Response

Although V/STOL configurations are not expected to be inherently noisier than today's fixed wing aircraft, the requirement for close operation near the city center presents a serious noise problem to the urban population. Vehicle noise must be controlled to minimize the disturbance of normal community life patterns. Today, with the public expressing increased concern over the effects of noise, every effort must be made to establish harmony between the community and VTOL port. However, any attempts to arrive at a plausible solution to the noise problem are complicated by a lack of well-defined public acceptance criteria and effective means of noise level measurement.

At the present time, the most widely accepted measure of human response to noise is the perceived noise level (PNdb). The PNdb measure recognizes that spectrum shape is an important influence in human reaction to noise and weighs the effects on the receiver of various octave band sound pressure level measurements. Thus, high frequency noise is considered more objectionable than low frequency noise. However, the amount of noise that can be tolerated by people is dependent upon a number of factors, including over-all noise level, frequency, duration, and tone quality. Recent research is aimed at further refinement of the PNdb concept by the inclusion of factors to express the added annoyance due to the time duration and the pressure of pure tones which usually prove more irritating than broad band noise of the same pressure level. This measure is known as the effective perceived noise level (EPNdb).

Sufficient data is not available to establish definite criteria in order to judge community reaction to aircraft noise. There have been many attempts to specify "acceptable" noise levels, but invariably these levels are not universally recognized. This is understandable since human reaction to noise depends upon complex physical, economic, and psychological factors. Background noise levels are often suggested, but it is felt that this is not a satisfactory criterion, since in most cases it is already objectionably high and attempts are being made to reduce it. The best approach, and certainly the most flexible one to this problem is to place bounds on the criterion, treating it as a variable within these bounds. Therefore, general guidelines will be given, but it is emphasized that they are considered approximate since reaction to noise varies significantly from person to person. Bolt, Beranek, and Newman[5] propose a scale, the Composite Noise Rating (CNR) in which corrections are added to the PNdb level to account for the numbers of flight operations per hour and the time of day (Table 1). These values are intended for use with a suggested land use compatibility chart (Figure 1) which indicates the anticipated noise reaction for different noise sensitive areas.

Noise Sensitivity Zone	Composite Noise Rating (CNR) Takeoffs & Landings	Residential	Commercial	Industrial	Schools, Hospitals	Hotel, Motel	Theaters, Auditoriums	Outdoor Amphitheaters	Outdoor Recreational (Non-Spectator)
I	< 90	yes	yes	yes	yes	yes	Note (A)	Note (A)	yes
II	90-100	yes	yes	yes	Note (C)	yes	Note (C)	no	yes
III	100-115	Note (B)	yes	yes	no	Note (C)	no	no	yes
IV	> 115	no	Note (C)	Note (C)	no	no	no	no	yes

NOTE (A) - Possible interference for indoor or outdoor music auditoriums and outdoor theaters. Make more detailed noise studies.

NOTE (B) - Case history experience indicates that individuals in private residences may complain, perhaps vigorously. Concerted group action is possible.

NOTE (C) - Potentially serious interference, with likelihood of serious adverse reactions from individuals and groups affected.

FIGURE 1 LAND USE COMPATIBILITY CHART

Total Activity

Number Per Hour	Correction
≥ 20	+15
7-19	+10
2-6.9	+5
0.7-1.9	0
0.2-0.69	-5
< 0.2	-10

Flight Path Utilization

Utilization	Correction
30% - 100%	0
10% - 29%	-5
3% - 9%	-10
< 3%	-15

Time of Day

Time of Day	Correction
0700 - 2200	0
2200 - 0700	+10

TABLE 1

CORRECTIONS TO BE ADDED TO PERCEIVED NOISE LEVEL TO OBTAIN COMPOSITE NOISE RATING

2.2.2 Operational Restrictions

Two avenues of approach appear most promising for reducing noise pollution. The first is through aircraft design changes and involves finding acceptable methods of producing less noise per unit thrust through modification of the aircraft's power plants and operating conditions (e.g. reduction of propellor tip speeds for tilt wing aircraft). Extensive research efforts may result in considerable noise level reductions (Estimates range from about 10-20 db), but even allowing for this, it will still be necessary to implement the second means of noise control: modification of aircraft operations, in terms of distance to be maintained between the aircraft and populated areas, in order to elicit no serious public reaction. This is the approach of interest here.

A simplified model of the noise propagation characteristics of a noise source with known noise level dB_1 at R_1 is given by

$$dB = dB_1 - 20 \log_{10}(R/R_1) - (K_a + K_g)(R-R_1) \qquad (1)$$

$$dB + \text{corrections} = CNR \qquad (2)$$

where

dB = noise level at distance R (range from source)

K_a = atmospheric attenuation factor

K_g = ground attenuation factor

As indicated, in addition to the inverse square law energy decay, there is also an atmospheric and terrain attenuation effect described by K_a and K_g. Neglecting K_a and K_g, doubling the range decreases the sound level by six db. Atmospheric attenuation is a complex function of frequency, wind speed, turbulence, humidity, and temperature.

Octave Band (cps)	Attenuation (K_1) dB/1000 ft.
20-75	0
75-150	0.15
150-300	0.3
300-600	0.6
600-1200	1.2
1200-2400	2.4
2400-4800	4.8
4800-10000	10.0

FIGURE 2 (a) Atmospheric Attenuation

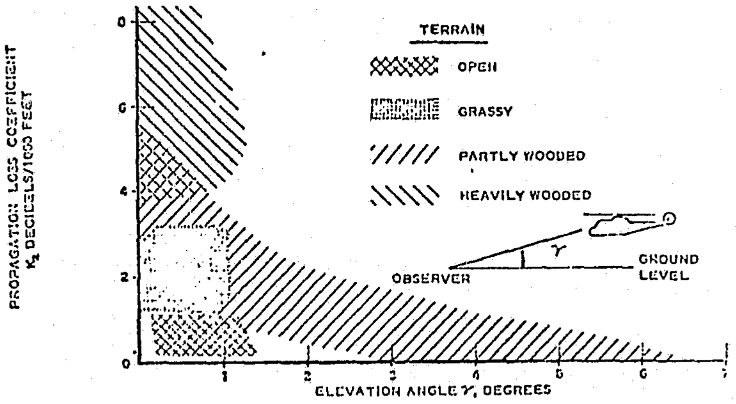


FIGURE 2(b) Attenuation Due to Terrain Effects

Average attenuation factors are given in Figure 2a.[6] The terrain effect attenuation shown in Figure 2b is a function of aircraft flight path angle and for most practical cases may be ignored because of the steep elevation angles of V/STOL approaches and departures.

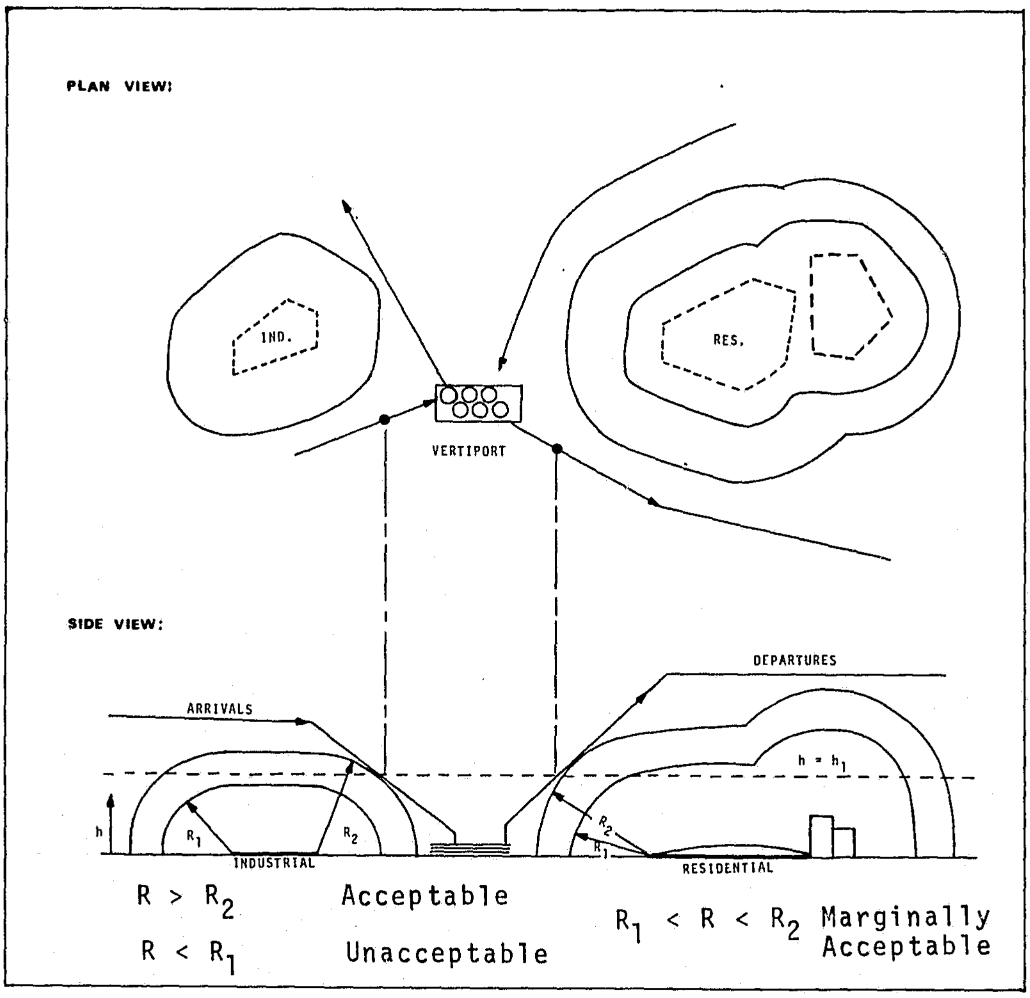
Equations (1) and (2) allow the calculation of the distance required for attenuation from the aircraft noise value to the allowable value of the noise sensitive area. The terminal airspace may be resolved into noise restricted and non-restrictive space as shown in Figure 3 constraining V/STOL's from exceeding the stated noise criteria. Using the land use compatibility chart in Figure 1 as a guide, the following noise criteria have been selected for this study.

Sensitivity Zone	Schools Hospitals	Residential Areas	Commercial Industrial
Acceptable (1)	<85 CNR	<95 CNR	<110 CNR
Marginal (2)	85-95 CNR	95-105 CNR	110-120 CNR
Unacceptable (3)	>95 CNR	>105 CNR	>120 CNR

2.3 Obstacle Clearance Considerations

Requirements for obstacle clearances for V/STOL ports have not yet been established, because they are determined largely by the navigation and guidance capabilities of V/STOL aircraft which, in turn, are not completely defined. However, since the V/STOL operational environment consists of take-offs and landings in confined areas with maneuvering relatively near large elevated structures, some sort of safe and realistic criteria must be established. In the terminal approach area, obstacle clearance is provided by requiring aircraft to maintain specified lateral and vertical clearances about each major obstruction. In the immediate vicinity of the vertiport where the above requirements would be overly constraining, approach clearance

FIGURE 3



$R > R_2$ Acceptable

$R < R_1$ Unacceptable

$R_1 < R < R_2$ Marginally Acceptable

COMMUNITY ACOUSTIC ISOLATION

surfaces specify the minimum descent angle that must be maintained to clear surrounding obstacles during an approach to landing. The Heliport Design Guide[7] suggests clearance surfaces for IFR helicopter approaches that are curvilinear and extend at a slope of 15:1. Such clearance specifications would make V/STOL port siting extremely difficult. However, with advances in guidance and control technology, future V/STOL's will be capable of executing approaches much steeper than are possible with today's helicopter, permitting a corresponding decrease in the approach surface requirements.

2.4 Traffic Interfaces

Adequate aircraft separation must be maintained in order to insure safe operation in high density terminal areas. The routing of V/STOL and CTOL traffic in the terminal area must be consistent with this objective without unnecessarily restricting the operation of both types of aircraft. The V/STOL's low speed maneuver capability will permit operations independent from but simultaneous with conventional traffic. V/STOL's will operate at 1500-2000 feet while in the approach area around and under fixed wing traffic patterns until sufficient spatial separation is established. When operating below CTOL traffic, special precautions should be taken to avoid the turbulent wakes associated with these aircraft, especially departing CTOL aircraft which generate strong vortices when fully loaded. Wing tip vortices move downward at 400-500 ft/min until they decay 800-900 feet below the aircraft.

2.5 Aircraft Performance Limitations

2.5.1 Estimated Performance

Although expected to be extremely versatile due to their unique low speed maneuverability, V/STOL aircraft do possess limiting performance characteristics. For instance, in terms of flight time, fuel, and air traffic capacity, vertical descents and climbs are very costly. In general, V/STOL performance characteristics will be modelled after those for the aircraft designs described in Reference 8, some of which are listed in Table 2. The aircraft will have the desirable low speed characteristics listed in Table 2 and in addition will be capable of maximum approach angles of 15° and maximum climb-out angles of 20°. These characteristics are consistent with pilot/control capabilities and are acceptable in terms of fuel cost.[2] The V/STOL concept allows operations in several modes with many variations in flight path angles. Upon reaching operational status, they should be equipped with some form of stability augmentation and advanced control system such as a ground referenced velocity control system which permits landings independent of wind direction. Modest restrictions will have to be placed on cross and tail wind landings depending upon the aircraft's specific handling characteristics. When low and slow, just prior to landing, V/STOL's can turn into the wind to continue the descent to touchdown. The stabilization and guidance equipment to carry out these functions either automatically or with a pilot guiding a stabilized vehicle using suitable displays is presently under development for military systems and further development can be expected by 1980.

2.5.2 Noise Characteristics

It is suggested that with continued state of the art improvements in noise reduction techniques, future V/STOL aircraft will have a peak noise rating of about 95 PNdb at 500 feet. It now appears that the FAA will require this value for noise certification.[9] In addition, further reductions to 90 PNdb should prove technologically feasible within the next decade. It is desirable to know how the aircraft's noise level varies with power setting in order to examine the tradeoff between increased power to climb at steep angles, (acting to increase noise), noise duration and gain in altitude (tending to attenuate noise level). Lack of operational data precludes this and the assumed value is taken as an average for both take-off and landing operations. Since the aircraft's weight is supported by direct engine lift rather aerodynamic lift during the final approach to landing and initial hover during take-off, the noise levels are approximately equal in any case. This simplified model of the aircraft's noise output yields conservative results at higher altitudes but accurate results at the lower altitudes where the noise constraint is most significant.

TABLE 2

Estimated VTOL Aircraft Performance

	Lift Fan/Cruise Fan
Takeoff	
Time to 50 ft.	6 sec.
Speed at 50 ft.	vertical flight
Conversion	
Speed Change	0-180 kts.
Time	36 sec.
Acceleration	5 knots/sec.
Climb Angle	20 deg.
Climb Rate	3800 f.p.m.
Turn Radius at 15 deg. Bank	1190 ft. at 60 kts. 5800 ft. at 180 kts.
Conversion to Approach Configuration	40 sec. to convert from aerodynamic lift at 208 kts. to powered lift and slowdown to 45 kts., decel. rate = 4.1 kts./sec.
Speed Range for Vectoring in Terminal Area	45-150 kts.

Chapter III

Application and Operation of Computer Generated Display

3.1 General

The ultimate objective in the terminal area study is to determine acceptable approach and departure paths for a specified site. The approach taken in this study requires the accomplishment of the tasks outlined in Figure 4. In the preliminary stage of the analysis, information describing the terminal area and the nature of the constraints is compiled and reduced into a form acceptable to the computer. The computer then processes and displays the desired images. Specifically, the preliminary stage involves the following tasks.

(1) Review site proposals and select trial site.

(2) Identify and define the major constraints and accompanying criteria.

(3) Transpose information describing the terminal area into suitable map models.

In the preceding chapter, an attempt was made to define the major constraints in the terminal environment and to set reasonable constraint criteria. This chapter is concerned with the final phase in the study, the application of the computer graphics display in synthesizing the approach and departure paths. The Boston metropolitan area has been studied extensively in previous work and will be used as a demonstration model in this chapter.

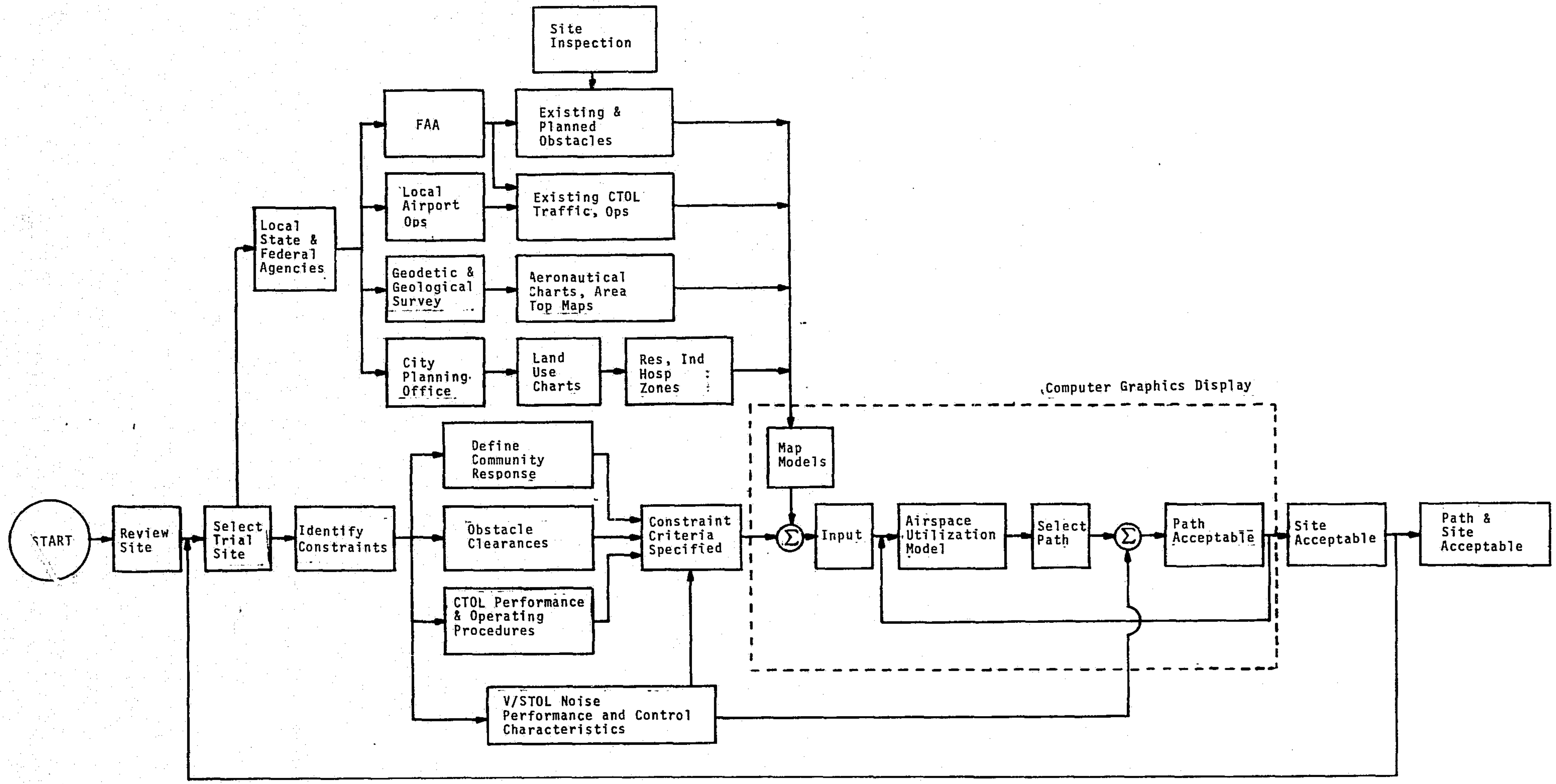


FIGURE 4 PLANNING SEQUENCE DIAGRAM FOR THE DETERMINATION OF V/STOL FLIGHT PATHS

3.2 Description of Display

3.2.1 Computer Graphics

The technique involves the generation of graphic representations of the terminal area and surrounding airspace constraints with a computer generated display. An Adage Graphics Terminal (AGT 30) was used. The graphics terminal consists of a general purpose digital computer with both computational and image processing capabilities. The user programs the machine to generate a set of lines or text on a cathode ray tube which results in images that can be scaled, displaced and rotated in three-dimensional space. Real time interaction with the program is achieved through a set of function switches and variable control dials. These interactive devices allow the programmer to select various subimages, to call specified subprograms or to change certain program variables. Details on hardware and software implementation are given in Appendices A and B.

