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MLS MATHEMATICAL MODELING STUDY FOR WENATCHEE AIRPORT, RUNWAY 29, WENATCHEE, WASHINGTON

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INTRODUCTION

Microwave Landing System (MLS) Math Modeling personnel evaluated the proposed MLS installation for runway 29 at Wenatchee, Washington. The MLS math model predicts the effects of an airport environment on the MLS signal. Appendix A is an introduction to MLS and an introduction to the MLS mathematical model can be found in Appendix B. Analysis of the airport environment identified terrain as having a potential effect on the signals from the proposed azimuth site 1. Two obstacles were identified as having potential effects on the MLS signals from the proposed azimuth site 3. The obstacles of concern are a VOR and its supporting building, both with potential multipath reflection and shadowing effects.

SITES AND FLIGHTPATHS

The systems modeled were a 2° beamwidth Bendix azimuth with a +/- 40° scan, a 1.5° beamwidth Bendix elevation, and a DME/P with a pulse rise time of 1200 nano-seconds. Figure 1 illustrates the relative locations of the MLS and DME/P systems, the VOR and supporting building, and the terrain. The dashed lines represent the possible effects of the terrain surfaces on the respective azimuth site.

For this study, offset azimuth sites 1 and 3 were considered. Azimuth (AZ) site 1 is located 3860 feet from the stop end and 250 feet off the centerline. AZ site 3 is located 380 feet from the stop end and 250 feet off the centerline. The Precision Distance Measuring Equipment (DME/P) is collocated with each azimuth and was also modeled. Elevation (EL) site 1 was used to determine the coordinates of the flightpath (4.5° glidepath on centerline). Site coordinates were provided by the Northwest Mountain Region Airway Facilities Division. All the sites are located on the left side of the runway, from the pilot's point of view. Copies of the input files used for the 4.5° approach to AZ sites 1 and 3 are included as tables 1 and 2 respectively.

Terrain effects on AZ site 1 were modeled by two separate regions as shown in figure 1. The first region in front of AZ Site 1 was modeled as three separate surfaces based on data provided by the regional personnel. The surface closest to the runway was almost flat with a very slight rise as the distance from the runway increased. The middle 50 foot wide region had a very steep rise (about a 15% slope) and the region farthest from the runway continued to rise with approximately a 3% slope. The region in front of the EL was modeled as a single surface with a 10% upslope as the distance increased away from the runway. The effects on the EL system of the terrain surface in front of the EL also was modeled resulting in negligible errors and therefore not considered in this report. The effect of the VOR cone on AZ site 3 was modeled as a single surface, 17 feet high (including the counterpoise height) with a width of 10 feet. The supporting building was modeled as a single flat surface 10 feet high with a width of 41.7 feet. This representation results in a "worse case" scenario. For multipath effects the VOR cone surface was oriented

parallel to the centerline of the runway. Shadowing effects were created by orienting the surface perpendicular to the line of sight of the azimuth and VOR. Figure 2 shows the dimensions of the VOR structure and the arrangement of the surfaces for multipath and shadowing effects on azimuth site 3.

The approach flightpaths examined for this installation consisted of three approaches with glidepath angles of 3.5°, 4.5° (the minimum glide path angle), and 5.5°. The MLS approach simulated was an AZ boresight approach beginning approximately 5 nautical miles from the centerline intercept point. (The azimuth boresight is rotated to intercept centerline 3000 feet out from the runway threshold). In addition to the approach flightpaths, partial orbit flightpaths with the same glide path angles were modeled to evaluate potential effects throughout the MLS coverage volume. These partial orbit flightpaths extend between the scan angle limits of the azimuth subsystem at a radius of 10 nautical miles from the DME/P.

RESULTS AND CONCLUSIONS

Analysis of the terrain effects on AZ site 1 revealed some effects on the azimuth subsystem. By examining the Path Following Error (PFE) plots for the 4.5° partial orbit and approach flightpaths, figures 3 and 4, respectively, one can see that these errors are contained well within the tolerance lines (the horizontal dashed lines). Figure 5 shows that the Control Motion Noise (CMN) error for the approach is very large but remains within the tolerance limits with an acceptable level of error. The CMN plot for the approach showed that this error was well within tolerance and is not presented.

