Report No. FAA-CT-81-165

PROGRAM VALIDATION OF LINCOLN LABORATORY MICROWAVE LANDING SYSTEM MATH MODEL

Jesse D. Jones

PROJECT PLAN

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Prepared for
U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
TECHNICAL CENTER
Atlantic City Airport, N.J. 08405

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1. OBJECTIVE.

The Microwave Landing System (MLS) mathematical model computer program developed by the Lincoln Laboratory of the Massachusetts Institute of Technology will be converted by Federal Aviation Administration (FAA) Technical Center personnel to operate on their Honeywell 66/60 computer. The program will be exercised at the Technical Center and at Lincoln Laboratory to model various field siting configurations. The objective of this project is to verify that essentially identical results are obtained from the Technical Center Honeywell 66/60 computer as are obtained from the Lincoln Laboratory International Business Machines (IBM) 370/168 computer for the same model input parameters. Subsequently, the FAA will have the capability to model and analyze MLS performance at planned field installations.

2. BACKGROUND.

The use of radio beams to provide information for instrument landings is subject to errors generated by reflections and/or shadowing of the radio signals by terrain, buildings, and large aircraft. The term "multipath" is used to describe the reflection/shadowing phenomena because several possible paths exist for signals to travel between the transmitter and receiver as opposed to the single (direct) path assumed in initial system design. The continuing construction of buildings in the vicinity of the approach and landing zone and the increasing use of wide body aircraft (both potentially significant multipath sources) emphasize the importance of multipath effects to the design and selection of any landing system.

Thus, to aid in MLS selection and siting optimization, there is a need for a realistic multipath model to evaluate the real-world airport environments. This model will be used to assess the degradation of a guidance path when subjected to various levels of multipath interference.

The Lincoln Laboratory of the Massachusetts Institute of Technology has developed an MLS model that has been used to analyze MLS performance for various field siting configurations. This model will be converted for operation on the FAA Technical Center's Honeywell 66/60 computer. The capability will then exist at the Technical Center to evaluate the performance of an MLS in a real-world environment prior to actual installation.

3. RELATED DOCUMENTATION/PROJECTS.

a. MLS Multipath Studies, Phase 3, Final Report, Volume, I, April 25, 1979; Volume II, February 7, 1980; Volume III, (to be published April 1981); and Volume IV, (to be published June 1981); Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, Massachusetts 02173.

4. SYSTEM/EQUIPMENT DESCRIPTION.

The MLS simulation program is written in the FORTRAN IV computer language and has been successfully used on computers in the United Kingdom and the Federal Republic of Germany. It has three major parts: multipath parameter computations and graphical output, system error computations, and error manipulation and plotting. The relationship of these various parts is shown in figure 1. Multipath characteristics (level, separation, angle, etc.) are computed by the propagation model based on a particular airport environment; e.g., transmitter, building and aircraft locations, building sizes, terrain electrical properties, etc. specified by the user (in a block data subroutine). Flight paths of up to 35 segments are computed from waypoints supplied in a block data subroutine with the corresponding perturbation smoothing points. A special version of the flight path generating routine fits a smooth curved path between pairs of nonconnected linear segments.

For a given flight path, a loop over all the evaluation points is established to calculate the receiver coordinates as illustrated in figure 1. At each evaluation point, the program loops through all transmitter locations; e.g., all angle functions such as azimuth, elevation, and distance measuring equipment (DME). For a fixed transmitter-receiver geometry, a second loop is established to calculate the multipath parameters for each scattering object in the airport model. Multipath amplitude levels are initially determined as though the transmitter antenna pattern were omnidirectional. Subsequent routines are used for directional antenna patterns as inputted depending upon the specific transmitter and receiver antenna characteristics.

The multipath information to be passed to the receiver subroutines consists of the relative multipath amplitude, phase, time delay, azimuth, and elevation planar angles, specifying the direction of propagation of the direct wave and Doppler shift of the total (direct and reflected) received signal (due to the velocity of the aircraft). This information is then used for calculation of the interference frequencies by a receiver subroutine.