3.2.2 Airspace Utilization Model

The airspace utilization model is a graphic representation of all the terminal constraints at any given altitude level. Two basic input mechanisms are used in building a complete description of the model. The first involves fixed map model inputs such as geographical features, CTOL traffic routings, obstructions and noise sensitive areas which completely describe the terminal area. The map models which are defined and stored in external programs are singly dimensioned arrays containing the coordinates of noise sensitive areas, obstacle locations, traffic waypoints and other geographic features. These map coordinates are subsequently scaled and translated in the main program and defined with respect to a set of axes at the center of the CRT. On line teletype input, the second basic input mechanism, is a unique and essential feature of the program. With this capability the user may specify any set of constraint criteria he desires, thereby building several airspace model descriptions. Significant constraint parameters are obstacle lateral and vertical clearances, peak aircraft noise level and acceptable residential noise values.

The display operation is outlined in the functional diagram in Figure 5. The machine first requests the map coordinates of the VTOL port site, which subsequently positions a rectangular vertiport image at the origin of a right-handed coordinate system centered in the CRT. The coordinate system is oriented with the z axis out of the CRT and as diagrammed in Figure 6, the x, y and z axes correspond to east, north and vertically up, respectively. Constraint criteria inputs such as desired obstacle clearances and residential and aircraft noise values are then selected. The computer now has all the necessary information to construct the airspace model image. The operator selects the altitude plane he wishes to view and the machine displays in plan view (x-y plane), the airspace utilization at that altitude. Obstacle restrictions appear as circles with radii equal to the specified lateral clearances. Noise restrictions appear as equidistant contours about noise sensitive areas where the horizontal distance extending from the areas is a function of both altitude and the distance required for sound energy attenuation to the specified noise criteria. Figure 7a is a photograph of the computer generated display, showing in plan view, the 1000 ft. plane for the Boston metropolitan region. The vertiport is shown at the center of the photograph. A true north indicator in the upper right-hand corner of the photograph and a corresponding set of axes establish image orientation. For this demonstration, an acceptable residential value of 80 PNdb is specified (after applying a 15 db CNR correction). The noise sensitive areas are outlined by dashed lines in the ground plane and the resulting noise restricted airspace at the altitude is within the contours. An aircraft operating within or on a noise

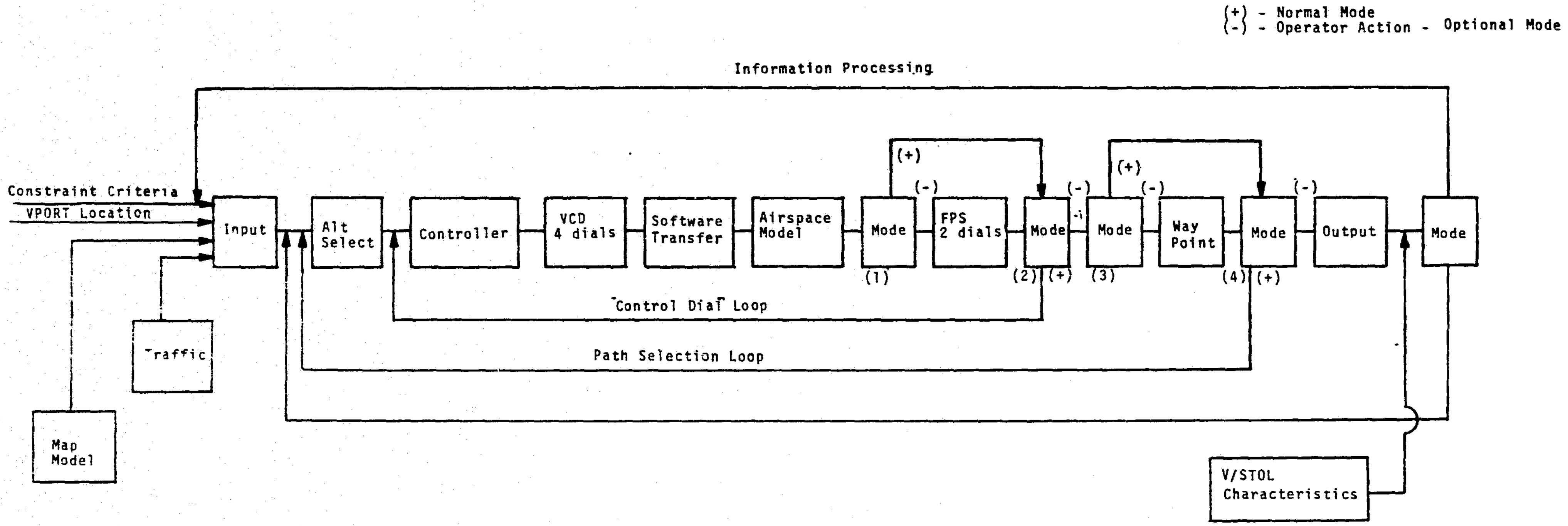


FIGURE 5 FUNCTIONAL DIAGRAM OF COMPUTER DISPLAY

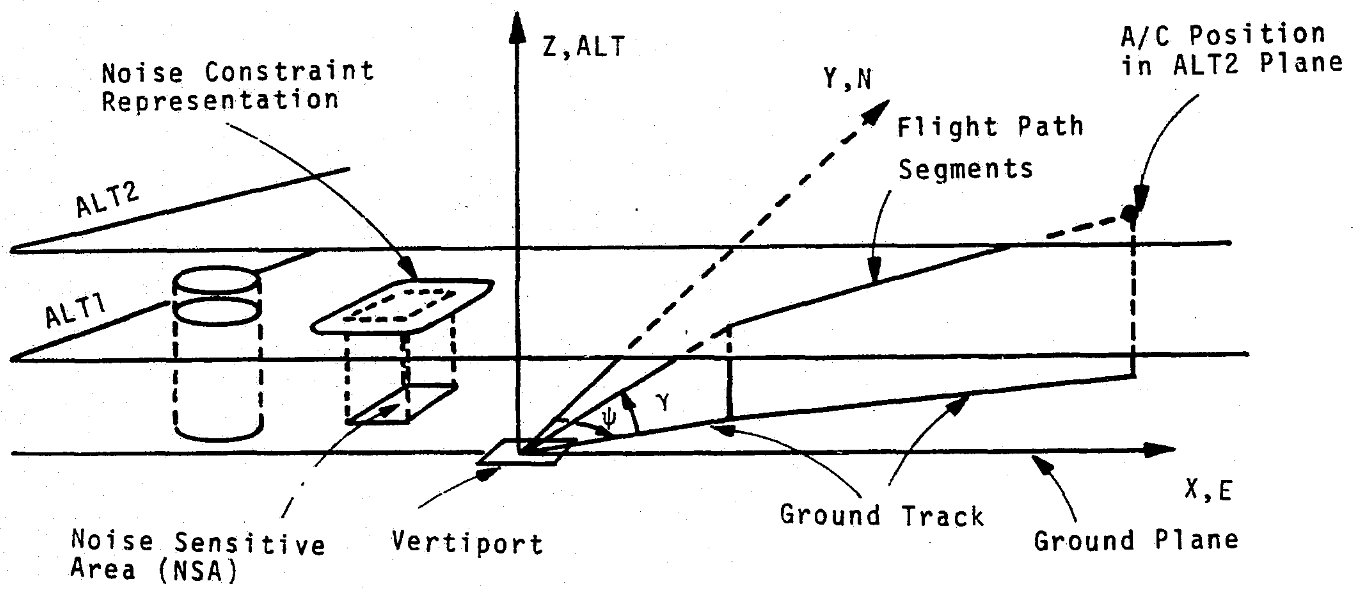


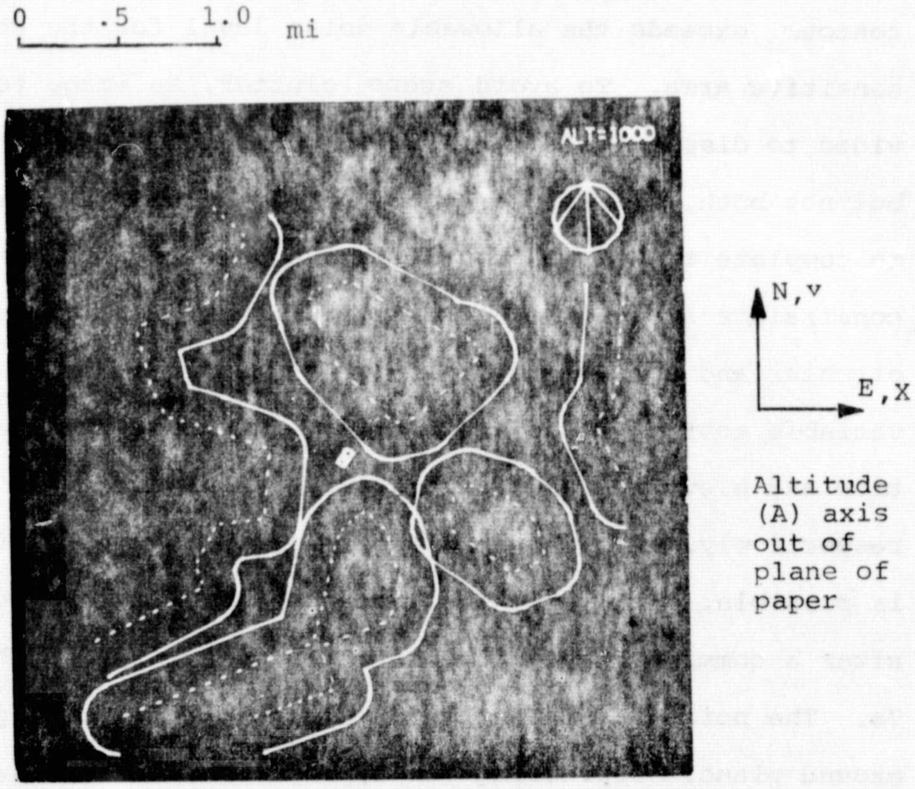
FIGURE 6 AIRSPACE MODEL GEOMETRY

AC DB = 90

CNR = 80

Noise Sensitive Areas in Ground Plane

Obstacles not shown.



Altitude (A) axis out of plane of paper

Figure 7a Noise Restricted Contours in 1000 ft Plane

AC DB = 90

CNR = 80

1000 ft Obstacle Clearance

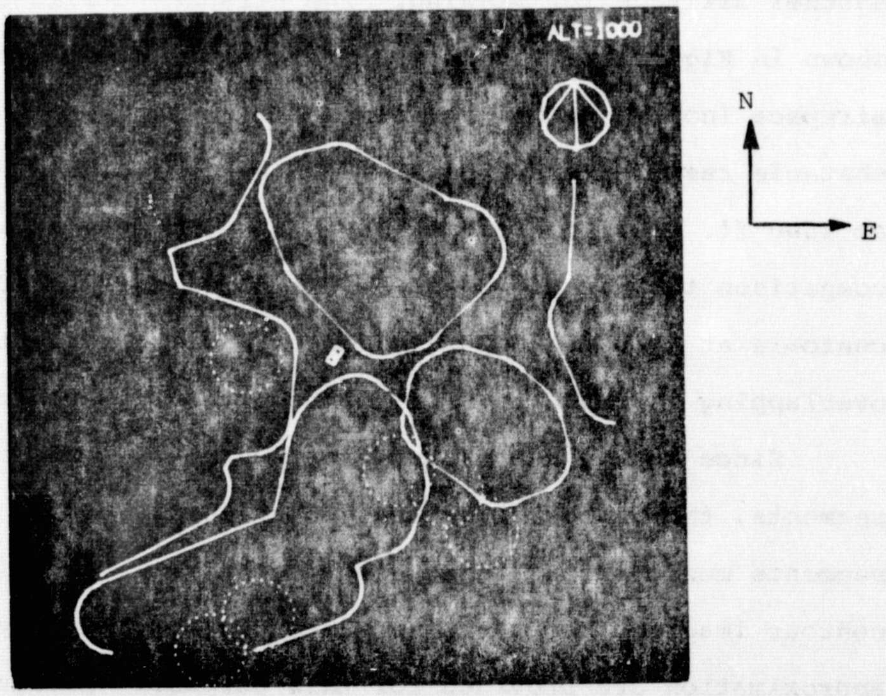


Figure 7b Airspace Utilization at 1000 ft

Note: All aircraft noise rating at 500 ft. All residential values are in PNdb. Altitude scale is doubled.

contour exceeds the allowable noise level for the corresponding noise sensitive area. To avoid scope clutter, an image select mode is provided to display either the noise sensitive areas or obstacle restrictions but not both. In Figure 7b the obstacle restrictions have been included to complete the airspace utilization model at 1000 feet. To satisfy the constraints at this level, V/STOL aircraft must operate outside the circular and contour regions. In the normal mode of operation, four variable control dials are available to command image scaling, translation and elevation and azimuth rotations about the x and z axes respectively. Thus three dimensional image viewing from any direction is possible. Figure 8, for instance, illustrates the resulting view after a commanded elevation rotation is applied to the image in Figure 7a. The noise sensitive contours appear in a plane parallel to the ground plane. Depressing the appropriate function switch (mode switch #2 in Figure 5) turns off the display and allows the operator to select another altitude for viewing. The airspace utilization at 500 ft. is shown in Figure 9a. There is considerably greater noise restricted airspace (note contour overlapping) as well as an increased number of obstacle restrictions. Figure 9b illustrates the reduced noise contours at 1500 ft. where the noise sensitive areas are shown for reference and comparison to Figures 7a and 9a. Figures 10a and 10b show the noise contours at 1500 and 1000 ft. for a 93 PNdb aircraft. Extensive contour overlapping is indicative of the reduction in usable airspace.

Since curvilinear boundaries must be approximated by straight line segments, the degree of accuracy that is desired in drawing curved segments must be specified. Two program variables (for obstacle and contour images), representing the angle sustended by the chord segment approximation are provided for this purpose. A value of 30 degrees yields only a 4% error in chord-arc modelling and is adequate in most cases. A smaller angle provides a finer approximation, of course, but