The MLS math model predicted no significant effects to AZ site 3 from the cone shaped VOR or the supporting building for any of the flightpaths described above for any of the subsystems (azimuth or DME/P). In fact, only the partial orbit flightpath scenarios for the VOR generated any effects at all. Between the azimuth angles of 3° and 10°, an amplitude effect (shadowing) from the VOR structure was predicted for the DME/P uplink and downlink subsystems. Figure 6 is a depiction of the DME/P uplink shadowing. The DME/P downlink and uplink for all 3 partial orbit flightpaths have the same representation. By examining these effects further, figure 7, the DME/P PFE plot reveals no errors were generated, indicating that these effects were extremely small. The CMN errors (not shown) were also negligible.

In conclusion, the MLS math model predicts no significant effects on the MLS and DME/P systems from the VOR, the supporting building, or the terrain modeled for the approach to runway 29 at Wenatchee. Analysis of simulated partial orbit flightpaths shows no area of the coverage volume where these obstacles will generate out-of-tolerance MLS signals. We conclude, on this basis, that the proposed MLS azimuth sites 1 and 3 are acceptable.

TABLE 1. AZIMUTH SITE 1, INPUT DATA

```
*****************MLS MATHEMATICAL MODEL INPUT DATA FILE***********************
SECTION  0
          = SCENARIO DATA
          RUN ID# :4TA4
          TITLE   :4 TERRAIN SURFACES, 4.5 DEG APPROACH
          AIRPORT :WENATCHEE, WASHINGTON
          RUNWAY  :29
          LENGTH  :5500.
          WIDTH   :150.
          ARDH    :50.0
          MGPA    :4.5
          UNITS   :FEET   (feet, meter) FOR ENTRIES IN FILE
SECTION 1A
          = ANGLE TRANSMITTER DATA
          PHASE CENTER:  X        Y        Z    FREQ(mhz)  LSL   USL    TYPE
                        -------- -------- -------- --------- ----- ----- --------
          AZIMUTH  :   3860.0   -250.0     5.3    5000.0 -40.0  40.0 AZBL2040
          ELEVATION:  4955.54   -250.0     9.7    5000.0   0.0  15.0 ELB15
SECTION 1D
          = DME/P TRANSMITTER DATA
          PHASE CENTER:  X        Y        Z      TYPE
                        -------- -------- -------- --------
          DME/P    :   3860.0   -250.0     15.3 DMBN

            = OTHER DME DATA
                      FREQ(mhz)  SHAPE    TRG  F   SW    AS    TRS  SIGM   RMI
                      --------- -------- -- -- ----- ----- ----- ----- -----
          UPLINK   :    1001.0 PCOC21200 DAC NOF   0.5   0.5 0.125   0.0   0.0
          DOWNLINK :    1001.0 PCOC21200 DAC NOF   0.5   0.5 0.125   0.0   0.0
SECTION  2
          YES - DO ANY GROUND REFLECTION PROCESSING (CALL GREFC) (yes,no)
          YES - DO FULL INTEGRATION FOR SPECULAR GROUND SCATTERING (yes,no)
          = DEFAULT DIELECTRIC CONSTANT AND ROUGHNESS HEIGHT
          DIELECTRIC CONSTANT : 80.0        -54.0
          ROUGHNESS HEIGHT    : 0.0
        * FOR MULTIPLE SCATTERING PATHS FROM AIRCRAFT AND BUILDINGS
          DIELECTRIC CONSTANT : 80.0        -54.0
          ROUGHNESS HEIGHT    : 0.0
SECTION  4
          = SCATTERING FROM BUILDINGS (MAXIMUM OF 10)
          YES - RUN SCATTERING BUILDINGS (yes,no)