Editing is subsequently performed to remove minor components, and multipath characteristics are then written to a user-specified data set (usually a digital tape). Multipath diagnostics are plotted along with an airport map showing the placement of obstacles. The multipath programs require approximately 325,000 bytes of storage on the Lincolm IBM 370/168 computer. (In addition, the Lincoln Laboratory IBM/370 system typically requires 120,000 to 200,000 bytes of additional memory for the operating system.) The amount of computer time used depends on the number of obstacles and data points used. For a "typical" 200-point run with 10 scatterers and no perturbation smoothing, 2 minutes of central processing unit (CPU) time is required on the Lincoln IBM 370/168 computer.

The system model part of the simulation takes time reference scanning beam (TRSB) system parameters (initialized in the block data subroutine and/or provided in special subroutines), reads the multipath data generated by the propogation model, and computes the resulting errors as illustrated by figure 2. The program takes the errors and writes them out on a data set (typically a digital tape) to be used by the third part of the simulation. For a typical run with 200 points, no perturbation smoothing or static errors, and 10 scatterers, it takes about 3 to 10 minutes of CPU time for the TRSB elevation system to be processed. This time is

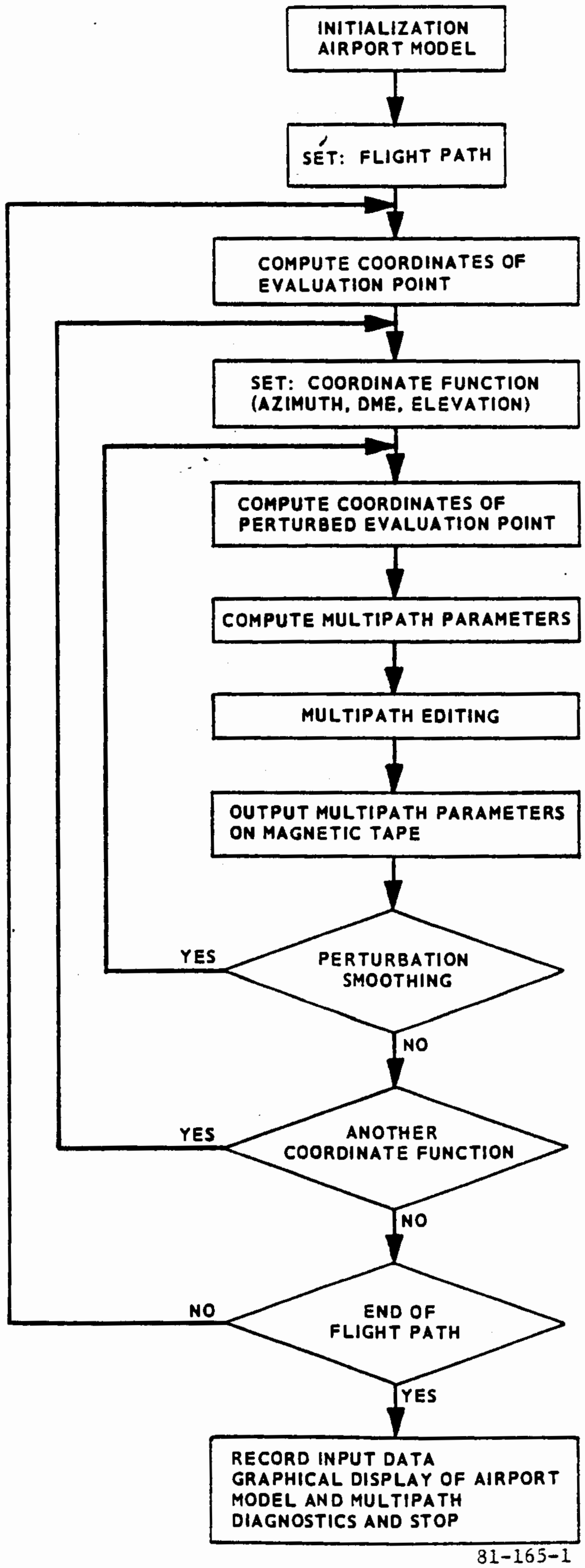

FIGURE 1. MULTIPATH SECTION FLOW CHART

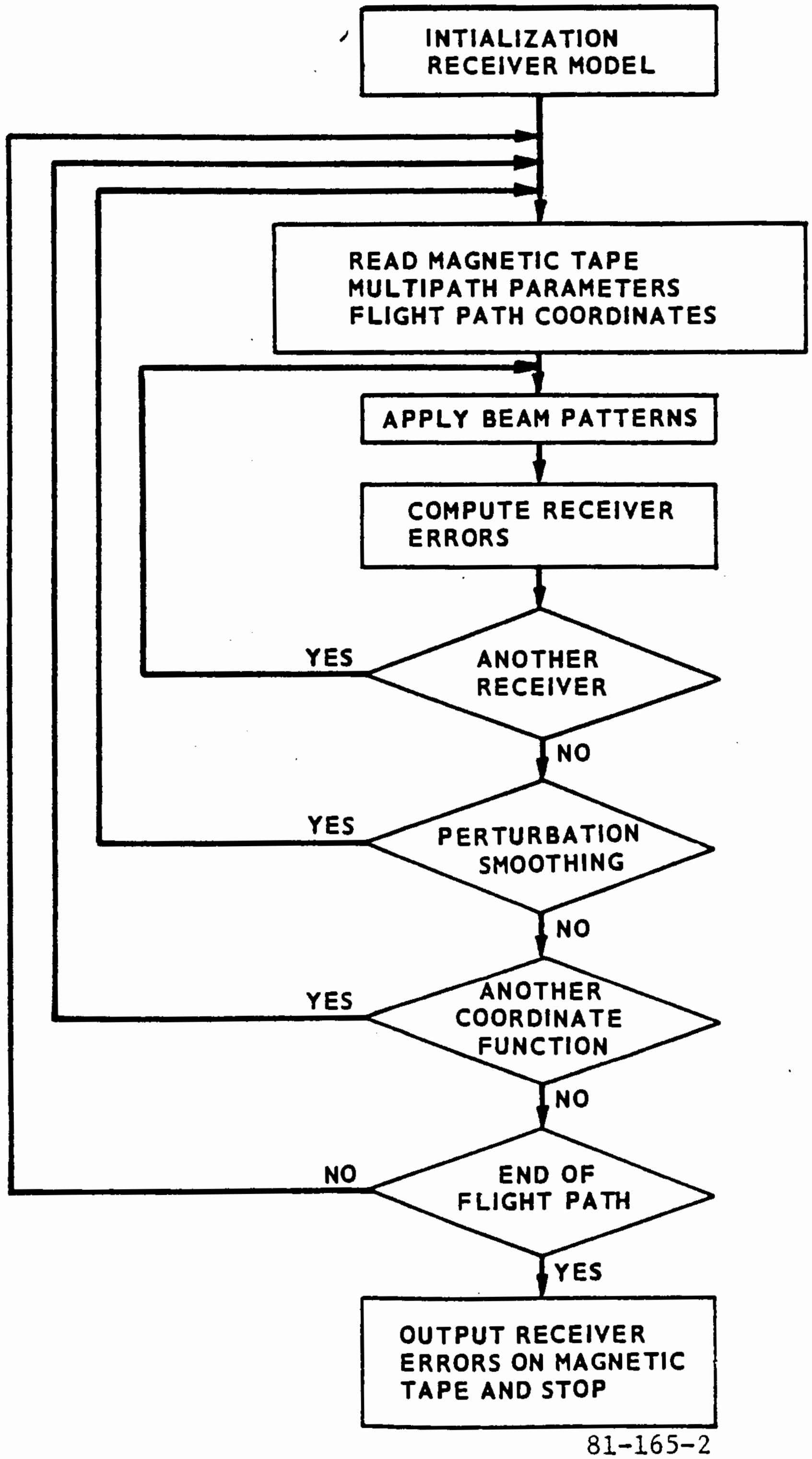

FIGURE 2. RECEIVER SECTION FLOW CHART

highly dependent on the number of multipath components and beam patterns used. The TRSB azimuth system typically runs two to three times faster than the elevation system. The system model programs require about 200,000 bytes of storage on the Lincoln 370 computer. A plotting program is used to plot the errors generated by the receiver routines.