AC DB = 90

CNR = 80

Obstacles not shown

NSA in Ground Plane

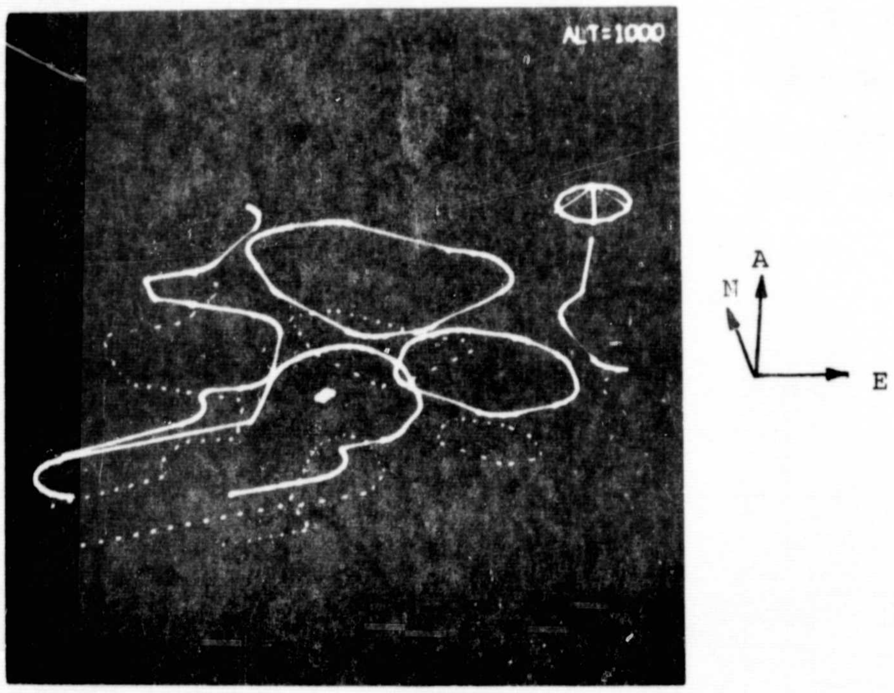


Figure 8 3D View After X Axis Rotation

AC DB = 90

CNR = 80

Note Increased Obstacle Restrictions and Contour Overlap

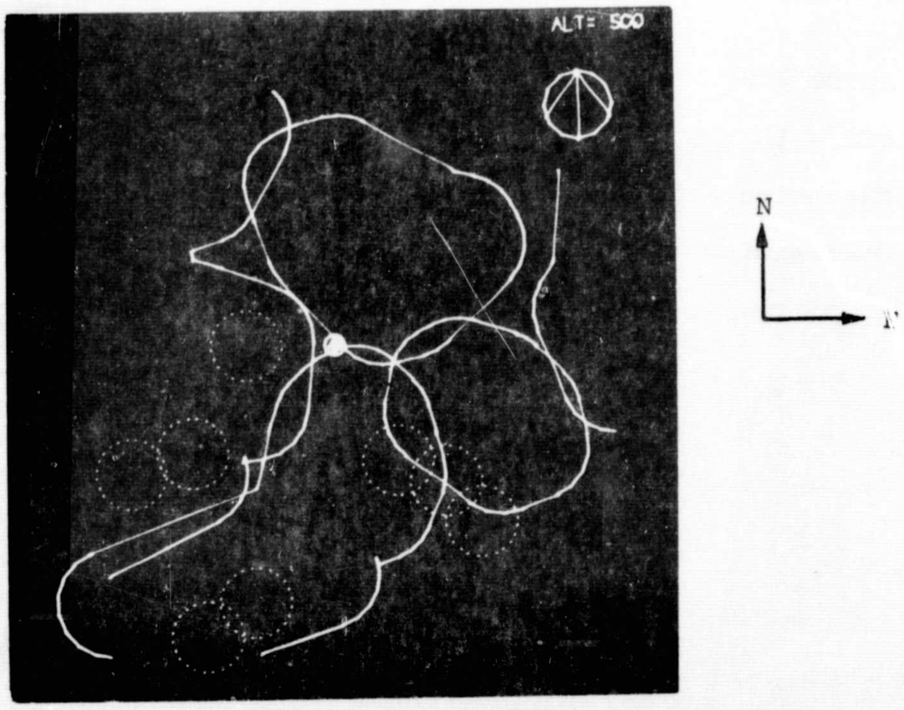


Figure 9a Airspace Utilization at 500 ft

AC DB = 90
CNR = 80
Ground NSA
are shown

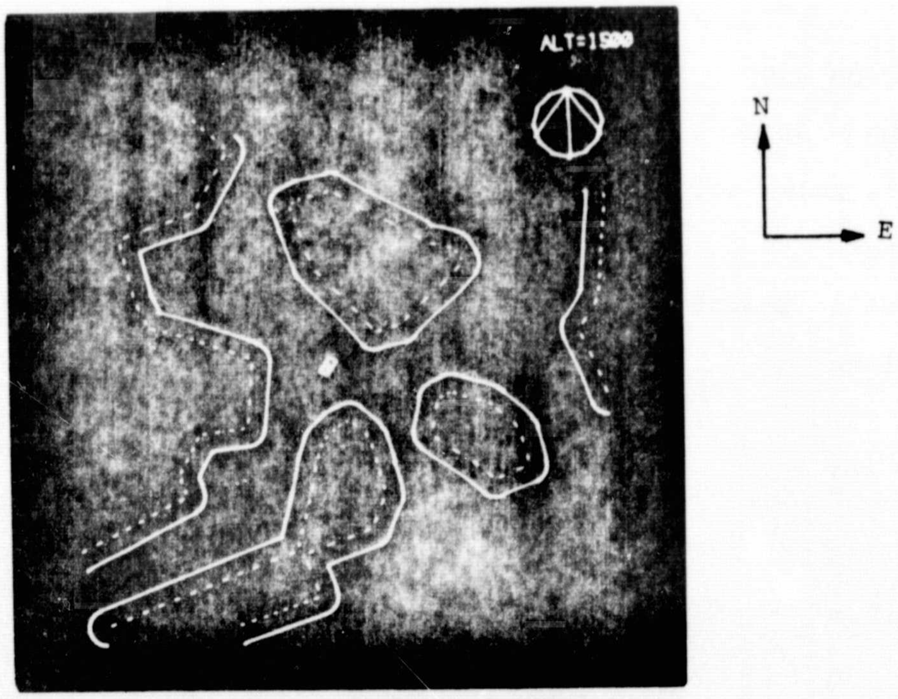


Figure 9b Noise Contours at 1500 ft., 90 db A/C

AC DB = 93
CNR = 80
Extensive Contour
Overlapping

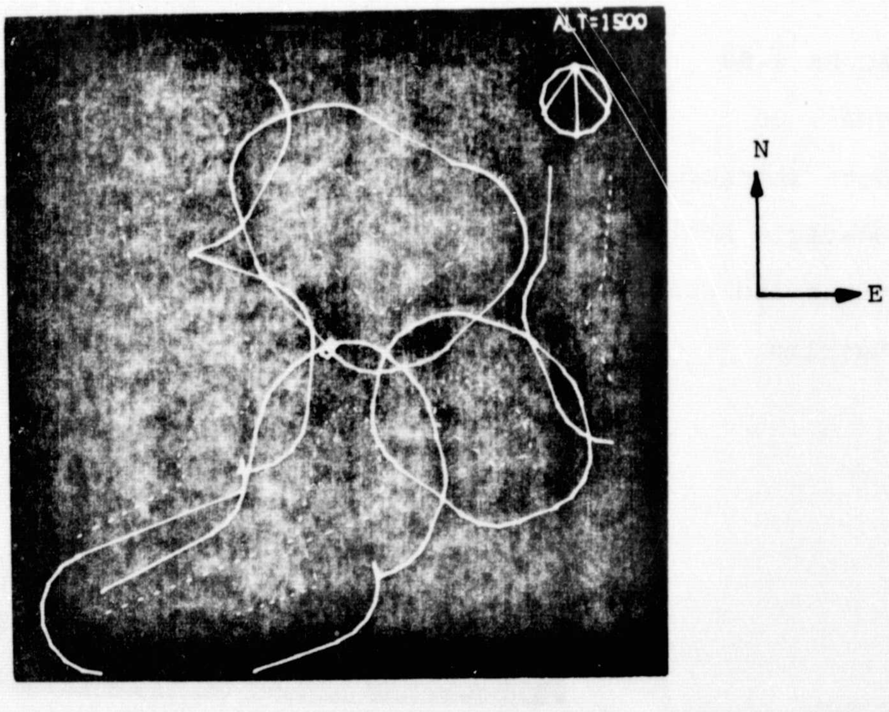


Figure 10a Noise Contours at 1500 ft., 93 db A/C

AC DB = 93

CNR = 80

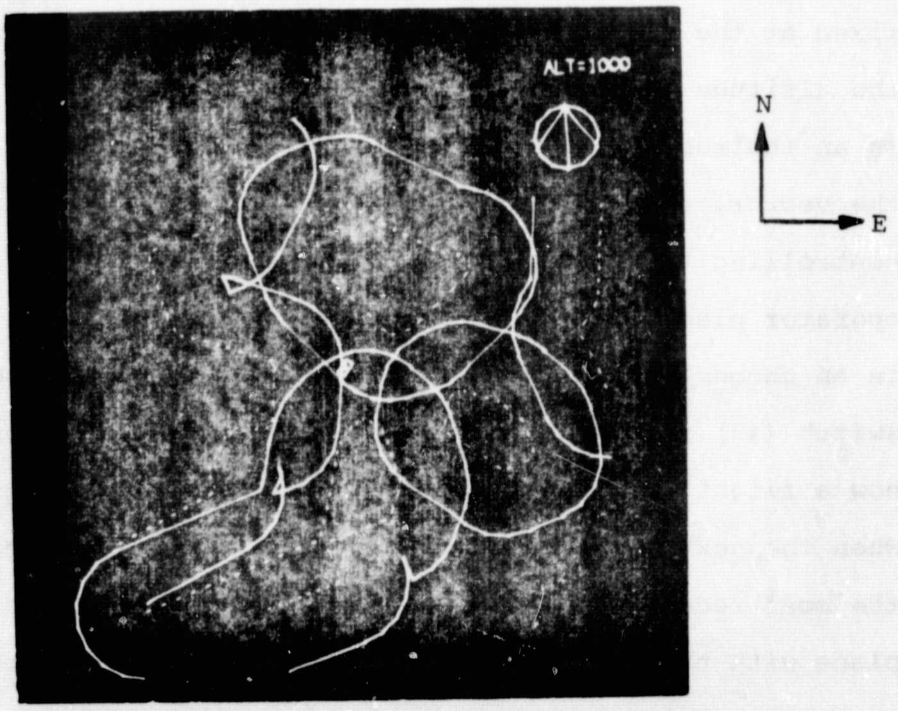


Figure 10b Noise Contours at 1000 ft., 93 db A/C

is undesirable since it increases the time required to process and draw line elements.

3.2.3 Flight Path Selection

The flight path selection process, indicated in Figure 5, requires the activation of a mode (#1) which displays in addition to the airspace model, the FPS (Flight Path Selection) image. The FPS image consists of a vector whose magnitude and azimuth are controlled by two variable control dials. The objective is to locate the vector, representing the aircraft's actual flight path, in unconstrained airspace. Path construction proceeds in segments, each segment defined between selected altitude levels. The initial point of the vector is at first fixed at the vertiport and the end point is constrained to move in the altitude plane currently being examined. Hence, vector magnitude is an indirect measure of the aircraft's flight path angle, the larger the vector, the shallower the path angle between altitude levels. By controlling the azimuth and magnitude (elevation) of the vector, the operator places the terminal point, representing the aircraft's position, in an unconstrained region of the altitude plane. Depressing a function switch (#3) instructs the computer to define and store the selected point, now a flight path waypoint, and to proceed to the next altitude plane. When the next altitude is selected, a path line segment is drawn to the most recent waypoint. The operator explores the new altitude plane with the FPS image which has been translated to the last waypoint. This procedure continues until an unconstrained altitude has been reached and/or the operator chooses a new set of constraint criteria. Since it is possible that the path violates the constraints at altitudes other than those which have been examined, provision has been made to reexamine any altitude plane after constructing the path. At an intermediate altitude a circle (FINDR image) locates the path-plane intersection point, thereby permitting the operator to check if the path satisfies the constraints. The two remaining control dials are still available for commanded image rotation in elevation and azimuth.

During path selection the user may request teletype output describing either the most recently defined waypoint or all waypoints defined up to that time. The output consists of waypoint coordinates with respect to the vertiport (in feet), ground track and path segment heading and elevation. This output is then compared with the aircraft's performance capabilities to determine if the path is acceptable.

To fix ideas, the construction of an approach path to a specified site will be illustrated with Figures 8, 9, 10 and the accompanying teletype printout in Table 3. The site is positioned with the specified map coordinates and the elevation of the pad ground level is set at 150 feet. Lateral and vertical obstacle clearances are 1000 feet and 500 feet respectively, and the desired circular arc segment approximation is 30 degrees. A peak aircraft noise rating of 90 PNdb at 500 feet is assumed and the acceptable residential noise value is taken as 80 PNdb. These values may be varied as path selection proceeds. The objective is to determine an approach from the southwest that terminates 50 feet above the landing pad. Since there are no initial conditions for the approach case, path selection proceeds from the vertiport to an unspecified altitude. Following the teletype input/output operation listed in Table 3, it is seen that a vertical (approximately) path segment is constructed from the pad to 200 feet. After selecting a waypoint at 500 feet and prior to viewing the 1000 ft. plane, the operator interrupts normal program operation to redefine the noise constraint parameters. Figure 11 demonstrates the use of the FPS vector in exploring the 1000 ft. plane. A circle with radius equal to the vector projection on the altitude plane indicates the area in

TABLE 3

Demonstration Printout

```
VTOL SITE -X,Y MAP COORD- & PAD ELEV
-.31
-.3
150.

LAT & VERT OBSTRUCTION CLEARANCE, ARC MODEL
1000.
500.
30.                                                  Constraint Input
                                                     Parameters
RESDEN & AC DB VALUES, ARC MODEL
80.
90.
20.


            SELECT ALTITUDE
200.


            SELECT ALTITUDE
500.

RESDEN & AC DB VALUES, ARC MODEL
80.
88.                                                  Redefine Noise
20.                                                  Criteria


            SELECT ALTITUDE
1000.

            SELECT ALTITUDE
1300.


            SELECT ALTITUDE
1500.


TERMINAL AIRSPACE FREE OF CONSTRAINTS
PROCEED TO OR FROM ENROUTE ASSIGNMENT



                         FLIGHT PATH PARAMETERS

CNR    AC DB    MAG HDG    FPA    ALTITUDE    X POSIT    Y POSIT    GRD TRK
 80     90        243      83.0
                                     200          4          4          6
 80     90        248      16.1
                                     500       -827       -617       1032
 80     88        208      13.1
                                    1000      -1317      -2715       3187
 80     88        235       3.6
                                    1300      -4380      -6304       7898
```

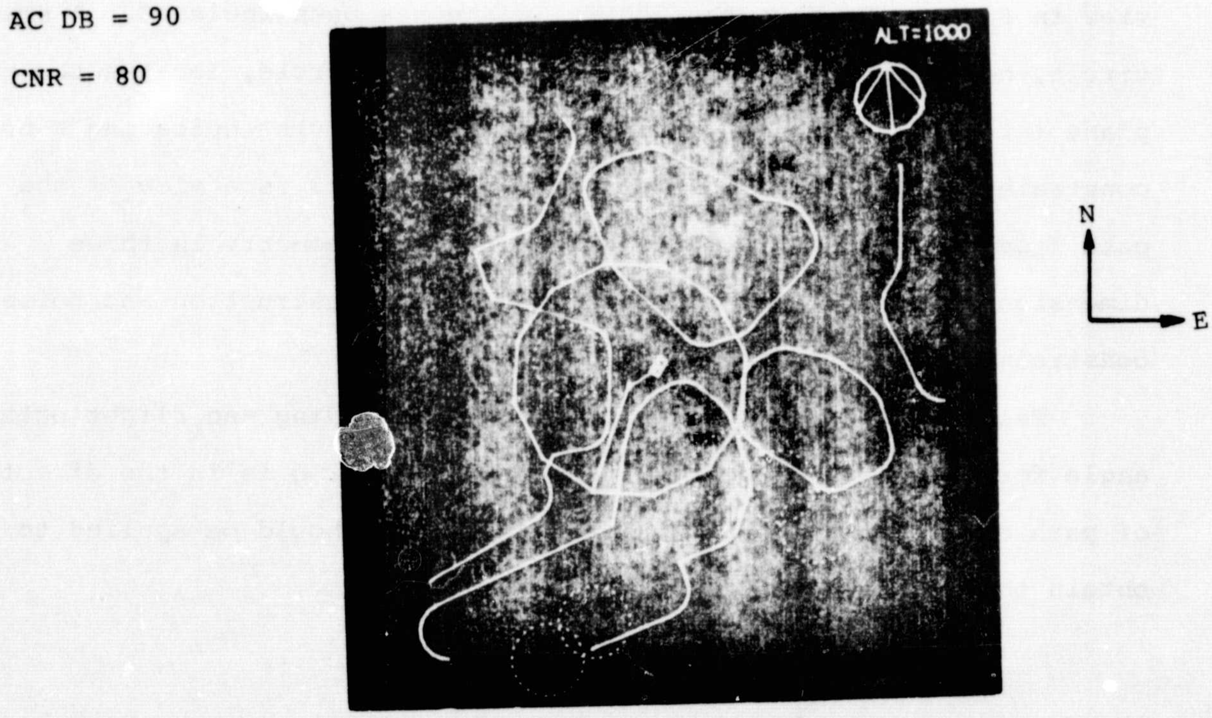


Figure 11 Flight Path Selection in 1000 ft Plane.

consideration and provides a qualitative measure of the flight path angle. After locating the terminal point of the vector (intersection of the vector and circle) in an unconstrained region of the plane, the operator instructs the computer to define and memorize this as the next waypoint and proceed to the next altitude. Upon reaching the 1500 ft. plane, the computer informs the operator that an unconstrained altitude has been reached. The resulting approach is shown in plan view in Figure 12 where the 700 ft. plane has been included. A small circle, hereafter referred to as the "finder" circle, locates the path-plane intersection point within one of the contours indicating a noise constraint violation at this altitude. Figure 13 is a view of the path from the southeast, illustrating the path geometry in three dimensions. At 150 ft., the pad is below the obstruction and noise constraint regions in the 700 ft. plane.

Teletype output provides the magnetic heading and flight path angle for each path segment. The magnetic heading is in the direction of path construction so a 180° transformation should be applied to obtain the approach headings.

AC DB = 90

CNR = 80

Note Finder Circle Locating Path Plane Intersection

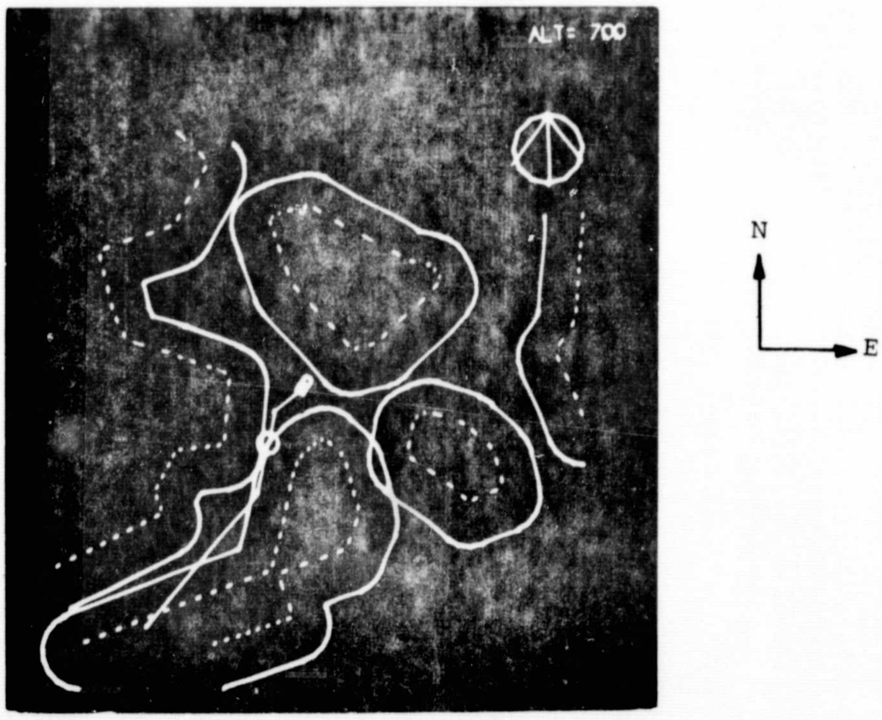


Figure 12 Northeast Approach, Plan View

AC DB = 90

CNR = 80

Note Finder Circle

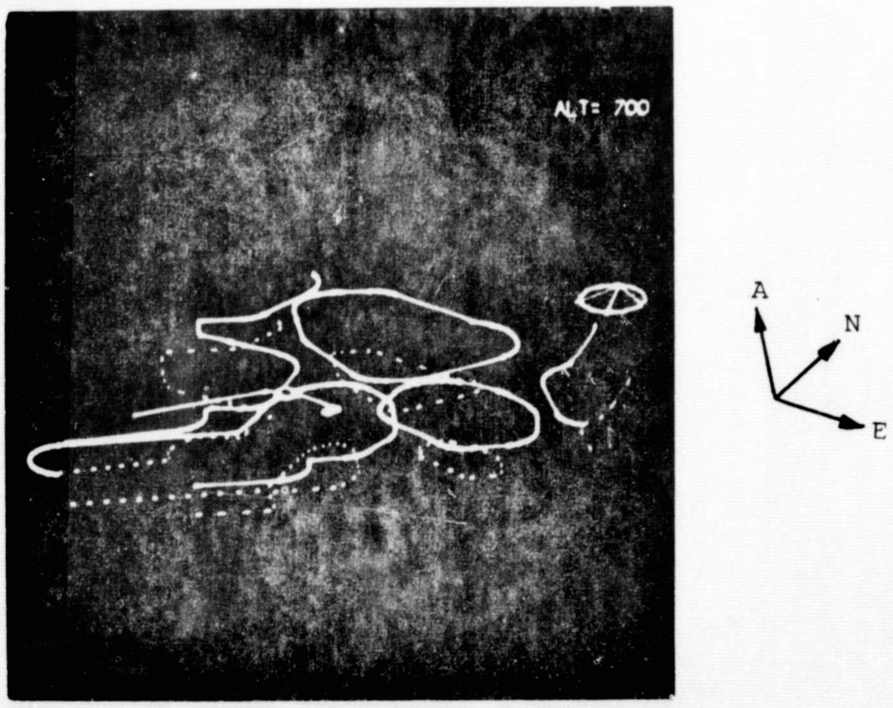


Figure 13 Northeast Approach, 3D View

Chapter IV

Site Analyses

4.1 General

The previous chapters have described the computer display development and the implementation procedures for use in synthesizing approaches and departures. In this chapter, the application and usefulness of the design program will be demonstrated in the analyses of several sites in different localities.

The generality of the display program results from the fact that all map data is stored in files external to the main program. Consequently, adapting the program for other localities entails only the creation of new map data files. However, it is impossible to develop a program that can handle all the specific features and characteristics of a given site. The program has been designed with the necessary elements and subprograms to treat the fundamental constraints of noise, obstacles and traffic and the required image descriptions. In applications to other sites, it may be necessary to make minor additions or modifications to the program to illustrate, for instance, special geographic features or CTOL airports. The modifications are easily accomplished without disturbing the fundamental structure of the program (See Appendices A & B).

Reference 4 contains a detailed analysis of three sites within the metropolitan Boston region. It provided the motivation and basis for the computer display development and should be regarded as a companion study. The sites considered in this chapter were chosen because they are prime candidates for a future V/STOL short-haul flight transportation system. All are located near city centers where the constraints are most critical. Two of the sites, in Boston and Hartford, are currently being considered for the recently proposed

Pan American/Sikorsky helicopter shuttle service for the Northeast Corridor.[10] The remaining site, at Washington's Union Station, has been proposed for a future V/STOL transportation system. The intent of this chapter is not to evaluate the desirability of the sites, but rather to develop approaches and departures for the given locations. Many site determining factors not provided in this study should be considered in such an evaluation. However, whenever appropriate, comments will be made regarding the site locations.