        ##  X-LEFT   Y-LEFT   X-RGHT   Y-RGHT   ELV   HGT   TLT   GRCORR   CMP
        -- -------- -------- -------- -------- ----- ----- ----- -------- -----
        nn xxxxxxxx yyyyyyyy xxxxxxxx yyyyyyyy eeeee hhhhh ttttt cccccccc mmmmm
        01   1988.5   -433.7   1998.5   -433.7  13.3  17    0     0       METAL
        02   1978.8   -423.0   1993.6   -408.1   3.3  10    0     0       METAL
SECTION  5
          = SPECULAR SCATTERING FROM RECTANGULAR GROUND SURFACES (MAX OF 10)
          YES - RUN RECTANGULAR GROUND (yes,no)
          THIS SECTION MAY BE SKIPPED DEPENDING ON ANSWERS IN SECTION 2
        ##  X-VALU   Y-VALU   Z-VALU   DCREAL   DCIMAG   ROUGHN  SF
        -- -------- -------- -------- -------- -------- -------- --
        nn x1x1x1x1 y1y1y1y1 z1z1z1z1 rrrrrrrr iiiiiiii rrrrrrrr is
           x2x2x2x2 y2y2y2y2 z2z2z2z2
           x3x3x3x3 y3y3y3y3 z3z3z3z3
        01   4140.0   -100.0     -2.5                          0.0  1
             4140.0   -280.0     -2.3
             4300.0   -280.0     -2.3
        02   4140.0   -280.0     -2.3                         0.0  1
             4140.0   -300.0      0.6
             4300.0   -300.0      0.6
        03   4140.0   -300.0      0.6                          0.0  1
             4140.0   -380.0      1.9
             4300.0   -380.0      1.9
        04   5200.0   -250.0      0.2                          0.0  1
             5200.0   -300.0      5.5
             5600.0   -300.0      5.5
SECTION  9
          = SHADOWING BY BUILDINGS (MAXIMUM OF 10)
          YES - RUN SHADOWING BUILDINGS (yes,no)
        ##  X-LEFT   Y-LEFT   X-RGHT   Y-RGHT   ELV   HGT
        -- -------- -------- -------- -------- ----- -----
        nn xxxxxxxx yyyyyyyy xxxxxxxx yyyyyyyy eeeee hhhhh
        01   1992.9   -438.7   1994.1   -428.7  13.3  17.0
        02   1993.6   -408.1   2004.2   -448.4   3.3  10.0
SECTION 12
          = FLIGHTPATH
          FAF      : 5.0          NAUTICAL MILES
          DATUM    : 4955.5   0.0      4.0
          TYPE     : SEGMENTED     (measured,distance,orbit,radial,
        *                           segmented,straight)
          VELOCITY : 200.0
          INCREMENT: 40.0
          DATA RATE: 0.2
        *  IF "straight" SUFFICIENT DATA ARE AVAILABLE TO COMPUTE FLIGHTPATH
        *  IF "radial" ENTER ANGLE,ELEVATION & STARTING AND ENDING DISTANCES
        *                (nm from dme/p)
          ANGLE: aaaaaaa
          SDIST: dddddd
          EDIST: dddddd
          ELEV : eeeeeeee
        *  IF "orbit" ENTER RADIUS (nm from dme/p) & ELEVATION
          RADIUS: 10                                nm
          ELEV  : 5850
        *  IF "measured" X,Y,Z COORDINATES AND TIME WILL BE READ FROM UNIT 15
        *     WITH VELOCITY AND DATA INCREMENT COMPUTED FROM INPUT
        *  IF "segmented" or "distance" ENTER SEGMENT #,X,Y,Z,VELOCITY AND
        *     INCREMENT
        ##    XS       YS       ZS       VEL      INC
        -- -------- -------- -------- -------- --------
        nn xxxxxxxx yyyyyyyy zzzzzzzz vvvvvvvv iiiiiiii
        03 38880.0   1798.5   2684.4    200.0     40.0
        02  8500.0      0.0    289.3    200.0     40.0
        01  5400.0      0.0     49.8    200.0     40.0
END DATA
```