Graphical routines used for the simulation are from the integrated graphics system of the Datagraphix Company with some modification by the Lincoln Laboratory support staff. The simulation program displays the graphical outputs of a Tektronix storage scope. The multipath part of the simulation produces a printout of the parameters used in the simulation run, an airport map locating the obstacles and transmitters, and multipath diagnostics. The diagnostics contain information about the multipath amplitude and separation angles along the flight path indicating the obstacles which generate significant multipath components.

The system model part of the simulation does not generate plots. The receiver error plotting program writes out a title page identifying the run and then plots the azimuth, DME, and elevation errors along the flight path for a specific system. If desired, x,y,z positional errors from the corresponding system can be plotted. Plots of the means, standard deviations, and peak errors can be obtained if perturbation smoothing was used. The single measurement errors are plotted over the dynamic errors with a different symbol. Also, if desired, the error histories may be passed through digital filters to give the path following, control-motion, and rate-error characteristics.

The plotting routines exist in separate subroutines in all but a few cases. No propagation or system model routine directly calls any plotting routine. Thus, the program may be adapted to other installations not having the Lincoln graphical routines.

The simulation routines involved with the computation of multipath receiver errors were written to be as independent as possible. That is, they generally do not depend on the calling routine. For routines to work faster and more efficiently, especially when doing perturbation smoothing, some routines do have knowledge of the structure of the calling routine. However, the complexity this introduces is fairly small, and, as a result, the routines can be used independently for a variety of other studies.

Similarly, several test programs have been written which can check out the various multipath and receiver routines and/or be used as a tool in multipath measurement test design, system optimization, etc. Specific test programs include multipath from a single obstacle and performance of a specific receiver when one or more multipath components are present. The FORTRAN routines are highly interactive and generate graphical output so that specific cases can be examined easily and in great detail.

5. TESTING AND DATA COLLECTION.

All parts of the MLS simulation program will be exercised by the use of special Lincoln Laboratory test programs and actual simulations, as necessary. Any actual simulations to be run will be selected from previously modeled sites after the specific site characteristics required to exercise the program are determined. All test programs and simulations will be run on both the FAA Technical Center Honeywell 66/60 computer and the Lincoln Laboratory IBM 370/168 computer (as available). Quantitative (printout of calculated values) as well as qualitative (plots of calculated data) data will be obtained. The project engineer will travel to Lincoln Laboratory to participate in the modeling simulations on its computer.

6. DATA REDUCTION AND ANALYSIS.

The quantitative outputs from the simulations on either computer are expected to be essentially identical. Because of differences in precision the results from the two computers are not expected to be exactly identical. The program conversion to the FAA Technical Center computer will not be considered valid until the output data from both computers agrees to two decimal places when three or more decimal places are displayed.

7. INSTRUMENTATION AND FACILITIES.

The facilities required for this project will be the Lincoln Laboratory IBM 370/168 computer and the FAA Technical Center Honeywell 66/60 computer and peripherals.

8. COORDINATION AND AREAS OF RESPONSIBILITY.

a. The Systems Test and Evaluation Division, ACT-100, is responsible for project planning, conduct, coordination, performing the program validation, monitoring the simulations at Lincoln Laboratory, and running the simulations (program validation and future site modeling) at the FAA Technical Center.

b. The Data Engineering and Development Division, ACT-700, is responsible for the conversion of the Lincoln Laboratory MLS simulation program to run on the FAA Technical Center Honeywell 66/60 computer.

c. Coordination with Lincoln Laboratory is required by ACT-700 for program conversion and by ACT-100 and the Navigation and Landing Division, ARD-300, for program validation.