The computer display is an effective synthesis tool in terminal area studies, drastically reducing the time and effort spent in the study. However, in a typical application a good deal of time is spent during the preliminary phase of the analysis in the tedious process of locating the noise sensitive areas, assigning map points and establishing data files for the computer program (altogether a 6-10 hour task). The actual planning of the approach and departure routes consumes from one to two hours depending upon how extensively the area is examined. This represents a ten-fold time reduction over the comparable manual task. The computer display program has the capability for multiple constraint criteria inputs, thereby permitting extensive site analysis not possible when performed manually. Further reductions in time spent in the preliminary phase may be achieved with an Adage Data Tablet (see Appendix A.4). This device, not available at the M.I.T. facility, allows the operator to trace map boundaries with a special pick-up stylus. Hence real time map modelling is possible through discrete or continuous stylus inputs.

4.2 Presentation Format

A description of the general locality, major constraints and resulting airspace utilization is given for each site. Approaches are developed from all possible directions and the results are documented in photographs and the accompanying data output in Table 4. Three dimensional views show the general characteristics of the path and indicate any violation of the constraints at a specified altitude. The true north indicator in the photograph and the associated set of axes orient the resulting images. In some cases, the noise sensitive areas are outlined in the ground plane. Departure paths have not been shown since in almost all cases the maximum climb capabilities of the aircraft must be employed. Departing aircraft utilize vertical rise noise abatement by ascending 100-200 ft. above the pad before climbing out at 20° to 2000 ft.

4.3 Boston

This site, suggested in Reference 10 is located near Boston's North Station and the State Dept. of Public Works building about $\frac{1}{2}$ mile northwest of the central business district. The surrounding area is characterized by residential areas on all sides and major obstructions to the southeast. CTOL traffic to the north, generated by departures from Logan runway 33L, presents no major constraint, since it may be easily re-routed or avoided.[4]

Figures 7,8 and 9 of Chapter III provide an accurate representation of the airspace utilization for the Boston region. The 80 PNdb residential value results from assuming a CNR value of 95 PNdb and applying a 15db correction due to 100% flight path utilization with at least 20 operations/hr. between 0700-2200 hours (see Table 1). A peak aircraft noise value of 90 PNdb at 500 feet is for an advanced state of the art V/STOL aircraft with quiet engines. As illustrated in Figures 7,8 and 9, the predominant constraint at low altitudes is noise with little variation in noise restrictive airspace at the lower altitudes. Since the only non-restrictive airspace at 500 feet is just west of the vertiport, approaches from the north and southwest are particularly attractive for the specified noise values. However, at the 150 ft. altitude plane, the assumed elevation of the pad, the vertiport is entirely within the noise restricted contours, indicating the possibility of serious adverse reactions from surrounding communities. Surrounding buildings and soundproofing baffles on the pad may provide increased noise attenuation at low altitudes where the noise constraint is most critical. Because of the proximity of the surrounding residential areas, there is little area available for maneuvering about the vertiport at low altitudes. This is a distinct disadvantage since V/STOL's should be able to turn into the wind while maneuvering into final position during the final phase of the approach.

Figure 14 shows a three dimensional view of a southeast approach path passing through the 500 ft. plane. Data output in Table 4 gives the position of the selected waypoints with respect to the vertiport and the flight path characteristics. In all the photographs the altitude scale has been doubled for easier viewing. Consequently, the paths are not as steep as they appear and Table 4 should be referred to for a true indication of path elevations. The "finder" circle locates the path just outside the noise restricted contours at the 500 ft. altitude. However, the noise constraint must be violated below 500 ft. if the aircraft's performance limitations are not exceeded. All paths terminate in a hover 50 feet above the vertiport surface which is 150 ft. above ground level.

The display program is useful in aircraft design applications where it is desired to study the tradeoff between aircraft performance and noise reduction. For instance, the only way the southwest approach shown in Figure 15 can be accomplished is by reducing the aircraft's noise level at 500 and 1000 feet. Referring to Table 4 for the corresponding printout, it is evident that even small db reductions result in considerably greater airspace available for aircraft

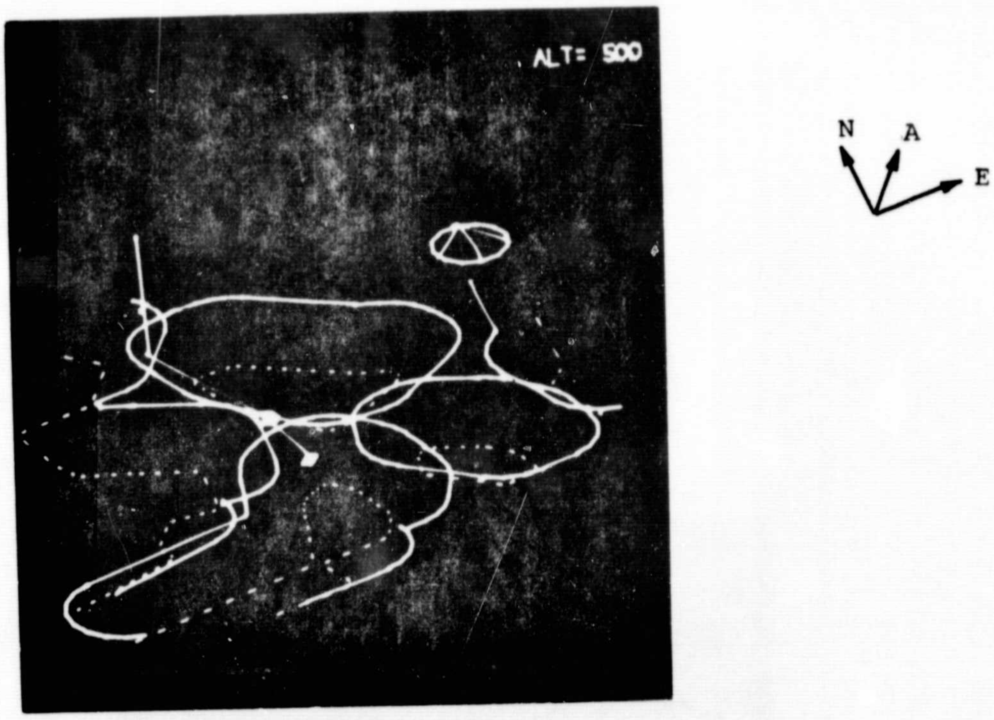


Figure 14 BOS-Southeast Approach

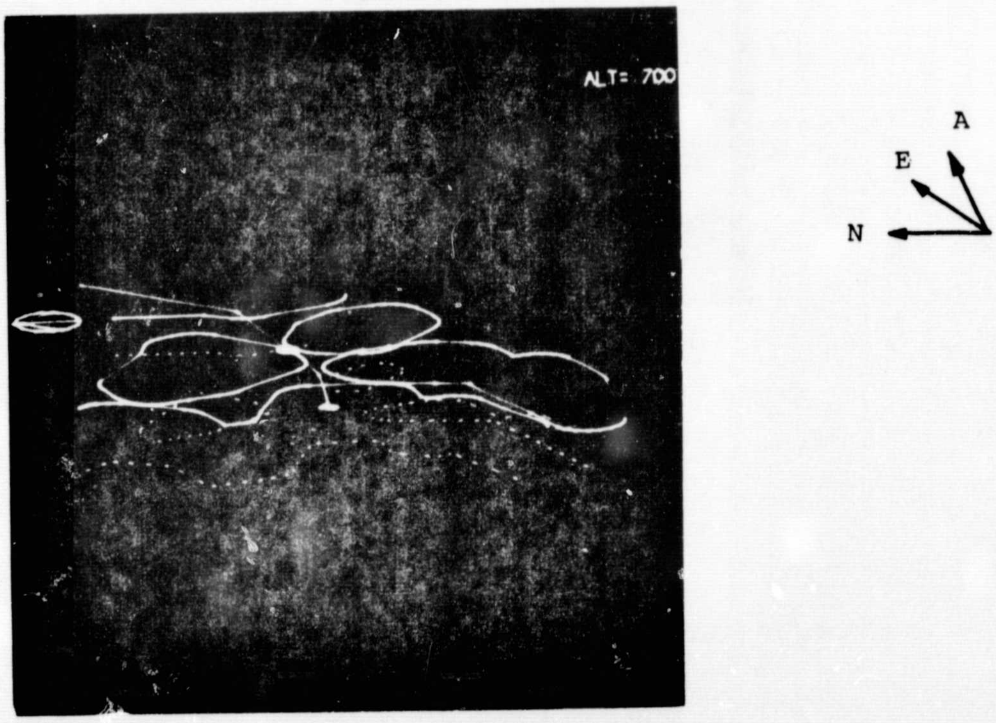


Figure 15 BOS-Southwest Approach

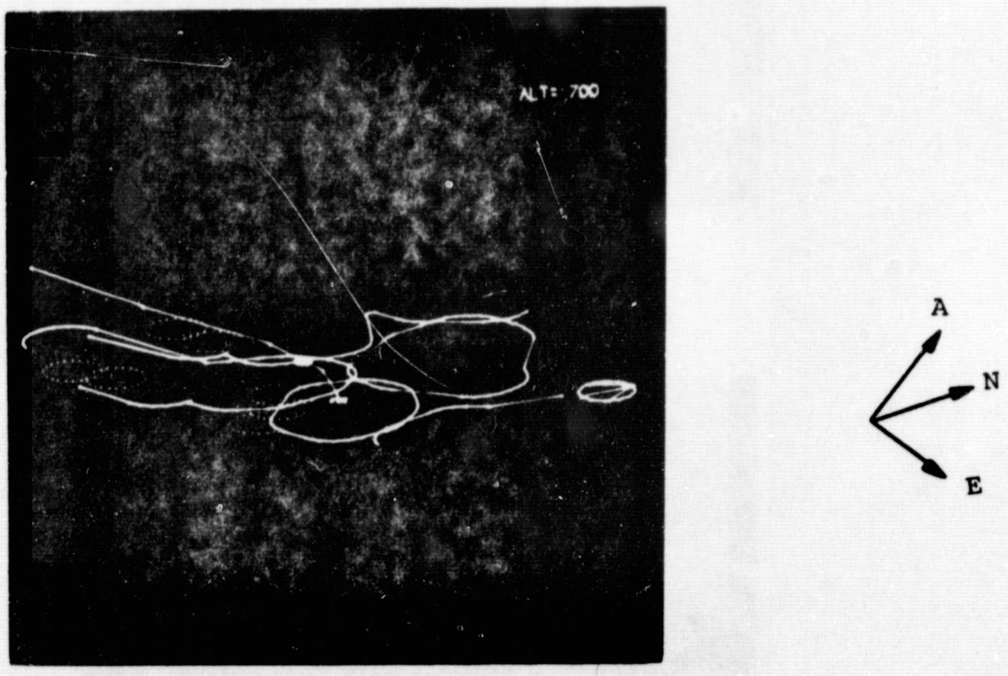


Figure 16 BOS-Northeast Approach

operations.

A northeast approach, similar to the one demonstrated in Chapter III, is shown in Figure 16. In that chapter the approach was to a vertiport examined in Reference 4 which is near the area presently under consideration. A comparison of the data output for both cases shows that much steeper elevation angles are required for noise abatement purposes in the approach illustrated in Figure 16. As might be expected, repositioning the site relatively small distances, in this case about $\frac{1}{2}$ mile, makes a significant difference in ground level noise exposure and flight path characteristics. However, for reasonable glide slope angles, this approach must pass through several noise contours at low altitudes. Note that the finder circle locates the path-plane intersection point in a region of overlapping contours at 700 feet.

4.4 Hartford/Brainard Airport

Another site suggested in Reference 10 is at Brainard Airport (72'-39", 41'-45") approximately two miles southeast of the city of Hartford. As shown in Figure 17, the vertiport is bounded on the east and west by residential areas with Rentschler Field about one mile to the northeast. Rentschler runways 4/22 and 36/18 as well as the take-off and landing traffic are shown in the photograph. Two vertiport positions were considered in the analysis, one at the north and the other at the south end of Brainard runway 02. Brainard's runways are not shown in the photograph.

The airspace utilization is shown in the ground plane in Figure 18 with an 80 PNdb residential noise value and 90 PNdb aircraft rating. Even at the most critical position, at the north end of Brainard runway 02, the vertiport is outside the noise contour of the nearest area. With an increased aircraft noise rating of 95 PNdb, the vertiport