TABLE 2. AZIMUTH SITE 3, INPUT DATA

```
*****************MLS MATHEMATICAL MODEL INPUT DATA FILE***********************
SECTION  0
          = SCENARIO DATA
          RUN ID# :VA14
          TITLE   :VOR  AZ1, 4.5 DEG APPROACH
          AIRPORT :WENATCHEE, WASHINGTON
          RUNWAY  :29
          LENGTH  :5500.
          WIDTH   :150.
          ARDH    :50.0
          MGPA    :4.5
          UNITS   :FEET   (feet, meter) FOR ENTRIES IN FILE
SECTION 1A
          = ANGLE TRANSMITTER DATA
          PHASE CENTER:  X        Y        Z    FREQ(mhz)  LSL   USL    TYPE
                        -------- -------- -------- --------- ----- ----- --------
          AZIMUTH  :    380.0   -250.0     5.4    5000.0 -40.0  40.0 AZBL2040
          ELEVATION:  4955.54   -250.0    21.1    5000.0   0.0  15.0 ELB15
SECTION 1D
          = DME/P TRANSMITTER DATA
          PHASE CENTER:  X        Y        Z      TYPE
                        -------- -------- -------- --------
          DME/P    :    380.0   -250.0    15.4 DMBN

            = OTHER DME DATA
                     FREQ(mhz)  SHAPE    TRG  F   SW    AS    TRS  SIGM   RMI
                     --------- --------- --- --- ----- ----- ----- ----- -----
          UPLINK   :    1001.0 PCOC21200 DAC NOF   0.5   0.5 0.125   0.0   0.0
          DOWNLINK :    1001.0 PCOC21200 DAC NOF   0.5   0.5 0.125   0.0   0.0
SECTION  2
          YES - DO ANY GROUND REFLECTION PROCESSING (CALL GREFC) (yes,no)
          YES - DO FULL INTEGRATION FOR SPECULAR GROUND SCATTERING (yes,no)
          = DEFAULT DIELECTRIC CONSTANT AND ROUGHNESS HEIGHT
          DIELECTRIC CONSTANT : 80.0        -54.0
          ROUGHNESS HEIGHT    : 0.0
        * FOR MULTIPLE SCATTERING PATHS FROM AIRCRAFT AND BUILDINGS
          DIELECTRIC CONSTANT : 80.0        -54.0
          ROUGHNESS HEIGHT    : 0.0
SECTION  4
          = SCATTERING FROM BUILDINGS (MAXIMUM OF 10)
          YES - RUN SCATTERING BUILDINGS (yes,no)
       ##  X-LEFT   Y-LEFT   X-RGHT   Y-RGHT   ELV   HGT   TLT   GRCORR   CMP
       -- -------- -------- -------- -------- ----- ----- ----- -------- -----
       nn xxxxxxxx yyyyyyyy xxxxxxxx yyyyyyyy eeeee hhhhh ttttt cccccccc mmmmm
       01   1988.5   -433.7   1998.5   -433.7  17.0  17    0     0       METAL
       02   1978.8   -423.0   1993.6   -408.1   7.0  10    0     0       METAL
SECTION  5
          = SPECULAR SCATTERING FROM RECTANGULAR GROUND SURFACES (MAX OF 10)
          NO  - RUN RECTANGULAR GROUND (yes,no)
          THIS SECTION MAY BE SKIPPED DEPENDING ON ANSWERS IN SECTION 2
       ##  X-VALU   Y-VALU   Z-VALU   DCREAL   DCIMAG   ROUGHN  SF
       -- -------- -------- -------- -------- -------- -------- --
       nn x1x1x1x1 y1y1y1y1 z1z1z1z1 rrrrrrrr iiiiiiii rrrrrrrr is
          x2x2x2x2 y2y2y2y2 z2z2z2z2
          x3x3x3x3 y3y3y3y3 z3z3z3z3
       01   4140.0   -100.0     -2.5                          0.0  1
            4140.0   -280.0     -2.3
            4300.0   -280.0     -2.3
       02   4140.0   -280.0     -2.3                         0.0  1
            4140.0   -300.0      0.6
            4300.0   -300.0      0.6
       03   4140.0   -300.0      0.6                          0.0  1
            4140.0   -380.0      1.9
            4300.0   -380.0      1.9
       04   5200.0   -250.0      5.5                          0.0  1
            5200.0   -300.0      5.5
            5600.0   -300.0      5.5
SECTION  9
          = SHADOWING BY BUILDINGS (MAXIMUM OF 10)
          YES - RUN SHADOWING BUILDINGS (yes,no)
       ##  X-LEFT   Y-LEFT   X-RGHT   Y-RGHT   ELV   HGT
       -- -------- -------- -------- -------- ----- -----
       nn xxxxxxxx yyyyyyyy xxxxxxxx yyyyyyyy eeeee hhhhh
       01   1992.9   -438.7   1994.1   -428.7  17.0  17.0
       02   1993.6   -408.1   2004.2   -448.4   7.0  10.0
SECTION 12
          = FLIGHTPATH
          FAF      : 5.0              NAUTICAL MILES
          DATUM    : 4955.5   0.0       4.0
          TYPE     : SEGMENTED         (measured,distance,orbit,radial,
        *                             segmented,straight)
          VELOCITY : 200.0
          INCREMENT: 40.0
          DATA RATE: 0.2
        * IF "straight" SUFFICIENT DATA ARE AVAILABLE TO COMPUTE FLIGHTPATH
        * IF "radial" ENTER ANGLE,ELEVATION & STARTING AND ENDING DISTANCES
        *      (nm from dme/p)
          ANGLE: aaaaaaa
          SDIST: ddddddd
          EDIST: ddddd
          ELEV : eeeeeeee
        * IF "orbit" ENTER RADIUS (nm from dme/p) & ELEVATION
          RADIUS: 10                          nm
          ELEV  : 5850
        * IF "measured" X,Y,Z COORDINATES AND TIME WILL BE READ FROM UNIT 15
        *     WITH VELOCITY AND DATA INCREMENT COMPUTED FROM INPUT
        * IF "segmented" or "distance" ENTER SEGMENT #,X,Y,Z,VELOCITY AND
        *     INCREMENT
       ##    XS       YS       ZS       VEL      INC
       -- -------- -------- -------- -------- --------
       nn xxxxxxxx yyyyyyyy zzzzzzzz vvvvvvvv iiiiiiii
       03  38880.0   1027.7   2692.9    200.0     40.0
       02   8500.0      0.0    300.7    200.0     40.0
       01   5400.0      0.0     61.2    200.0     40.0
END DATA
```