9. SCHEDULE.

Figure 3 shows the project schedule.

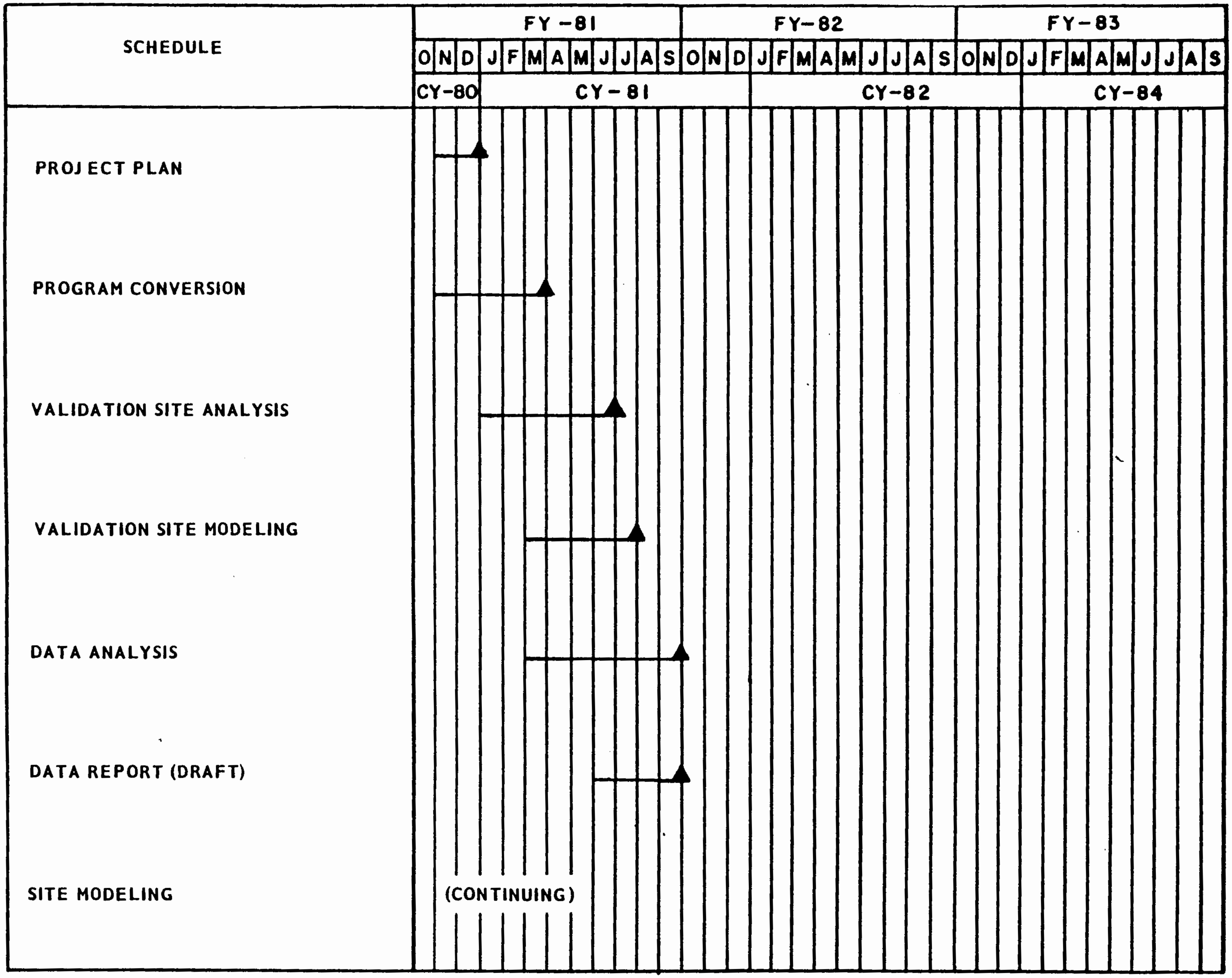

FIGURE 3. PROJECT SCHEDULE

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March 1981

Project Plan

Prepared by
DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration
Technical Center
Atlantic City, NJ 08405

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6. DATA REDUCTION AND ANALYSIS.