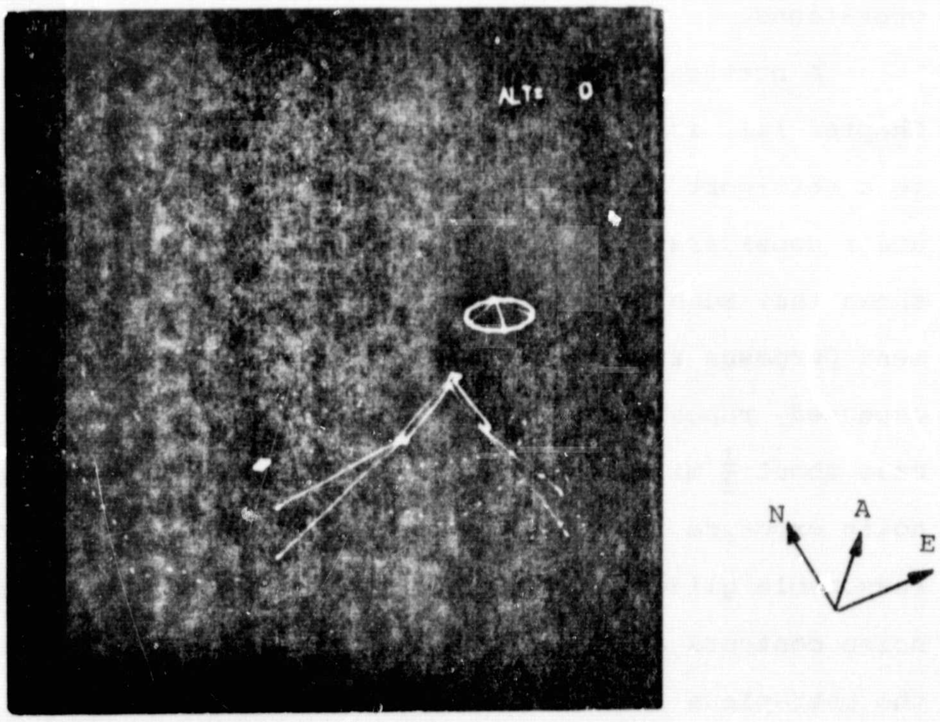


Figure 17 HRD Terminal Area

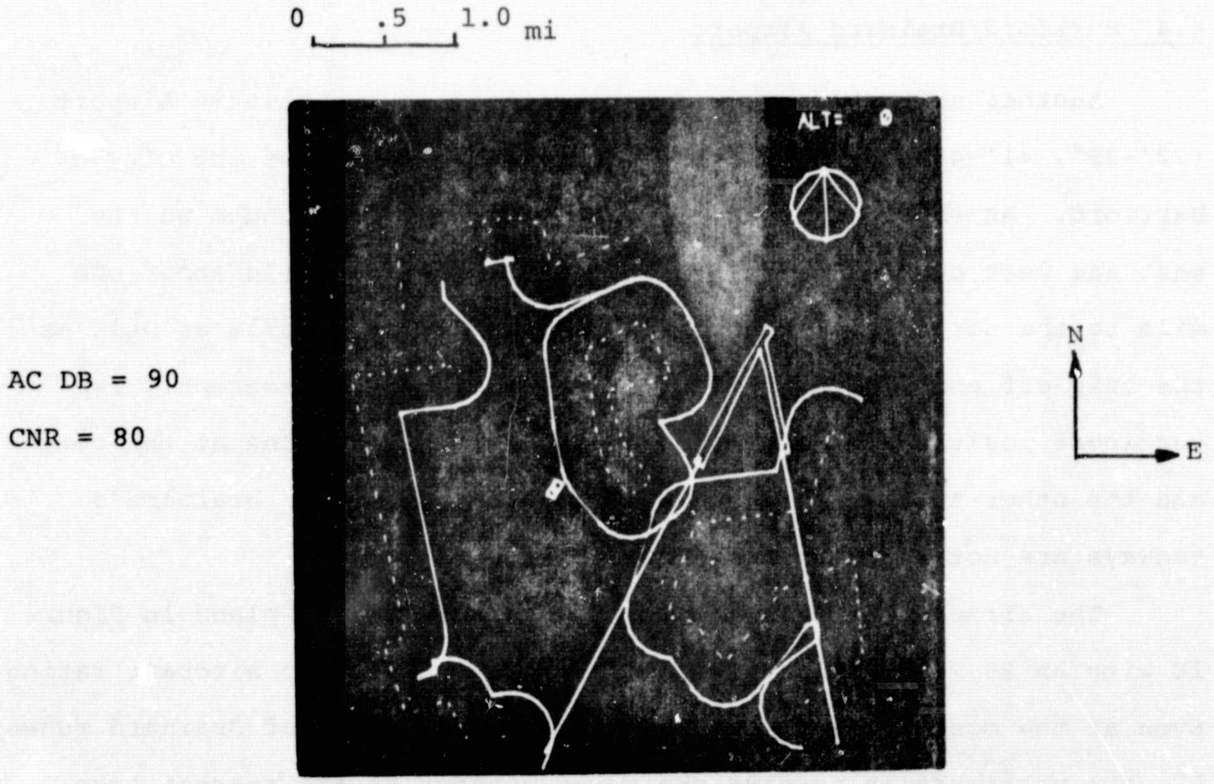


Figure 18 HRD Airspace Utilization at Ground Level

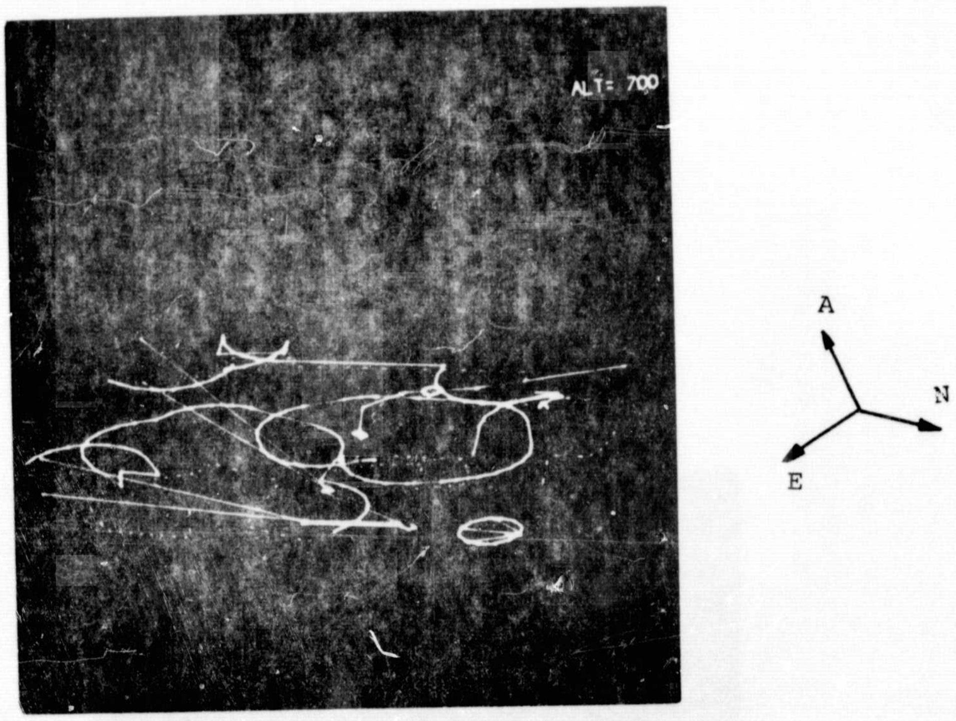


Figure 19 HRD-Southeast Approach

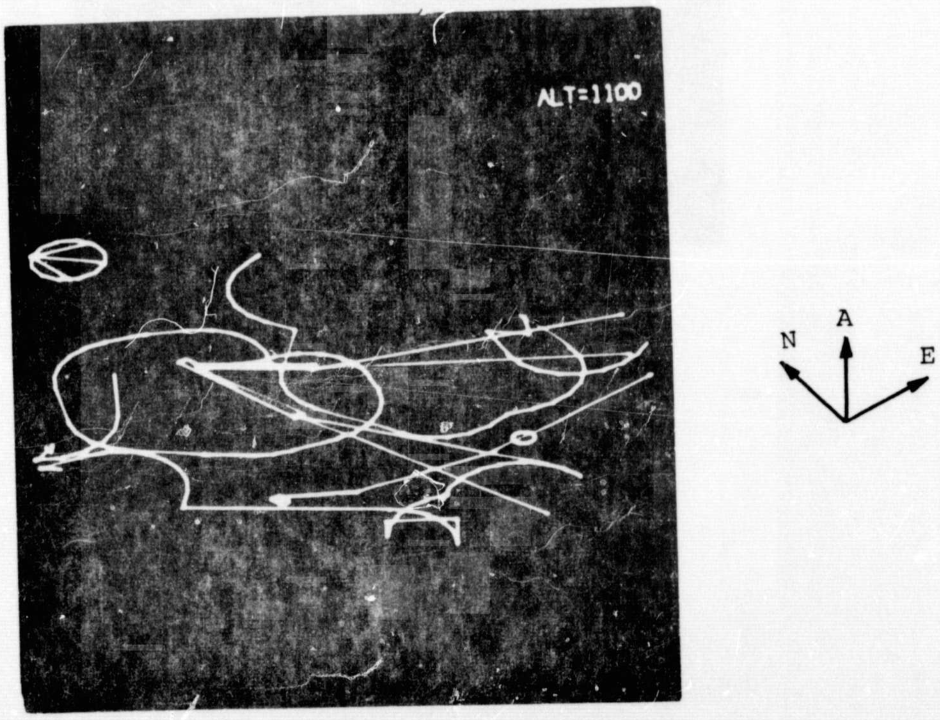


Figure 20 HRD-Northwest Approach

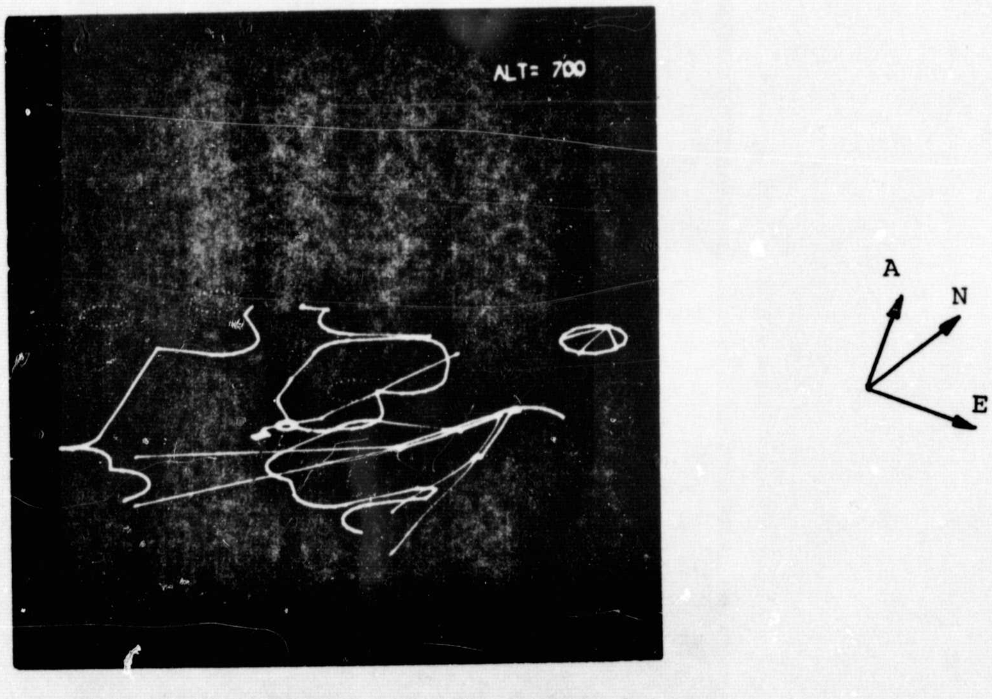


Figure 21 HRD-Southwest Approach

should be located south on the airport grounds. Although noise restrictions do not present difficulties at low altitudes, the requirement to avoid the noise contours at the higher altitudes (~1000 ft.) during the beginning of the approach, results in relatively steep glide angles in the final phase of the approach. Figure 19 shows a southeast approach for an aircraft noise rating of 95 PNdb. There is ample clear space about the vertiport so that aircraft can perform final approach maneuvers away from noise sensitive areas. Approaches from the south encounter conflicts with the CTOL traffic corridors established by take-offs and landings on Rentschler runways 4/22 and 36/18. Figure 20 illustrates such a conflict at 1100 ft., involving steep V/STOL approaches and departing Rentschler aircraft. If the vertiport is located at the south end of Brainard runway 02 then conflicts result with CTOL approaches to Rentschler runway 04.

An alternative to the northwest approach of Figure 20 is shown in Figure 21. In this case, V/STOL aircraft pass directly over Rentschler airport at 1000 feet, thus avoiding conventional traffic while satisfying the noise constraint.

4.5 Washington/Union Station

Union Station is often proposed as a site for a future V/STOL transportation system because of its proximity to downtown Washington, D.C. ($1\frac{1}{2}$ miles). The general area is very restrictive with residential areas on the west, north and east and the U.S. Capitol $\frac{1}{2}$ mile to the south. At the present time, the area bounded by the U.S. Capitol and the Washington Monument is designated as a prohibited traffic control area. It seems unlikely that this will change in the future and thus V/STOL approaches and departures would be confined to a narrow sector over the Union Station railroad yards.

Figure 19 illustrates the noise contours at 700 feet with an 80

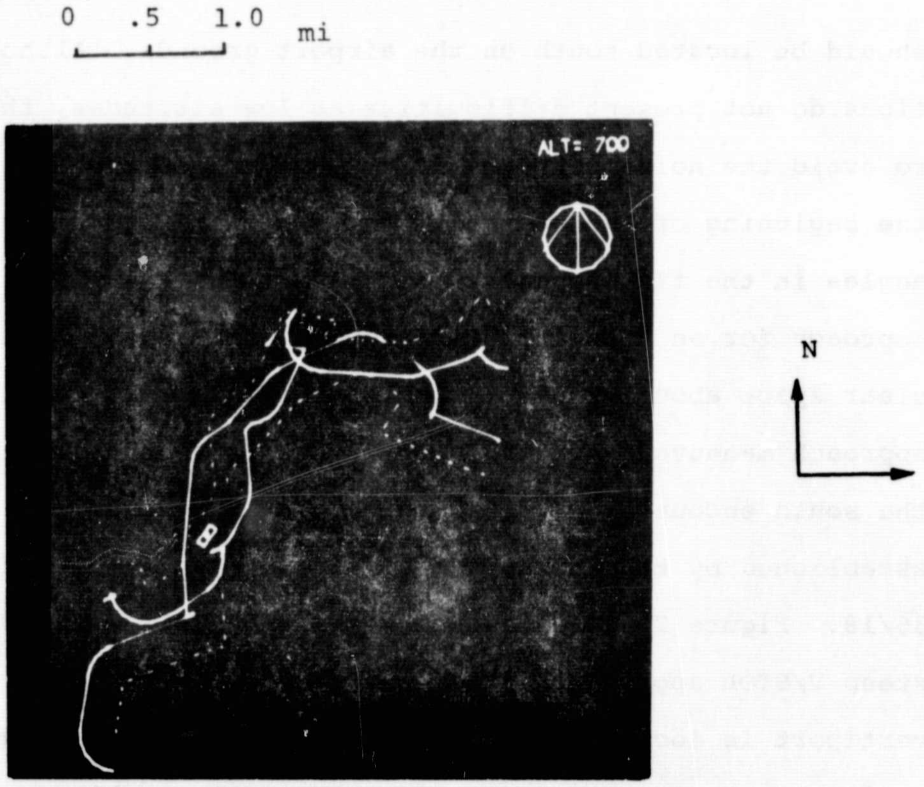


Figure 22 WASH-Noise Constraints at 700 ft.

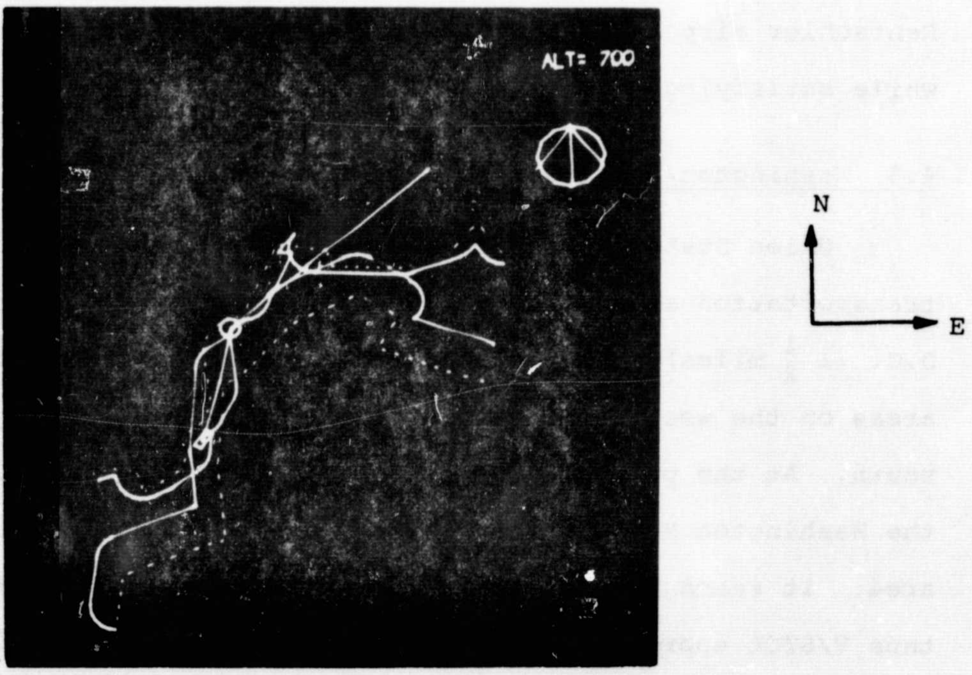


Figure 23 WASH-Southwest Approach

TABLE 4

Approach Path Waypoints*

FLIGHT PATH PARAMETERS

CNR	AC DB	MAG HDG	FPA	ALTITUDE	X POSIT	Y POSIT	GRD TRK
80	90	347	86.4				
				199	1	2	3
80	90	343	12.8				
				500	-688	1130	1323
80	90	331	9.1				
				1000	-2856	3395	4458
80	90	28	7.1				
				1500	-1910	7305	8481

BOS - Southeast Approach

FLIGHT PATH PARAMETERS

CNR	AC DB	MAG HDG	FPA	ALTITUDE	X POSIT	Y POSIT	GRD TRK
80	90	234	0.0				
				200	0	0	0
80	89	68	20.6				
				500	643	475	799
80	88	97	10.1				
				1000	3419	817	3597
80	88	45	5.7				
				1500	5961	5202	8648

BOS - Southwest Approach

* Notes: Subtract 180° from magnetic headings to get approach heading to vertiport

Altitudes are above ground level (AGL)

TABLE 4 (cont.)

FLIGHT PATH PARAMETERS

CNR	AC DB	MAG HDG	FPA	ALTITUDE	X POSIT	Y POSIT	GRD TRK
80	90	45	88.8				
				200	0	0	1
80	90	330	21.7				
				500	-526	541	754
80	90	231	19.7				
				1000	-1357	-577	2148
80	90	226	7.1				
				1500	-3432	-4017	6165
80	90	241	5.7				
				2000	-7062	-7517	11191

BOS - Northeast Approach

FLIGHT PATH PARAMETERS

CNR	AC DB	MAG HDG	FPA	ALTITUDE	X POSIT	Y POSIT	GRD TRK
80	95	289	85.1				
				50	4	0	4
80	95	255	12.7				
				300	-960	-554	1108
80	95	306	8.0				
				500	-2286	-23	2537
80	95	23	7.0				
				1000	-1702	4028	6630
80	95	1	4.3				
				1500	-3212	10474	13238

HRD - Southeast Approach

FLIGHT PATH PARAMETERS

CNR	AC DB	MAG HDG	FPA	ALTITUDE	X POSIT	Y POSIT	GRD TRK
80	95	222	85.1				
				50	1	3	4
80	95	205	8.5				
				500	-551	-2946	2997
80	95	171	5.9				
				1000	1392	-7377	7818
80	95	149	4.5				
				1500	5850	-11829	14105

HRD - Northwest Approach

TABLE 4 (concluded)

FLIGHT PATH PARAMETERS

CNR	AC DB	MAG HDG	FPA	ALTITUDE	X POSIT	Y POSIT	GRD TRK
80	90	169	85.1				
				50	-1	3	4
80	90	152	11.7				
				500	1465	-1592	2163
80	90	95	9.8				
				1000	4308	-1128	5044
80	90	42	3.8				
				1500	7804	5607	12622

HRD - Southwest Approach

FLIGHT PATH PARAMETERS

CNR	AC DB	MAG HDG	FPA	ALTITUDE	X POSIT	Y POSIT	GRD TRK
80	90	29	0.0				
				200	0	0	0
80	89	28	9.7				
				500	424	1701	1760
80	88	33	9.2				
				1000	1387	4641	4854
80	88	65	5.1				
				1500	5753	8212	10480

WASH - Southwest Approach

PNdb residential value and 90 PNdb aircraft rating. Extensive contour overlapping is indicative of the reduced airspace available for operations.

A southwest approach is shown in Figure 23. The aircraft noise rating has been reduced with increasing altitude to accomplish an approach which results in minimal violation of the noise constraint. However, below 500 feet the path is within the noise contours.

4.6 Path Geometry

The preceeding analyses illustrates the effect of various practical constraints on V/STOL aircraft operating in the city center environment. The results tend to confirm and reinforce the basic conclusions reached in reference 4 regarding path characteristics and terminal operations. In most cases, it is necessary to exercise the full capabilities of the aircraft to tailor approach and departure procedures for noise abatement purposes, thereby minimizing the impact of takeoff and landing noise on the surrounding neighborhoods. For instance, in order to avoid steep vertical descents which are costly in terms of fuel and time, steep gradient paths curved in the vertical and horizontal dimensions will be required. Noise abatement considerations force the final approach angles to be about 15°. This more than satisfies the approach plane clearance requirement which in extreme cases is about 10°[4]. Below 1500 ft. narrow three dimensional approach corridors, approximately 600 feet wide and 300 feet high should be established to prevent noise impingement on nearby sensitive communities. The sites considered do not have the omnidirectional approach capability generally assumed in the literature (without violating the constraints). The noise constraint severely restricts air access to vertiports near the city center. With 90 and 95 PNdb aircraft and an 80 PNdb acceptable value, noise difficulties will result from aircraft operation below 500 feet. This may be alleviated in part through appropriate thrust and noise management during the final descent. The program may be used to specify the noise values that will result in acceptable approaches. However, further work should be carried out in this area. Since in most cases few approach corridors are available for a given site, V/STOL aircraft must be able to fly the available approach paths independent of wind direction.

It has been shown that the V/STOL instrument approach providing the best utilization of terminal airspace is a curved decelerating trajectory. The selected paths are consistant with the general performance characteristics outlined in section 2.5.1. However, in order to determine if V/STOL aircraft are capable of flying these curvilinear and steep gradient paths, it is necessary to completely define the approach by specifying the velocity along the path. Therefore, the following velocity profile and sequence of events are suggested for a typical approach.

(a) Enroute aircraft approach at 1500-2000 feet maintaining 1000 ft. wake turbulence separation below CTOL traffic whenever possible. Aircraft ground speed is approximately 150 kts.

(b) At ground track distance of about 2 $\frac{1}{2}$ miles from the VTOL port and an altitude of 1500 ft., the descent is initiated. The initial approach speed is 150 kts. and the glide slope angle is -4°. After decelerating at .1 g between 1300 and 700 ft., the aircraft ground speed is 30 kts. During the deceleration the glide slope angle increases from -4° to -7°. Turning maneuvers which are normally performed below 1000 ft. are limited to 10° banks and 3°/sec turning rates. The radius of turn is less than 1500 feet.

(c) During the final approach leg from 700 ft., the aircraft maintains a constant speed of 30 kts. and increases the glide slope angle to -15° at 500 feet (descent rate is about 700 ft/min). The deceleration to hover is accomplished between 150 and 50 ft. above the pad. Hover and touchdown are performed visually with the aid of high intensity lighting on the pad.

The total time required for the approach is 2 $\frac{1}{2}$ minutes. Compared to a constant low speed approach from higher altitudes (1500 ft.), the curved decelerating path results in reduced fuel consumption and noise generation.

Chapter V

Conclusions and Recommendations

5.1 Conclusions

A computer generated display has been developed for use in terminal area studies and synthesis of V/STOL approach and departure paths. The design program is general and permits extensive study of terminal areas with a minimum of preliminary work and program modification. The user is only required to input the map coordinates of noise sensitive areas, obstacle locations and CTOL traffic waypoints. On-line teletype input is a unique and essential feature of the program, allowing detailed site analysis with various constraint criteria. The display program is an effective synthesis tool in terminal studies, greatly reducing the time and effort required in a comparable manual task while providing far greater flexibility in the selection of constraint criteria. The program is also useful in aircraft design applications where it is desired to study vehicle performance tradeoffs for increased noise reduction. While selecting flight paths, the operator may vary the aircraft noise rating to determine what noise characteristics will result in acceptable approaches.

Practical applications are demonstrated in the development of approach and departure paths for several sites of interest in the Northeast Corridor. Based upon the resulting analyses, the following observations are made with regard to path characteristics and terminal operations:

(1) For noise abatement purposes V/STOL aircraft should have the capability for performing high angle departure (20°) and curvilinear approaches with steep (15°) glide slopes.

(2) Because of noise and obstruction constraints, V/STOL aircraft should be able to navigate to within a few hundred feet of the nominal approach when below 1500 feet.

(3) The sites considered do not have the omnidirectional approach capability generally assumed in the literature. The noise constraint severely restricts air access to vertiports located near city centers.

5.2 Recommendations

Although all the display program objectives were achieved and the program is more than acceptable in its present form, there are several modifications and extensions which would increase its usefulness.

For detailed studies, a more sophisticated model of the vehicle's noise characteristics should be incorporated to study performance and noise reduction tradeoffs. For instance, it is of interest to know the tradeoff between increased power to climb at steep angles (increasing noise) and attendant gain in altitude (decreasing noise). In addition, continual refinements of the community response criteria which account for noise duration and tone effects should be included as they are defined. Noise duration corrections could be made by specifying the aircraft's velocity along the selected path and subsequently weighing the effects of certain noise levels during given time intervals near residential areas. Another improvement involves taking into account the vehicle's directional noise characteristics. This could be accomplished by displaying the projected ground level noise contours, suitably perturbed for directional corrections, as flight path construction proceeds. No difficulties are envisioned in incorporating these suggestions.

However, their implementation is dependent upon the further refinement and definition of vehicle characteristics and system constraints.

2

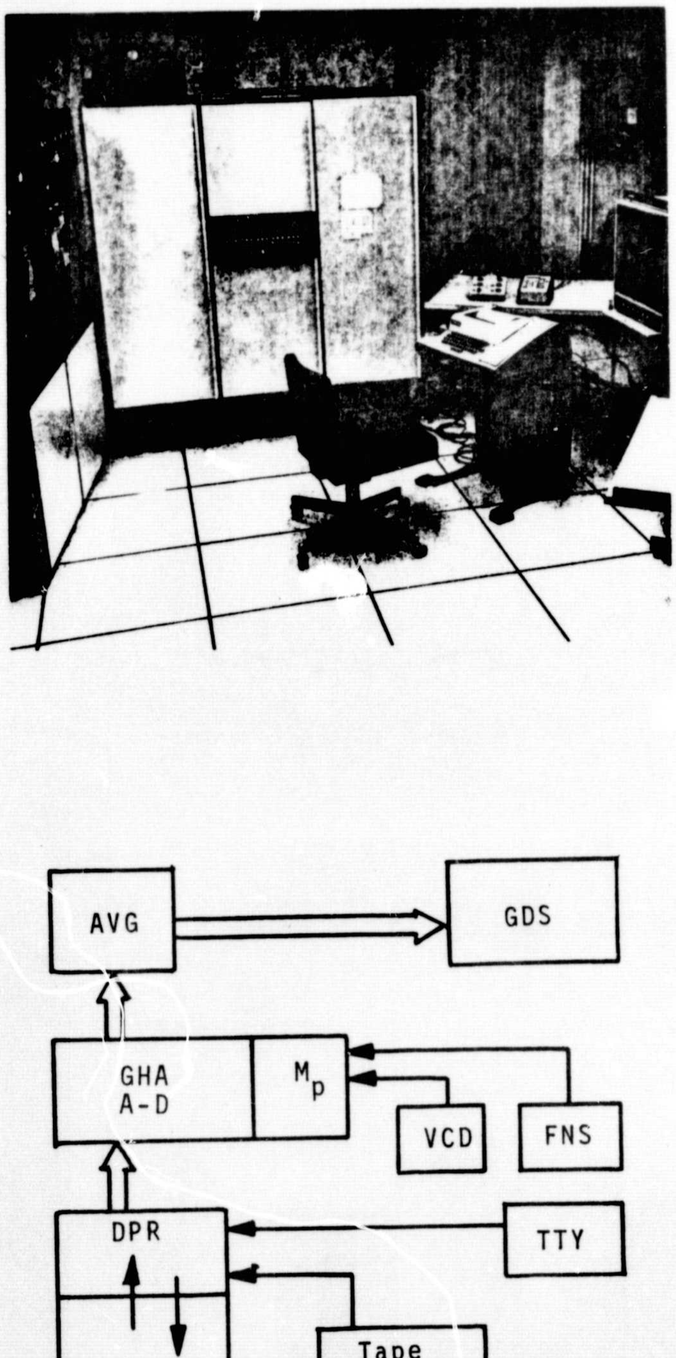


FIGURE A1 ADAGE 30 GRAPHICS TERMINAL

APPENDIX A

Computer Program Guide

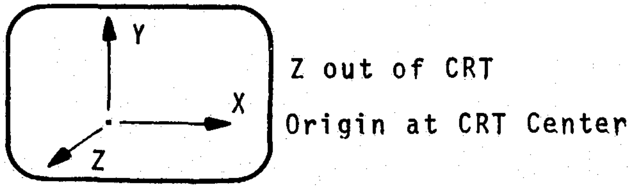
A.1 Equipment

The program was written for an Adage Graphics Terminal, (AGT 30) which provides the user with hardware for displaying and manipulating three-dimensional image descriptions. The terminal, shown in Figure A1, consists of a 30 bit, 16 k general purpose computer and graphics processing subsystems. The Digital Processor and Memory Unit (DPR/DME) processes displayed images, services operator requests, coordinates communications with external devices and monitors the entire system operation. The GHA Graphics Coordinate Transformation Array provides a hardware arithmetic operator and analog to digital converter for three-dimensional scaling, translation and rotation of displayed images. A fast built-in matrix transformation is performed on GHA digital inputs resulting in analog outputs which control the AVG vector generator. The AVG converts the GHA outputs into the appropriate horizontal, vertical and intensity drive signals for the Graphics Display Scope (GDS). Although the AVG accepts input signals corresponding to a 20 inch display space, the largest single vector that may be displayed on the CRT display scope is 10 inches. The vector generator can be programmatically controlled to interrupt the main digital program and fetch a newly computed set of vector coordinates while the display is being drawn. Dynamic images are implemented in this manner.

The user may interact with his program through a teletype unit, function switches and/or variable control dials. The FNS Function Switch unit includes two foot pedals and sixteen manual input switches which have a variety of program applications, such as setting initial conditions, selecting operational modes or processing of certain subroutines and images. The Variable Control Dial (VCD) box consists of six potentiometers which are be sampled and digitized by the computer for use as program variables.

A.2 Graphics Display Concepts

Images are constructed with the use of a display language, the software interface to the graphics processing subsystems of the AGT 30 terminal. Computational program elements generate a set of vector coordinate lists and transform specifying parameters which when placed in the proper language format are suitable for image processing. All displayed images result in viewable lines or text strings placed in the viewing space of the CRT, an imaginary three-dimensional space defined with reference to a right-handed coordinate system in the CRT.



Coordinate values describing a point in this space are limited to values in the range (-1.0,+1.0). An image or group of images may be displayed with reference to a new coordinate system defined relative to the initial one by a three-dimensional transformation. Images are kept in buffers, singly dimensioned Fortran arrays in which description of an image has been created. Image describing items may be added to the buffer to build up a description of the image. Element generating image items draw lines on the CRT, position the CRT beam, and draw character strings. Transform-specifying image items, called PLACE items, specify a change in scale, rotation or displacement of subsequent images or image portions. Dynamic images result when arguments to image describing items are varied through computation or direct input (variable control dials for instance) during display. A complete listing and detailed description of AFDSP calls and image defining items is given in Adage documentation. Appendix B illustrates the application of these calls and items in the build-up of the display.

All pictures on the CRT are refreshed at a constant frame rate specified by the user. The display language has provisions for the execution of programs once per frame by placing them on the "CLOCK chain." Routines placed on the CLOCK chain are executed while the vector generator is drawing lines. These programs may compute variable values which are arguments to image defining items.

A.3 Program Organization

This section explains the organization of the general computer-display program that is developed for V/STOL terminal studies. A listing of the main program and subroutines is included in Appendix B. Major program objectives are outlined below.

(1) Accept external terminal area describing inputs and accurately model the terminal constraints in three dimensions with a computer-generated display.

(2) Provide extensive on line machine/operator interaction permitting the operator to specify various constraint criteria, to plan approaches and departures, and to check the results through three-dimensional viewing and teletype output.

(3) Illustrate how fundamental program units are used in the build-up of a display so that others may easily adapt the program for

their uses. It should be noted that although the generality of the program is demonstrated, it is impossible to account for all the features of a given terminal area.

Computational tasks were performed with an augmented basic Fortran, AFORT, and images were processed with the aid of a Fortran compatible display language, AFDSP (AFORT Display Interface). Fortran has excellent input/output mechanisms which are especially suited for mapping techniques. It is widely used and easily interpreted and should prove useful in illustrating the basic algorithms and program structure.

In the developmental stage, all image generating programs were written to operate independently as subroutines. This simplifies the programming task considerably by reducing the debugging effort required to identify and isolate error. After verifying proper operation, image subroutines were combined into a format more suitable for presentation purposes (except routines which involve largely computational tasks). However, in applications where the total memory load may be exceeded, and it is desired to share available core storage with the AFORT overlay feature, image defining subroutines should be used extensively.

The main program, BOSTN (terminal area name) monitors system operation and controls the selection of various operating modes. It receives input describing noise sensitive areas, obstruction positions and constraint criteria and builds the basic subimages which will later be scaled and transformed to form the completed display. A unique feature of the program is that it generates new vector coordinate lists with each input rather than displaying a fixed list for a particular area. This accounts for the general nature of the program and its capability to handle a number of terminal areas. Variable control dial inputs are sampled, digitized, and scaled once per frame by programs VCD and SCALE (Both are placed on CLOCK chain.) and are transferred to the main program as arguments to image items. Consequently, the operator may command real time image movement as programmed. During each CLOCK cycle the computer program samples the dials, refreshes the image and returns control to the main program to service additional instructions.

A description of the individual programs as well as the input/output mechanisms is given below.

A.3.1 Teletype Input

On line teletype input permits the operator a wide choice of constraint criteria in terminal area studies. This is of special significance with regard to noise, since well defined public acceptance criteria do not exist. Input parameters include obstacle vertical and lateral clearances, acceptable community noise levels, peak aircraft noise rating, vertiport location, model arc segments, and, if desired, conventional traffic routings. Altitude level selection is also implemented in this manner.

A.3.2 DATRS

This routine contains the arrays which hold the X and Y coordinates of the noise sensitive area boundaries. The boundary coordinates are referred to an arbitrarily defined set of map axes. Boundaries must be defined as either closed or open.

A.3.3 DATBL

The elevations and position map coordinates of prominent obstacles are stored in arrays in DATBL.

A.3.4 CTOL

Conventional traffic routings are mapped and defining waypoints are stored in arrays in this program. CTOL aircraft heading, rate of climb and velocity must be specified for each path segment.

A.3.5 VCD

This assembly language program samples the control dial values and assigns symbolic names to them for common referencing by other programs.

A.3.6 SCALE

SCALE receives the dial inputs from VCD, scales and transfers them to the main program through a COMMON statement.

A.3.7 BOSTN

The main controlling routine, named after the appropriate terminal area, monitors input/output, prepares the image buffers for display and tests the function switch settings for various operational modes. Several switches are read after all data input has been received and the image is being constructed. The remaining switches are tested after control has been returned from the display program to the main program. Details of function switch implementation are given in Figure A2 and section A.5.

A.3.8 NOYS

The NOYS program determines the set of contour points equidistant from an irregular boundary and places them in tabular format for processing as an image. It is used to define the restricted airspace about noise sensitive areas. However, it may find wide applications in terminal area studies, particularly in specifying clearances about three-dimensional structures, such as mountains. Because it is fundamental to the development of the program, the algorithm is outlined in Figure A3.

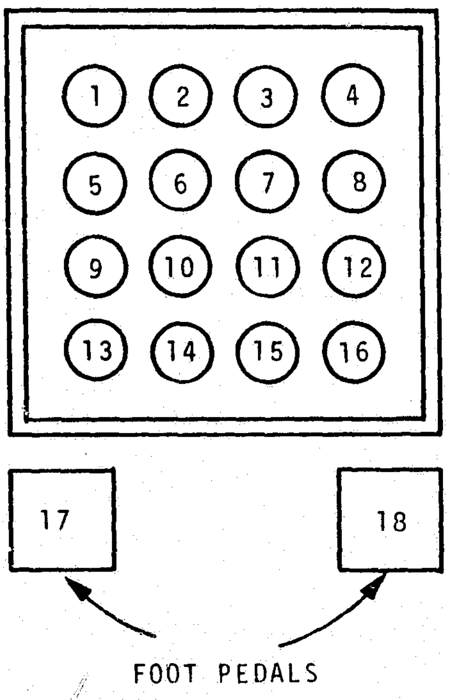
A.3.9 ANGLE and CRNR

These auxilliary routines are called by NOYS. ANGLE provides the angle of the contour line segments, and CRNR provides the intersecting contour point for consecutive line segments that form an inner corner.

A.3.10 Teletype Output

After selecting the flight path, the operator may request a typed record of the defined waypoints and path characteristics with which to check against the aircraft's performance capabilities.

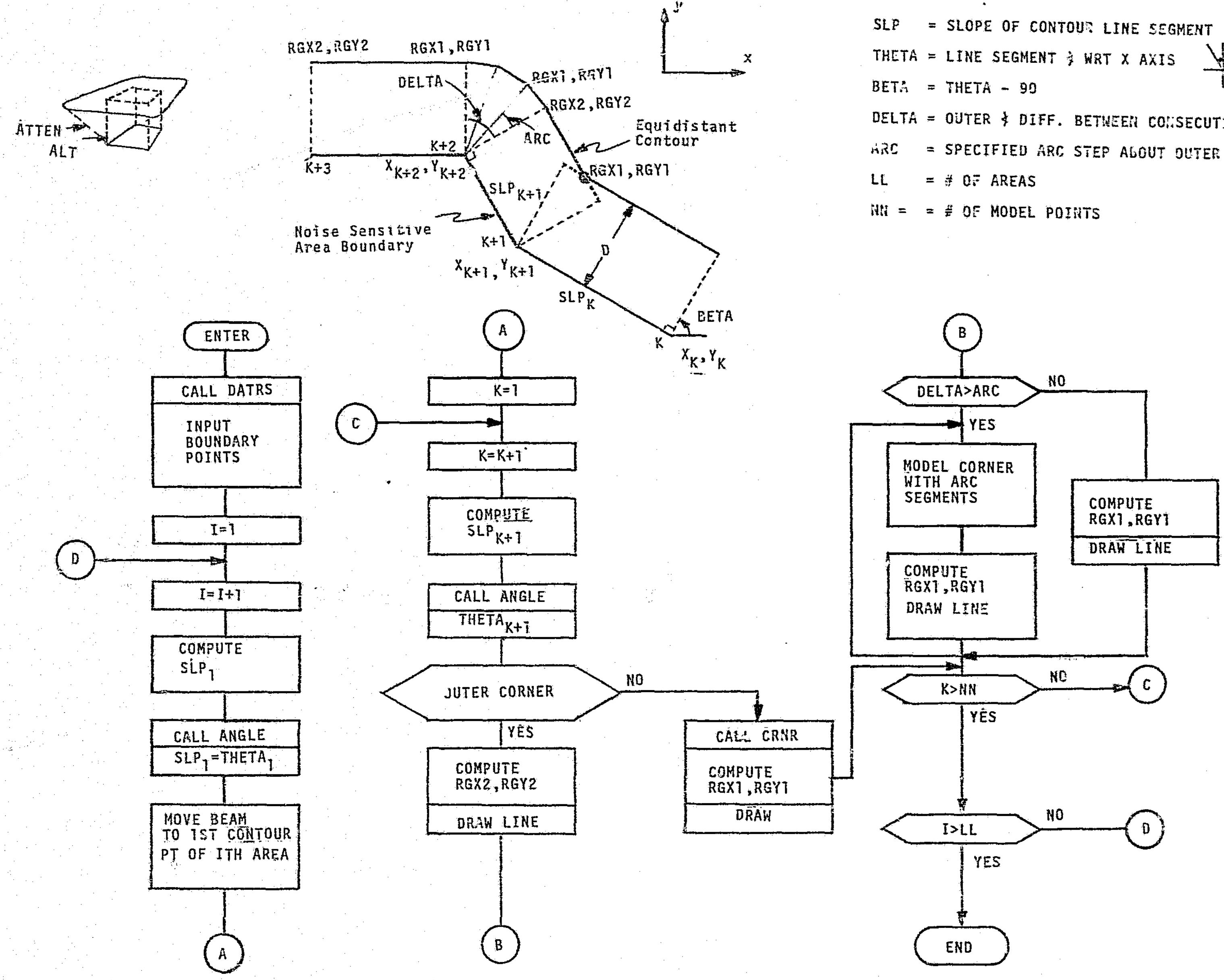
A list of the more important program symbols and their meanings is given in Table A.1. Tables A.2 and A.3 describe the image buffers and the applied transformation.



SWITCH ASSIGNMENTS

1	SKIP TRAF IMAGE
2	SKIP CNTUR IMAGE
5	TURN OFF DSPLY/RETURN TO MAIN PGRM
6	DATA OUTPUT MODE
10	MOST RECENT WAYPOINT OPTION
13	RSET NOYS
17	IMAGE VIEWING MODE/MEMORIZE
18	AREA SELECTION

FIGURE A2 FUNCTION BOX LAYOUT



ATTEN = $500 \cdot 10^{\frac{DB-CNR}{20}}$

SLP = SLOPE OF CONTOUR LINE SEGMENT

THETA = LINE SEGMENT ∠ WRT X AXIS

BETA = THETA - 90

DELTA = OUTER ∠ DIFF. BETWEEN CONSECUTIVE SEGMENTS

ARC = SPECIFIED ARC STEP ABOUT OUTER CORNER

LL = # OF AREAS

NN = = # OF MODEL POINTS

FIGURE A3 CONTOUR FLOW CHART

TABLE A.1

Program Symbols

Main Program:

Symbol	Meaning
MAPDX,MAPDY	Displacement vectors, translate from map coordinate axes to screen coordinates
MAPSF	Scale map coordinates to scope range (-1.0→1.0)
SFF	Scale feet to map units
FF	Scale feet to scope scale
OBRAD	Lateral obstacle clearance (ft)
VCL	Vertical obstacle clearance (ft)
ARND	Circle arc segments (degrees)
CNR	Acceptable residential noise values (db)
DB	Maximum aircraft noise output at 500 ft. (db)
ARC	Arc segments in contour construction (degrees)
PTSCL	Vertiport scale factor
HMAX	Highest obstacle elevation in ft.
VTOLX,Y,Z	Flight path waypoints
ATTEN	Distance at which A/C noise attenuates to CNR value
ALT	Altitude (feet or scope coordinates)
GAMMA	V/STOL Flight path angle
HEADG	V/STOL Flight path heading

TABLE A.1 (cont.)

Symbol	Meaning
XFIX,YFIX,ZFIX	Altitude plane, flight path intersection
GRDR	V/STOL ground track
VAL1 VAL2 VAL3 VAL4	Variable control dial inputs (scaled)
NOYS:	
SLP	Slope of contour line segments (+,-)
THETA	Line segment angle from X axis
RX,RY	Dummy coordinates representing boundary points
VCD:	
IA-IF	Symbolic names of control dials
SCALE:	
VAL1-VAL4	Scaled dial inputs

TABLE A.2

Image Descriptions

Image Buffer	Description
PATH	Contains image line elements which define the selected VTOL flight paths. All line elements are added to the buffer using IMCON calls.
AREA	These line elements form a image of the noise sensitive areas in the ground level plane. This image is formed by placing a set of X,Y coordinate pairs in table format.
VPORT	Image of a rectangle, representing the vertiport
CIRCL	A circle image with full scale radius (R = 1.0)
NORTH	An arrow image enclosed by a scaled CIRCL subimage indicating direction of true North
OBS	Set of CIRCL subimages scaled and moved to obstacle position coordinates
CNTUR	Set of contour points equidistant from AREA boundary points
FINDR	CIRCL subimage scaled and located at the intersection of the flight path and altitude plane
TRAF	CTOL traffic waypoints
FPS	Flight path selector image consisting of CIRCL subimage and path segment vector.
AMAP	All of the above images are subimages of AMAP which itself is a subimage of AIRSP.
AIRSP	Airspace model image. All other images are subimages of AIRSP.