A complete modeling simulation will yield two sets of graphical information created from two sets of numerical data. The multipath model computes and stores several parameters of the direct and multipath signals. These data are then entered into the TRSB system model which computes the error that would be received by an MLS receiver. Due to the difference in the bit length between the Lincoln Laboratory (LL) computer and the FAA Technical Center computer words, the FAA numerical data will have a precision of eight decimal digits, whereas, the LL data will only have a precision of about seven digits. This difference in precision is not expected to appreciably affect the final results; however, it will be a source of some differences in the numerical data.

Multipath and TRSB receiver output data from the two computers will be compared at the numerical intermediate steps and at the final output plot level. The output plots will be compared and considered analogous and the scenario validated if the plots convey the same information (trends, out-of-tolerance, etc.). Numerical comparisons will be performed as described in the following paragraphs; however, these comparisons will only be used for informational purposes.

The multipath part of the model generates a numerical data record for each observation point. This record contains information unique to that point and up to 20 multipath components. Nine numerical parameters are available from the multipath component part of the record for comparison. These parameters are:

1. Relative amplitude of multipath signal (direct wave is included with amplitude = 1).

2. Phase (direct = 0).

3. Time delay.

4. Azimuth planar direction angle of the multipath component (referenced to transmitter boresight).

5. Elevation planar direction angle of the multipath component (referenced to transmitter boresight).

6. Fractional Doppler frequency of multipath signal (not used).

7. Fractional receiver Doppler frequency (aircraft component of the Doppler shift).

8. Planar azimuth incidence angle of the multipath component at the receiver (referenced to a coordinate system aligned with the velocity vector of the aircraft).

9. Planar elevation incidence angle of the multipath component at the receiver (referenced to a coordinate system aligned with the velocity vector of the aircraft).

For each point modeled, the LL and FAA multipath data will be compared numerically according to the following rules:

1. A data record will be read from the LL data file and from the FAA data file.

2. A sequence check will be made to ensure that both records apply to the same observation point. Records will be discarded as necessary to bring the data files into sequence.

3. Both records will be compared to see if the same number of multipath components were computed. Since it is impossible (due to program multipath editing features) to insure comparison of the same multipath components when the number of components is not the same, both data records will be discarded.

4. Each multipath component will be checked for amplitude. If either amplitude is less than 0.05 (about -26dB) and out-of-beam, that component set will be discarded.

5. Any multipath component data set which passes the above tests will have the absolute differences computed for each of the nine parameter pairs.

6. An error counter will be incremented for each occurrence of any parameter difference which exceeds the following limits:

a. 0.05 (-26dB) for amplitude and in-beam
b. 0.09 radians (5°) for phase
c. 0.004 radians (0.25°) for planar direction angles
d. 5×10^{-5} seconds (quarter-wave at C-band) for time delay
e. 0.3 Hz for Doppler (scalloping frequency)
f. 0.02 radians (1°) for incidence angles

7. Each comparison will be separated into three parts, i.e., azimuth, DME, and elevation.

8. A mean error will be computed for all parameter pair catagories based upon the number of multipath components actually compared.

The MLS math model will be considered validated for all scenarios which are graphically analogous as of July 30, 1984. Separate documentation will be prepared for any validations performed after that date, since the model will be refined and upgraded as MLS installations are performed and flight check data are available.

7. INSTRUMENTATION AND FACILITIES.

The facilities required for this project will be the Lincoln Laboratory computer and the FAA Technical Center Honeywell 66/60 computer and peripherals.