TABLE A.3

Image Transformation

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \text{SCL } [R] \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} DX \\ DY \\ DZ \end{bmatrix}$$

IMAGE	SUBIMAGE	SCL	ROT	DX	DY	DZ
OBS	CIRCL	OBRADxFF	0	MAP POSITION		
NORTH	CIRCL	1.0	0		0	
FINDR	CIRCL	.03	0	XFIX	YFIX	ZFIX
FPS	CIRCL	1.0	0		0	
AMAP	PATH	1.0	0		0	
	AREA	1.0	0		0	
	VPORT	PTSCL	ZROT=-30°	VTOLX(1)	VTOLY(1)	VTOLZ(1)
	OBS	1.0	0	0	0	ALT
	NORTH	.1	0	.8	.8	ALT
	CNTUR	1.0	0	0	0	ALT
	FPS *	VAL1	ZROT=VAL2	VTOLX(MM)	VTOLY(MM)	ALT
	TRAF	1.0	0		0	
	FINDR	1.0	0		0	
AIRSP	(AMAP)$_1$*	1.0	XROT=VAL4,ZROT=VAL3		0	
	(AMAP)$_2$	VAL1	0	0	0	VAL2

* Flight Path Selector Mode

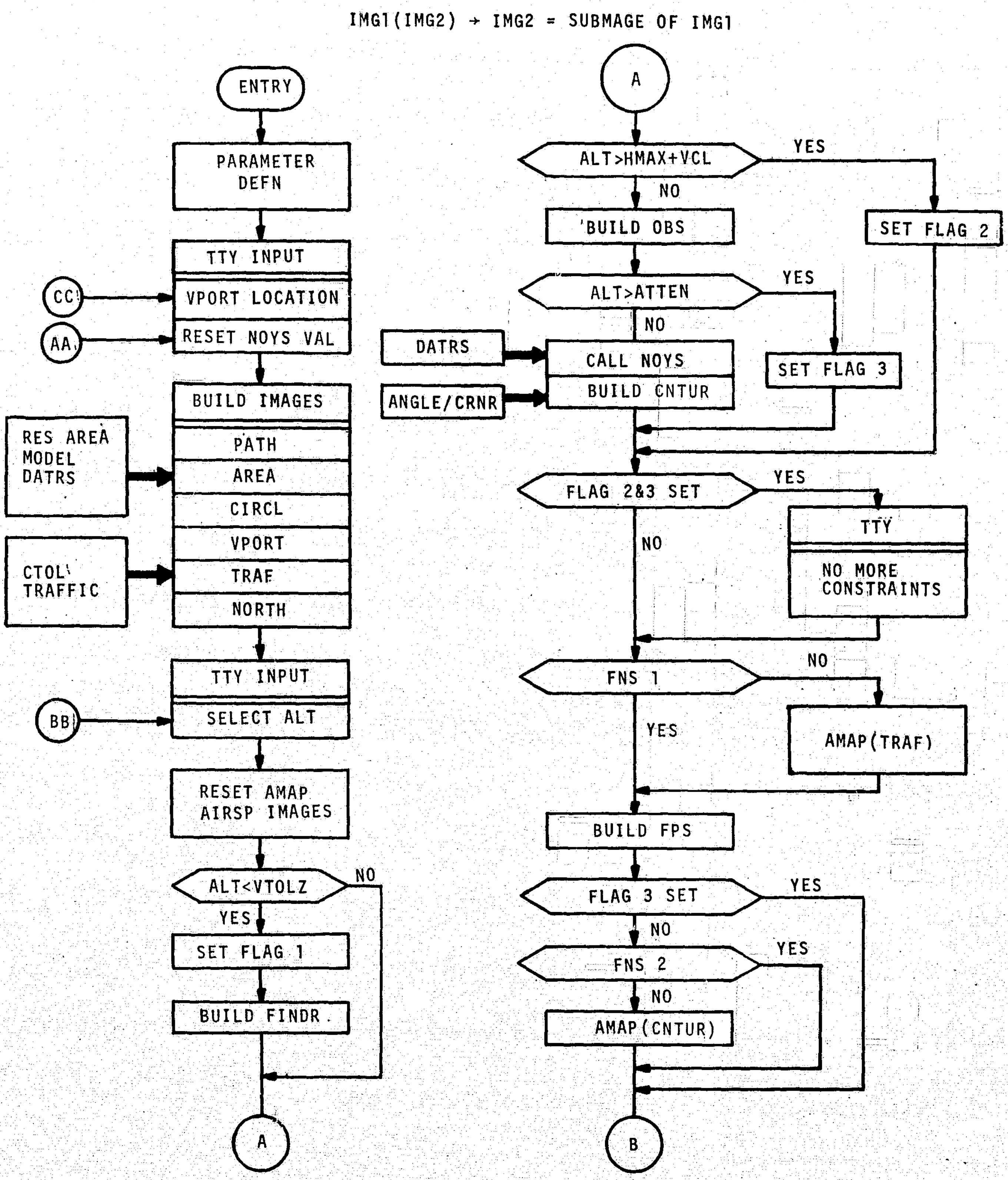
Note: X,Y,Z Axes Origin at Screen Center

A.4 Analog Data Tablet

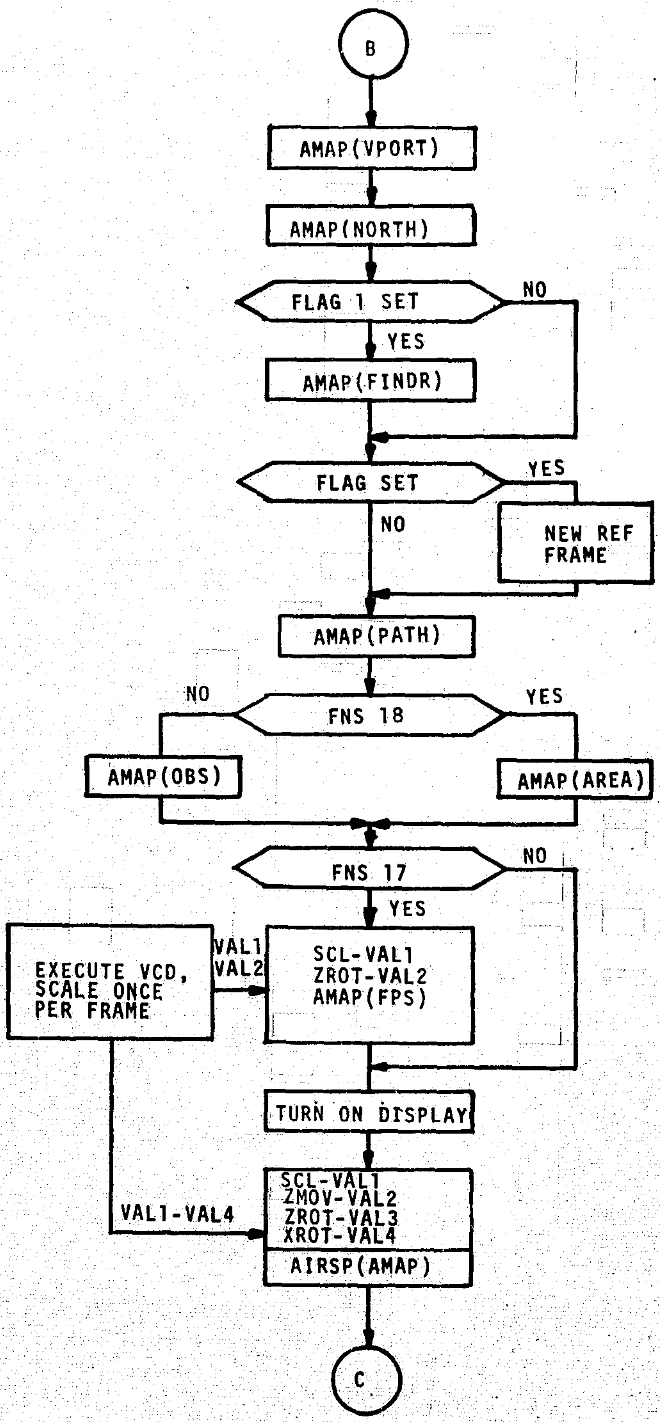
In the present form, the program requires the operator to establish external data files which contain the map coordinates of each noise sensitive area and obstacle in the terminal area. Even though the program provides the user with a very rapid means of examining the terminal airspace and selecting paths, the user must still perform the tedious task of modelling the areas with a discrete set of points and transferring the coordinates into array elements. However, certain auxiliary Adage equipment, not available on the M.I.T. facility, permits the user to transfer the area boundaries directly into the computer, thereby greatly reducing the overall effort. An Adage data tablet consisting of a 10" x 10" square of transparent glass, allows the user to give two-dimensional analog inputs to the AGT-30. When a pick-up stylus is placed on the tablet, it detects voltages corresponding to the x and y coordinate positions of the stylus. Hence the user may input map coordinates, store and/or display them on the screen when desired. Discrete or continuous inputs are accepted. With large maps, the coordinate transfer could be accomplished in sectors where each sector is identified by a displacement vector which will later be used to place the sector in the proper position to form the map.

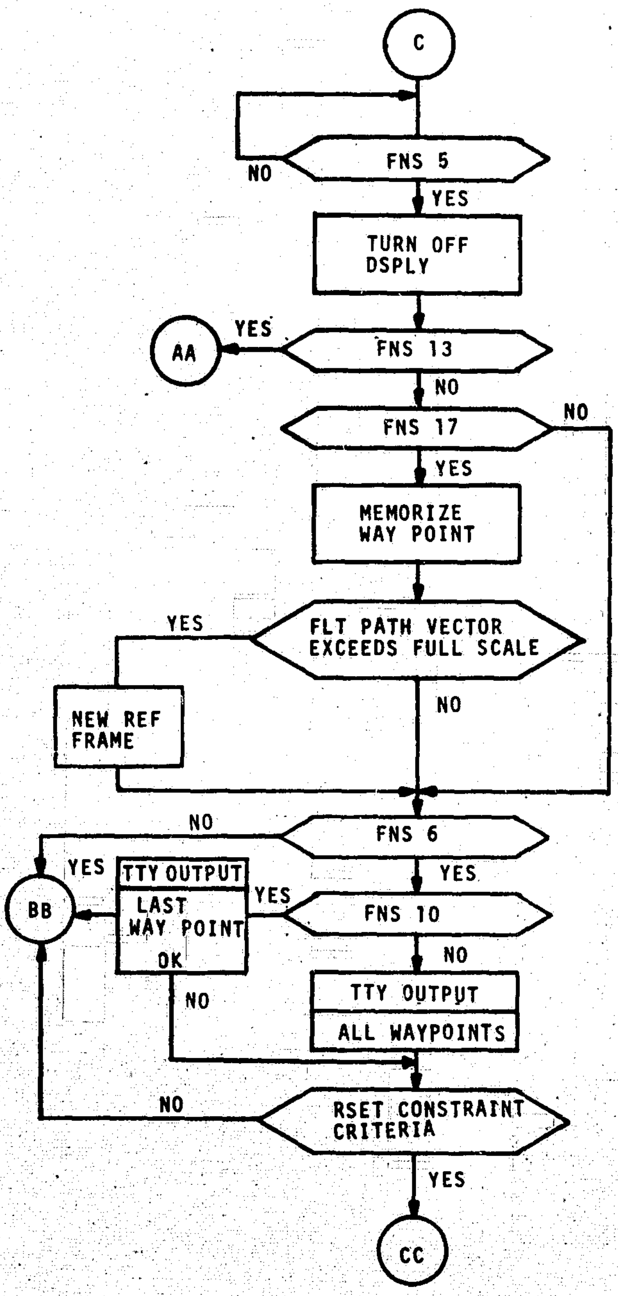
A5 INFORMATION FLOW DIAGRAM OF THE GENERAL PROGRAM

DETAILS OF THE PROGRAM
OPERATION ARE GIVEN BELOW



A5 (Cont.)


B
AMAP(VPORT)
AMAP(NORTH)
FLAG 1 SET
NO
YES
AMAP(FINDR)
FLAG SET
YES
NO
NEW REF FRAME
AMAP(PATH)
NO
FNS 18
YES
AMAP(OBS)
AMAP(AREA)
FNS 17
NO
YES
EXECUTE VCD, SCALE ONCE PER FRAME
VAL1
VAL2
SCL-VAL1
ZROT-VAL2
AMAP(FPS)
TURN ON DISPLAY
SCL-VAL1
ZMOV-VAL2
ZROT-VAL3
XROT-VAL4
VAL1-VAL4
AIRSP(AMAP)
C


C
NO
FNS 5
YES
TURN OFF DSPLY
AA
YES
FNS 13
NO
FNS 17
NO
YES
MEMORIZE WAY POINT
YES
FLT PATH VECTOR EXCEEDS FULL SCALE
NO
NEW REF FRAME
NO
FNS 6
YES
YES
TTY OUTPUT
LAST WAY POINT
OK
YES
FNS 10
BB
NO
NO
TTY OUTPUT
ALL WAYPOINTS
NO
RSET CONSTRAINT CRITERIA
YES
CC

APPENDIX B

Computer Program

```
THE MAIN PROGRAM, NAMED AFTER THE APPROPRIATE TERMINAL AREA,
MONITORS SYSTEM OPERATION AND CONTROLS THE SELECTION OF
OPERATIONAL MODES THROUGH FUNCTION SWITCHES



      SUBROUTINE BOSTN
      DIMENSION   AMAP(100),BND(200),DUMX(15,5),DUMY(15,5),NA(5),
     CRX(25),RY(25),SLP(25),SLPA(25),THETA(25),CB(5),CIRCL(10),RND(50),
     CCX(20),CY(20),ZONE(75),AREA(10),LA(5),CNTUR(10),VTOLX(15),
     CVTOLY(15),VTOLZ(15),CPS(10),GAMMA(15),HEADG(15),PATH(50),
     CCNP(15),DB(15),H(15),VPORT(10),KT(10),PT(10),LB1(20),
     CNORTH(10),FINDE(10),EPS(10),TRAF(10),AIPSP(25)
      COMMON        K,RX,RY,SLPA,SLP,DELTA,ALPHA,THETA,D
      COMMON        VAL1,VAL2,VALL1,VALL2,VAL3,VAL4
      COMMON        CNTUR,BND,ALT,FF,ARC
      EXTERNAL    IFSW
      CALL NOSUB

C     MAP MODEL DATA INPUT DESCRIBING NOISE SENSITIVE AREAS

      CALL DATRC(AMAPS,SFF,AMAPX,AMAPY,DUMX,DUMY,LA,N,CB)
      NRATE=5
      AA=1.
      BB=.75
      PTSCL=.003
      SFF=.001*SFF
      FF=AMAPS/SFF
      DSHOB=1.
      DSHAR=1.
      SF=AMAPS
      DX=AMAPX
      DY=AMAPY
  603 FORMAT((F10.3))
      WRITE(5 ,608)
  608 FORMAT(//,35HMODE SELECT - MAP SCALE, DOUBLE ALT)
      READ(5 ,603) SF,FLAG
      IF(FLAG) 270,270,271
  271 FF=2.*FF
      DAU=2.
      GO TO 240
  270 DAU=1.
  240 CONTINUE
      WRITE(5 ,605)
  605 FORMAT(/,43HALL DATA FLOATING PT. 1 ELEMENT PER LINE)
      WRITE(5 ,611)
  611 FORMAT(5X,11H+1. =AFFIRM,7X,8H-1. =NEG)
```

```
C       ON-LINE TELETYPE INPUT TO SELECT SITE AND SET CONSTRAINT CRITERIA
C       TELETYPE UNIT = 50

 631    WRITE(50,605)
 605    FORMAT(//,36HVTOL SITE -X,Y MAP COORD- & PAD ELEV)
        READ(50,603) XX,YY,ZZ
        WRITE(50,604)
 604    FORMAT(/,43HLAT & VERT OBSTRUCTION CLEARANCE, ARC MODEL)
        READ(50,603) OBRAD,VCL,ARND
        MM=1
        GAMMA(1)=0
        HEADG(1)=1.34
        CNR(1)=0
        DB(1)=0
        SKIP=-1.
        VTOLX(MM)=(XX+DX)*SF
        VTOLY(MM)=(YY+DY)*SF
        VTOLZ(MM)=ZZ*FF

C       INITIALIZE PATH BUFFER AND BUILD IMAGE

        CALL  RSET(PATH,50)
        CALL  IMCON(PATH,MOVBM(PT1(VTOLX(MM),VTOLY(MM),VTOLZ(MM))),ERR)
 360    CONTINUE
        WRITE(50,606)
 606    FORMAT(/,32HRESDEN & AC DB VALUES, ARC MODEL)
        READ(50,603) RNOYS,ADB,ARC
        CNR(1)=RNOYS
        DB(1)=ADB

C       INITIALIZE AND BUILD AREA,CIRCL,VPORT,TRAF & NORTH IMAGES

        CALL  RSET(AREA,10)
        IF(DSHAR) 16,16,17
 17     CALL  DSH(AREA,ERR)
 16     CONTINUE
        CALL  TABL(AREA,ZONE,ERR)
        M=1
        ZONE(1)=ZSET(0)
        DO 150 I=1,N
        X=SF*(DUMX(1,I)+DX)
        Y=SF*(DUMY(1,I)+DY)
        M=M+1
        ZONE(M)=TDFUN(X,Y,0,0)
        L=LA(I)-1
        DO 150 J=1,L
        X=SF*(DUMX(J+1,I)+DX)
        Y=SF*(DUMY(J+1,I)+DY)
        M=M+1
        ZONE(M)=TDFUN(X,Y,1,0)
 150    CONTINUE
        ZONE(M+1)=TDFUN(0,0,0,1)
        IF(DSHAR) 18,18,19
 19     CALL  NODSH(AREA,ERR)
 18     CONTINUE
```

```
      CALL  RSET(CIRCL.10)
      CALL  TABL(CIRCL.RND.ERR)
      RND(1)=ZSET(0)
      M=1
      RAD=1.0
      RN=360.0/ARND
      NNN=RN
      M=M+1
      RND(M)=TDFUN(1.0.0.0.0)
      DO 125 J=1.NNN
      AJ=J
      PHI=(ARND*AJ)/57.3
      X=RAD*COS(PHI)
      Y=RAD*SIN(PHI)
      M=M+1
      RND(M)=TDFUN(X,Y,1.0)
  125 CONTINUE
      RND(M+1)=TDFUN(0.0.0.1)
      CALL  RSET(VPORT.10)
      CALL  TABL(VPORT.RT.ERR)
      RT(1)=ZSET(0)
      RT(2)=TDFUN(-AA.BB.0.0)
      RT(3)=TDFUN(AA.BB.1.0)
      RT(4)=TDFUN(AA.-BB.1.0)
      RT(5)=TDFUN(-AA.-BB.1.0)
      RT(6)=TDFUN(-AA.BB.1.0)
      RT(7)=TDFUN(0,0,0.1)

C     IF TRAFFIC CONSTRAINTS. CALL CTOL SUBPROGRAM AND INPUT
C     TRAFFIC WAYPOINTS

      ETA=20./57.3
      XPT=COS(ETA)
      YPT=SIN(ETA)
      CALL  RSET(NORTH.10)
      CALL  TABL(NORTH.PT.ERR)
      PT(1)=ZSET(0)
      PT(2)=TDFUN(0..-1..0.0)
      PT(3)=TDFUN(0..1..1.0)
      PT(4)=TDFUN(-XPT.-YPT.1.0)
      PT(5)=TDFUN(XPT.-YPT.0.0)
      PT(6)=TDFUN(0..1..1.0)
      PT(7)=TDFUN(0.0.0.1)
      CALL  IMCON(NORTH.IMCAL(CIRCL).ERR)

C     VIEW AIRSPACE UTILIZATION AT SELECTED ALTITUDE

  632 WRITE(5 .607)
  607 FORMAT(//.10X.15HSELECT ALTITUDE)
      READ(5 .603) ALT
      FLAG1=-1.
      FLAG2=-1.
      FLAG3=-1.
```

```
C       RESET AIRSPACE UTL MODEL IMAGE AND AMAP SUBIMAGE

        CALL RSET(AIRSP,25)
        CALL RSET(AMAP,1[illegible])
        IALT=ALT
        CALL SETIO(LB1,20)
        WRITE(54,585) IALT
  585   FORMAT(4HALT=,I4)
        CALL IMCON(AIRSP,MOVBM(PT1(.8,1.,1.)),ERR)
        CALL IMCON(AIRSP,LABEL(LB1,1),ERR)

C       COMPUTE INTERSECTION OF FLIGHT PATH AND ALT PLANE
C       RESET & BUILD FINDR IMAGE

        ZFIX=ALT*FF
        IF(ZFIX-VTOLZ(MM)) 400,401,401
  400   FLAG1=1.
        CALL RSET(FINDR,1[illegible])
        DO 402 I=2,MM
        IF(ZFIX-VTOLZ(I)) 403,403,402
  402   CONTINUE
        GO TO 401
  403   CONTINUE
        DIST=(ZFIX-VTOLZ(I-1))*COS(GAMMA(I))/(DAU*SIN(GAMMA(I)))
        XFIX=VTOLX(I-1)+DIST*COS(HEADG(I))
        YFIX=VTOLY(I-1)+DIST*SIN(HEADG(I))
        CALL IMCON(FINDR,PLACE(SHRNK(.[illegible]3),MOV(XFIX,YFIX,[illegible])),ERR)
        CALL IMCON(FINDR,IMCAL(CIRCL),ERR)
        CALL STPLC(FINDR,ERR)
  401   CONTINUE

C       CALL DATBL SUBPROGRAM TO INPUT ELEVATIONS AND MAP COORDINATES
C       OF MAJOR OBSTACLES IN TERMINAL AREA

        CALL DATBL(CX,CY,H,HMAX,L)
        DALT=ALT-(VTOLZ(MM)/FF)
        ATTEN=5[illegible].1[illegible]((ADR-[illegible])/[illegible].)

C       TEST FOR OBSTACLE CONSTRAINTS

        IF(ALT-HMAX-VCL) 577,577,578
  578   FLAG2=1.
        GO TO 577
  577   CONTINUE
```

```
      CALL RSET(OBS,1.0)
      IF(DSHOB) 24,25,25
 25   CALL DSH(OBS,ERR)
 24   CONTINUE
      S=OBRAD*SF*SFF
      DO 130 I=1,L
      IF(H(I)+VCL-ALT) 130,131,131
 131  CONTINUE
      X=(CX(I)+DX)*SF
      Y=(CY(I)+DY)*SF
      CALL IMCON(OBS,PLACE(SHRNK(S),XMOV(X),YMOV(Y)),ERR)
      CALL IMCON(OBS,IMCAL(CIRCL),ERR)
      CALL STPLC(OBS,ERR)
 130  CONTINUE
      IF(DSHOB) 26,26,27
 27   CALL NODSH(OBS,ERR)
 26   CONTINUE
 57   CONTINUE

C     TEST FOR NOISE CONSTRAINTS

      IF(ALT-ATTEN) 580,580,581
 581  FLAG3=1.
      D=
      GO TO 579
 580  D=(ATTEN**2.-ALT**2.)**.5
      D=D*SF*SFF

C     CALL NOYS SUBPROGRAM CONTAINING NOISE CONTOUR SUBIMAGE

      CALL NOYS
 579  CONTINUE
      IF(SKIP) 573,584,584
 573  IF(FLAG2+FLAG3-2.) 584,571,571
 571  SKIP=1.
      WRITE(5,600)
 600  FORMAT(//,37HTERMINAL AIRSPACE FREE OF CONSTRAINTS)
      WRITE(5,601)
 601  FORMAT(37HPROCEED TO OR FROM ENROUTE ASSIGNMENT)
 584  CONTINUE
      IF(IESW(1,9)) 281,281,282
 281  CALL IMCON(AMAP,IMCAL(TRAF),ERR)
 282  CONTINUE
      ALT=ALT*FF
      FP7=-(ALT-VTOLZ(MM))
      DALT=DALT*FF

C     BUILD FLIGHT PATH SELECTOR IMAGE

      CALL RSET(FPS,1.0)
      CALL IMCON(FPS,IMCAL(CIRCL),ERR)
      CALL IMCON(FPS,LINE(PT1(0.,0.,FP7),PT2(0.,1.,0.)),ERR)
```

```
C       FUNCTION SWITCH CONTOUR IMAGE SELECT

        IF(FLAG3) 245,245,251
 245    IF(IFSW(2,0)) 250,250,251
 250    CALL IMCON(AMAP,IMCAL(CNTUR),ERR)
 251    CONTINUE
        PNTR1=RSVA(EPS)
        PNTR2=RSVA(AMAP)
        CALL IMCON(AMAP,PLACE(ZTURN(-.2),SHRNK(PTSCL),MOV(VTOLX(1),
       CVTOLY(1),VTOLZ(1))),ERR)
        CALL IMCON(AMAP,IMCAL(VPCRT),ERR)
        CALL STPLC(AMAP,ERR)
        CALL IMCON(AMAP,PLACE(SHRNK(.1),MOV(.8,.8,ALT)),ERR)
        CALL IMCON(AMAP,IMCAL(NORTH),ERR)
        CALL STPLC(AMAP,ERR)
        IF(FLAG1) 210,211,211
 211    CALL IMCON(AMAP,PLACE(ZMOV(ALT)),ERR)
        CALL IMCON(AMAP,IMCAL(FINDR),ERR)
        CALL STPLC(AMAP,ERR)
 210    CONTINUE
        CALL IMCON(PATH,LINE(PT2(VTOLX(MM),VTOLY(MM),VTOLZ(MM))),ERR)
        CALL IMCON(AMAP,IMCAL(PATH),ERR)
        IF(IFSW(18,0)) 565,565,564
 564    CONTINUE
        CALL IMCON(AMAP,IMCAL(AREA),ERR)
        GO TO 566
 565    CONTINUE
        CALL IMCON(AMAP,PLACE(ZMOV(ALT)),ERR)
        CALL IMCON(AMAP,IMCAL(OBS),ERR)
        CALL STPLC(AMAP,ERR)
 566    CONTINUE

C       EPS MODE SELECT-NOTE SCALED ANALOG INPUTS VAL1 & VAL2

        IF(IFSW(17,0)) 568,568,567
 567    CONTINUE
        CALL IMCON(AMAP,PLACE(MOV(VTOLX(MM),VTOLY(MM),ALT)),ERR)
        CALL IMVAR(AMAP,PLACE(SHRNK(VAL1),ZTURN(VAL2)),ERR)
        CALL IMVAR(AMAP,IMCAL(PNTR1),ERR)
        CALL STPLC(AMAP,ERR)
        CALL STPLC(AMAP,ERR)
 568    CONTINUE

C       TURN ON DSPLY

        CALL SHOW(AIRSP,NDATE)
        CALL IMVAR(AIRSP,PLACE(ZTURN(VAL3),XTURN(VAL4)),ERR)
        IF(IFSW(17,0)) 591,591,590
 591    CONTINUE
        CALL IMVAR(AIRSP,PLACE(ZMOV(VAL2),SHRNK(VAL1)),ERR)
 590    CONTINUE
        CALL IMVAR(AIRSP,IMCAL(PNTR2),ERR)
        CALL STPLC(AIRSP,ERR)
        CALL STPLC(AIRSP,ERR)
```

```
C       MODE SELECT-TURN OFF DSPLY RETURN TO MAIN PROGRAM

 501    CONTINUE
        IF(IFSW(5,0)) 501,501,509
 509    CONTINUE
        CALL NOSHO

C       RSET NOYS CONSTRAINT OPTION

        IF(IFSW(13,0)) 540,540,360
 540    CONTINUE

C       MEMORIZE WAYPOINT OPTION
C       COMPUTE NEW WAYPOINT

        IF(IFSW(17,0)) 543,543,542
 542    CONTINUE
        GAMMA(MM+1)=ATAN(DALT/(DAU*VALL1))
        HEADG(MM+1)=1.57-(-3.14*VALL2)
        VTOLX(MM+1)=VTOLX(MM)+VALL1*COS(HEADG(MM+1))
        VTOLY(MM+1)=VTOLY(MM)+VALL1*SIN(HEADG(MM+1))
        VTOLZ(MM+1)=VTOLZ(MM)+DALT
        CNP(MM+1)=RNOYS
        DB(MM+1)=AO3
        MM=MM+1
 543    CONTINUE

C       DATA OUTPUT MODE

        IF(IFSW(6,0)) 632,632,541
 541    CONTINUE
        WRITE(50,510)
 510    FORMAT(///,20X,22HFLIGHT PATH PARAMETERS)
        WRITE(50,511)
 511    FORMAT(/,3HCNR,3X,5HAC DB,3X,7HMAG HDG,3X,3HFPA,3X,8HALTITUDE,
       C3X,7HX POSIT,3X,7HY POSIT,3X,7HGRD TRK)
        GRDP=0
        IF(IFSW(10,0)) 515,515,516
 516    KA=MM
        GO TO 549
 515    KA=2
        IF(VTOLZ(2)-VTOLZ(1)) 517,517,549
 517    VTOLX(2)=VTOLX(1)
        VTOLY(2)=VTOLY(1)
 549    CONTINUE
```

```
      DO 550  I=KA,MM
      GRDP=GRDP+(VTOLZ(I)-VTOLZ(I-1))*COS(GAMMA(I))/(DAU*SIN(GAMMA(I)))
      IHD=(90.0-(HEADG(I)*57.3))+15.0
      IF(IHD-360) 552,553,553
  553 IHD=IHD-360
  552 CONTINUE
      GA=GAMMA(I)*57.3
      IX=(VTOLX(I)-VTOLX(1))/(SF*SFF)
      IY=(VTOLY(I)-VTOLY(1))/(SF*SFF)
      IZ =VTOLZ(I)/FF
      IGRD=GRDP/(SF*SFF)
      ICNPR=CNR(I)
      IDBP=DB(I)

C     TELETYPE OUTPUT

      WRITE(50,559) ICNPR,IDBP,IHD,GA
      WRITE(50,560) IZ,IX,IY,IGRD
  550 CONTINUE
  559 FORMAT(I3,4X,I2,6X,I3,3X,F5.1)
  560 FORMAT(32X,I5,4X,I4,4X,I6,4X,I7)

C     RSET CONSTRAINT CRITERIA OPTION

      WRITE(50,521)
  521 FORMAT(//,27HSPECIFY CONSTRAINT CRITERIA)
      READ(50,603) FLAG5
      IF(FLAG5) 523,523,631
  523 CONTINUE
      IF(MM-KA) 632,632,631
  545 CONTINUE
      CALL NOSH2
      RETURN
      END
```

```
C       THE NOY  S  PROGRAM BUILDS THE NOISE CONTOUR IMAGE-
C       REFER T  C  TOUR FLOW CHART

        SUBROUTINE NOYS
        DIMENSION   T(2  ),DUMX(15,5),DUMY(15,5),NA(5),
       1RX(25), Y(  ),SLP(25),SLPA(25),THETA(25),CB(5),CNTUR(10)
        COMMON    K, X,RY,SLPA,SLP,DELTA,ALPHA,THETA,D
        COMMON    V  1,VAL2,VALL1,VALL2,VAL3,VAL4
        COMMON    CN UR,BND,ALT,FF,ARC
        DSHNA=-1.
        CALL DATRS(SF,SFF,DX,DY,DUMX,DUMY,NA,LL,CB)
        CALL RSET(CNTUR,10)
        IF(DSHNA) 4,4,5
 5      CALL DSH(CNTUR,ERR)
 4      CONTINUE
        CALL TAPL(CNTUR,BND,ERR)
        M=1
        R77=ALT*FF
        BND(1)=ZSET(R77)
        DO 1 0 I=1,LL
        RX(1)=SF (DUMX(1,I)+DX)
        RY(1)=SF (DUMY(1,I)+DY)
        RX(2)=SF (DUMX(2,I)+DX)
        RY(2)=SF (DUMY(2,I)+DY)
 6      SLP(1)=(RY(2)-RY(1))/(RX(2)-RX(1))
        SLPA(1)=ATAN(SLP(1))
        SLPA(1)=SLPA(1)*57.3
        K=
        CALL ANGLE(THET,THETR)
        THETA(1)=THET
        BETA=(THETA(1)-90.  )/57.3
        RGX1=RX(1)+D COS(BETA)
        RGY1=RY(1)+  SIN(BETA)
        M=M+1
        BND(M)=TDFUN(RGX1,RGY1,0,0)
        NN=NA(I)-1
 11     DO 2   K=1,NN
        IF(K-NN) 52,53,53
 53     IF(CB(I)) 54,55,55
 54     RX(K+2)=RY(K+1)
        RY(K+2)=RY(K+1)
        GO TO 56
 55     RX(K+2)=RX(2)
        RY(K+2)=RY(2)
        GO TO 56
 52     CONTINUE
        RX(K+2)=SF (DUMX(K+2,I)+DX)
        RY(K+2)=SF (DUMY(K+2,I)+DY)
 56     CONTINUE
        SLP(K+1)=(RY(K+2)-RY(K+1))/(RX(K+2)-RX(K+1))
        SLPA(K+1)=ATAN(SLP(K+1))
        SLPA(K+1)=57.3 SLPA(K+1)
```

```
      CALL      E(THE   1    2)
      THETA(K  )=THET
      ALPHA=A
      DELTA=A S(THETA(K+1)-THETA(K))
      IF(DELT -180.0) 12, 2,13
13    DELTA=3  .0-DELTA
12    CONTINUE
      IF(RY(K+1)-RY(K))   ,42,42
41    IF(THETA(K+1)-THET   45,46,46
46    IF(THETA(K+1)-(THET +180.)) 50,45,45
42    IF(THETA(K+1)-(THETR-180.0)) 50,44,44
44    IF(THETA(K+1)-THETR) 45,50,50
50    CALL CRNR(RGX1,RGY1,XC1,YC1)
      RGX1=XC1
      RGY1=YC1
      M=M+1
      BND(M)=TDFUN(RGX1,RGY1,1,0)
      GO TO 2
45    CONTINUE
      RGX2=RX(K+1)+D*COS((THETA(K)-90.0)/57.3)
      RGY2=RY(K+1)+D*SIN((THETA(K)-90.0)/57.3)
      M=M+1
      BND(M)=TDFUN(RGX2,RGY2,1,0)
      IF(ALPHA-DELTA) 7 ,80,8
7     REAL=(DELTA/ALPHA)+1.
      LREAL=REAL
      REAL=LREAL
      ALPHA=DELTA/REAL
      BETA=(THETA(K)-9 . )/57.3
      LREAL=REAL
      DO 3   J=1,LREAL
      RJ=J
      RGX1=RX(K+1)+D*COS(BETA+(RJ*ALPHA)/57.3)
      RGY1=RY(K+1)+D*SIN(BETA+(RJ*ALPHA)/57.3)
      M=M+1
      BND(M)=TDFUN(RGX1,RGY1,1, )
3     CONTINUE
      GO TO 2
8     RGX1=RX(K+1)+D COS((THETA(K+1)-90.0)/57.3)
      RGY1=RY(K+1)+D SIN((THETA(K+1)-90.0)/57.3)
      M=M+1
      BND(M)=TDFUN(RGX1,RGY1,1, )
2     CONTINUE
1     CONTINUE
      BND(M+1)=TDFUN( , , ,1)
      IF(DSHNA) 3,3,7
7     CALL N  SH(CNTUR,F  )
3     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ANGLE(TETA,REF)
      DIMENSION  RX(25),RY(25),SLPA(25),SLP(25),THETA(25)
      COMMON K,RX,RY,SLPA,SLP,DELTA,ALPHA,THETA,D
      IF(RX(K+2)-RX(K+1)) 21,22,22
22    IF(RY(K+2)-RY(K+1)) 25,26,26
26    TETA=SLPA(K+1)
      GO TO 27
25    TETA=SLPA(K+1)+360.0
      GO TO 27
21    TETA=SLPA(K+1)+180.0
27    CONTINUE
      IF(RX(K)-RX(K+1)) 31,32,32
32    IF(RY(K)-RY(K+1)) 35,36,36
36    REF=SLPA(K)
      GO TO 37
35    REF=SLPA(K)+360.0
      GO TO 37
31    REF=SLPA(K)+180.0
37    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CRNP(X1,Y1,RGXX,RGYY)
      DIMENSION RX(25),RY(25),SLPA(25),SLP(25),THETA(25)
      COMMON K,RX,RY,SLPA,SLP,DELTA,ALPHA,THETA,D
      RGXB=RX(K+1)+D*COS((THETA(K+1)-90.0)/57.3)
      RGYB=RY(K+1)+D*SIN((THETA(K+1)-90.0)/57.3)
      B1=Y1-(X1*SLP(K))
      B2=RGYB-(RGXB*SLP(K+1))
      RGXX=(B2-B1)/(SLP(K)-SLP(K+1))
      RGYY=(RGXX*SLP(K))+B1
      RETURN
      END
```

ASSEMBLY LANGUAGE PROGRAM TO SAMPLE DIAL INPUTS

```
TITLE DIALS
EXPUNGE
ENTRY VCD,DIALS
S5AS = 35500&H
MD07 = 27000&H
MACRO1 READ(CHAN,DEST,VAR)
MD07'L: CHAN
MDAR'L: DEST
NOOP
S5AS'F
ARMD VAR
ENDM
VCD: JUMP
DIALS:         NOOP
READ(1&H1,[illegible],$IA)
READ(1&H2,[illegible],$IB)
READ(1&H4,[illegible],$IC)
READ(1&H10,00000,$ID)
READ(1&H20,00000,$IE)
READ(1&H40,00000,$IF)
MDIR VCD
TERMINATE
```

```
C     PROGRAM TO SCALE & TRANSFER DIAL INPUTS TO ROSTN ROUTINE

      SUBROUTINE SCALE
      DIMENSION  RX(25),RY(25),SLPA(25),SLP(25),THETA(25)
      COMMON   K,RX,RY,SLPA,SLP,DELTA,ALPHA,THETA,D
      COMMON   VAL1,VAL2,VALL1,VALL2,VAL3,VAL4
      GLOBAL (IA,IB,IC,ID,IE,IF)
      VALL1=FLOAT(ID)/9200.
      VALL2=(FLOAT(IE)/3870.0)*(-2.0)
      VALL3=(FLOAT(IC)/8762.0)*(-1.0)
      VALL4=(FLOAT(IB)/5267.0)*(-1.0)
      VAL1=RMV(VALL1)
      VAL2=RMV(VALL2)
      VAL3=RMV(VALL3)
      VAL4=RMV(VALL4)
      RETURN
      END
```

```
C      DATRS CONTAINS THE ARRAYS WHICH DEFINE THE NOISE SENSITIVE AREAS
       SUBROUTINE DATRS(SCL,SCLFT,DELX,DELY,X,Y,LRES,NRES,BOUND)
       DIMENSION  X(15,5),Y(15,5),LRES(5),BOUND(5)
       SCL=2.
       SCLFT=.053
       DELX=.35
       DELY=-.25
       NRES=5
       LRES(1)=13
       LRES(2)=11
       LRES(3)=14
       LRES(4)=8
       LRES(5)=4
       BOUND(1)=-1.0
       BOUND(2)=1.0
       BOUND(3)=-1.0
       BOUND(4)=1.0
       BOUND(5)=-1.
       X(1,1)=-.68
       X(2,1)=-.52
       X(3,1)=-.53
       X(4,1)=-.5
       X(5,1)=-.43
       X(6,1)=-.42
       X(7,1)=-.5
       X(8,1)=-.57
       X(9,1)=-.59
       X(10,1)=-.61
       X(11,1)=-.5
       X(12,1)=-.45
       X(13,1)=-.5
```

CONTINUED

```
C      DATBL DEFINES OBSTACLE ELEVATIONS & MAP POSITION COORDINATES

       SUBROUTINE DATBL(X,Y,HT,HMX,LB)
       DIMENSION X(15),Y(15),HT(15)
       LB=8
       HMX=800.
       HT(1)=300.
       HT(2)=500.
       HT(3)=500.
       HT(4)=500.
       HT(5)=550.
       HT(6)=300.
       HT(7)=800.
       HT(8)=450.
       X(1)=-.52
       X(2)=-.22
       X(3)=-.15
       X(4)=-.1
       X(5)=-.44
       X(6)=-.61
       X(7)=-.5
       X(8)=-.43
```

CONTINUED

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