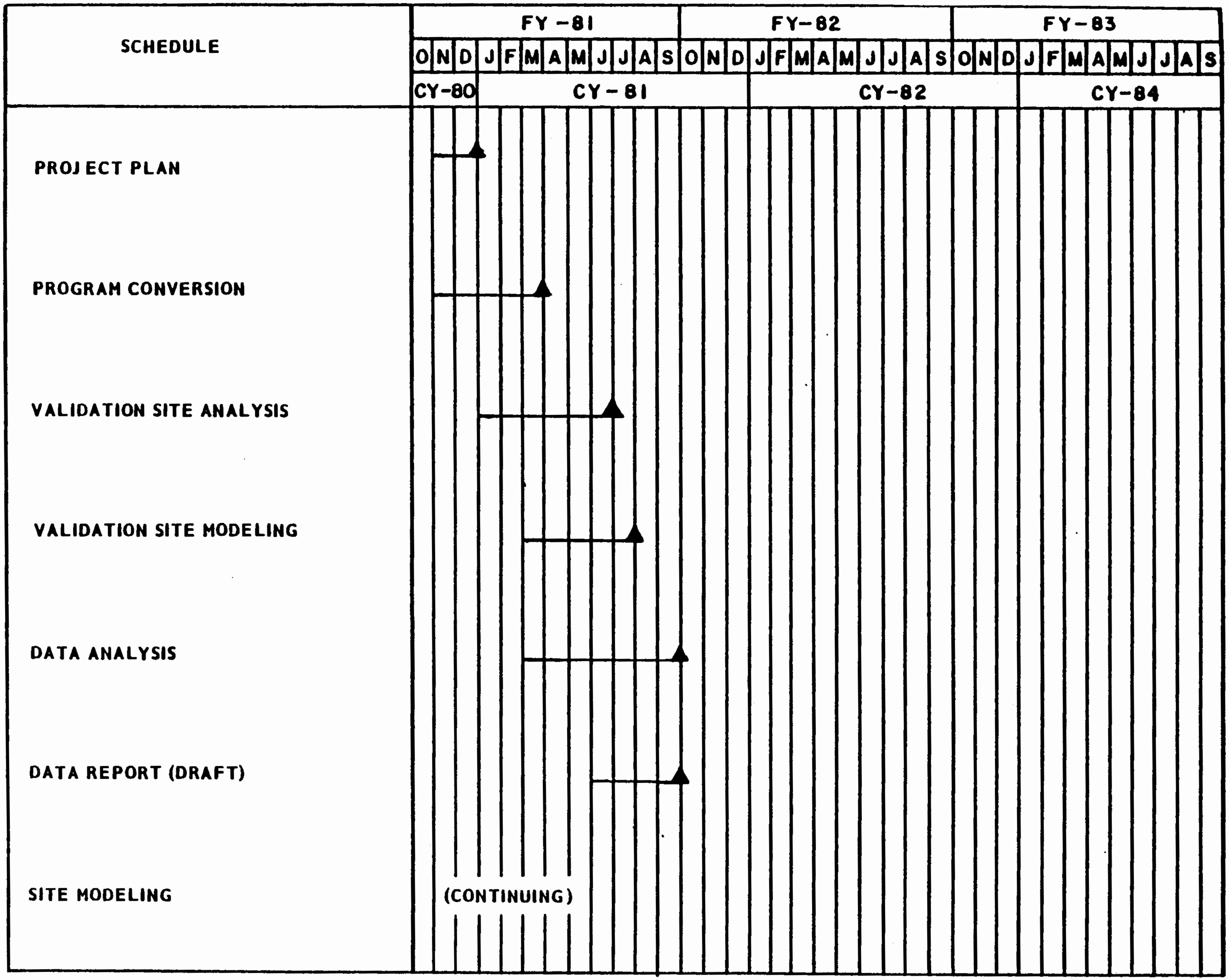
8. COORDINATION AND AREAS OF RESPONSIBILITY.

a. The Engineering Division, ACT-100, is responsible for project planning, coordination, performing the program validation, monitoring the simulations at Lincoln Laboratory, and running the simulations (program validation and future site modeling) at the FAA Technical Center.

b. The math model author at Lincoln Laboratory will provide consultation and technical assistance during the program validation and subsequent model refinement(s), as required.

9. SCHEDULE.

Figure 3 shows the project schedule.



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