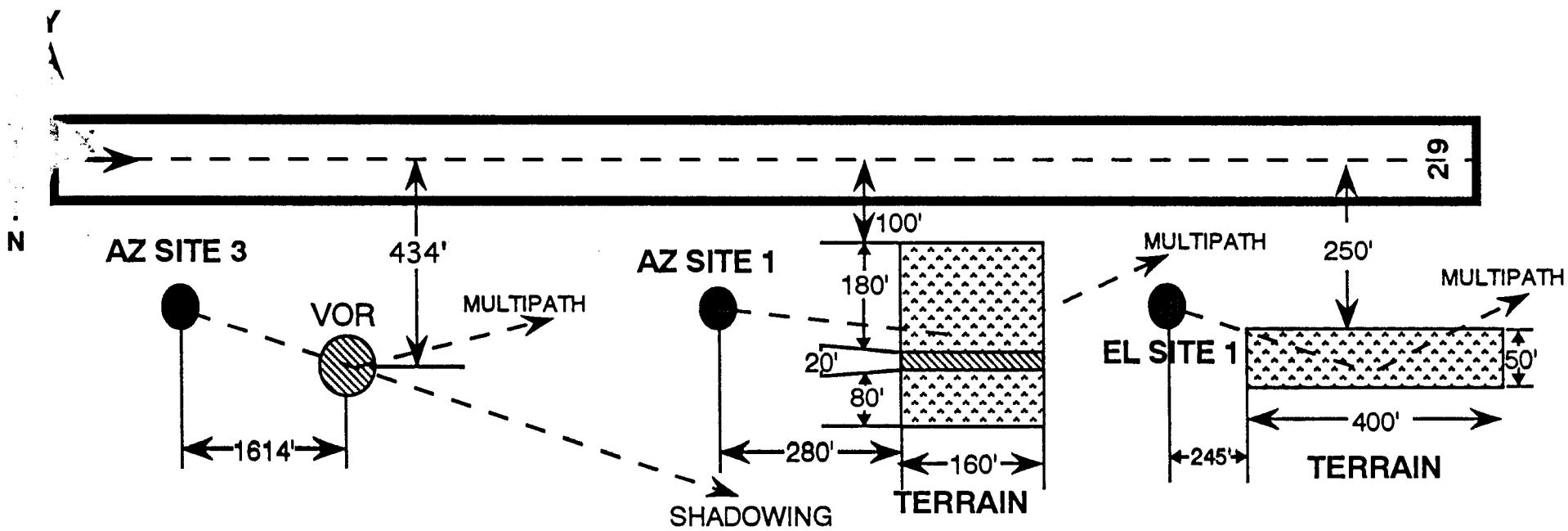


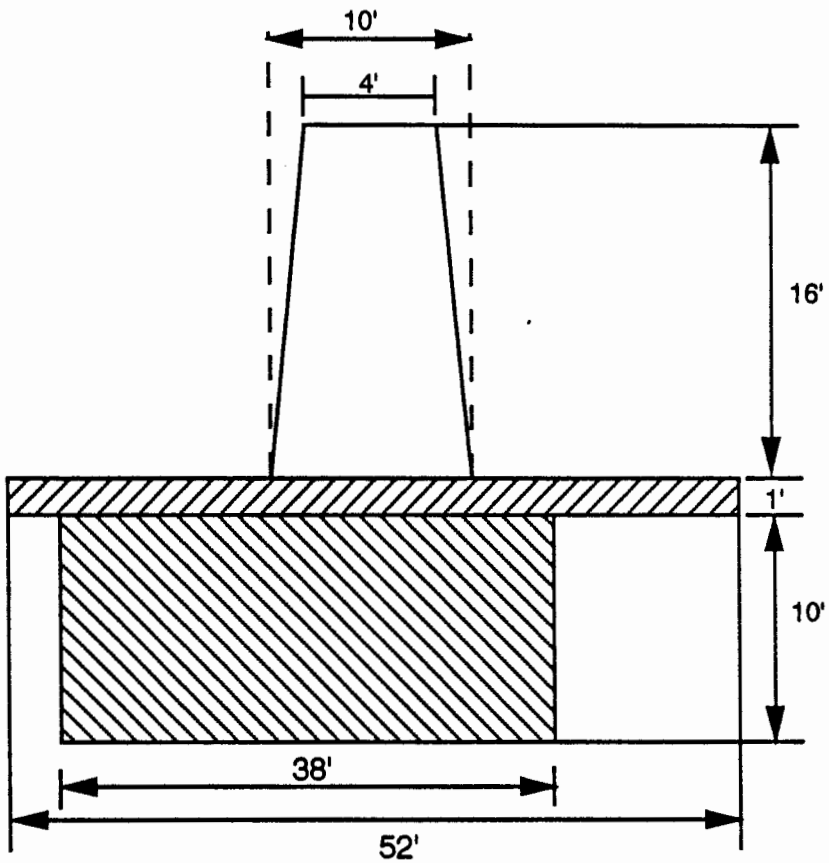
TABLE OF SITE LOCATIONS
(ANTENNA PHASE CENTERS)

	X	Y	Z
AZ1	3860.0	-250	1226.8 MSL
AZ3	380.0	-250	1219.0 MSL
EL1	4955.5	-250	1233.0 MSL

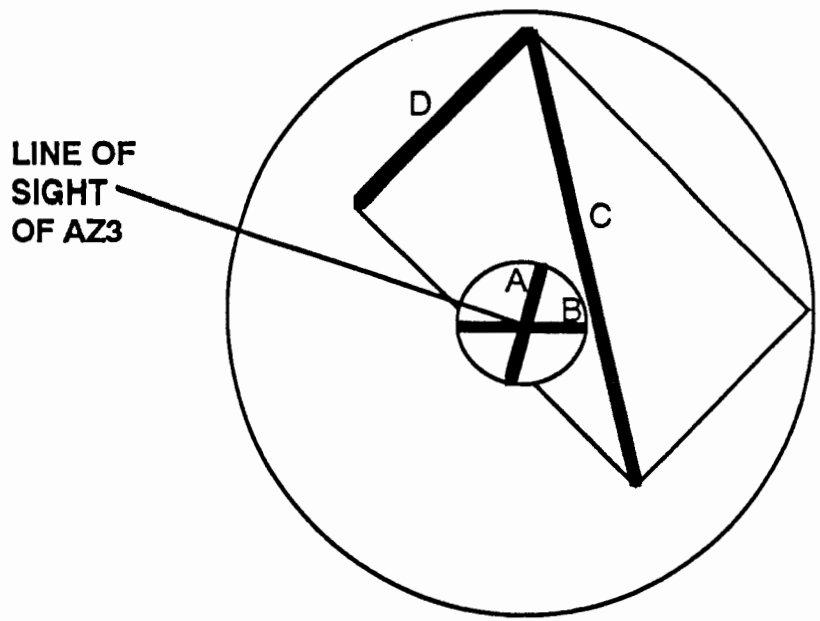
** Drawing not to scale*

FIGURE 1. MLS SITING LAYOUT FOR RUNWAY 29 - WENATCHEE, WASHINGTON

FULL VIEW
ALONG LINE OF SIGHT



REPRESENTATION OF PLATES



SHADOWING: A, C
MULTIPATH: B, D

** Drawings not to scale*

FIGURE 2. VOR STRUCTURE - EFFECTS ON AZIMUTH SITE

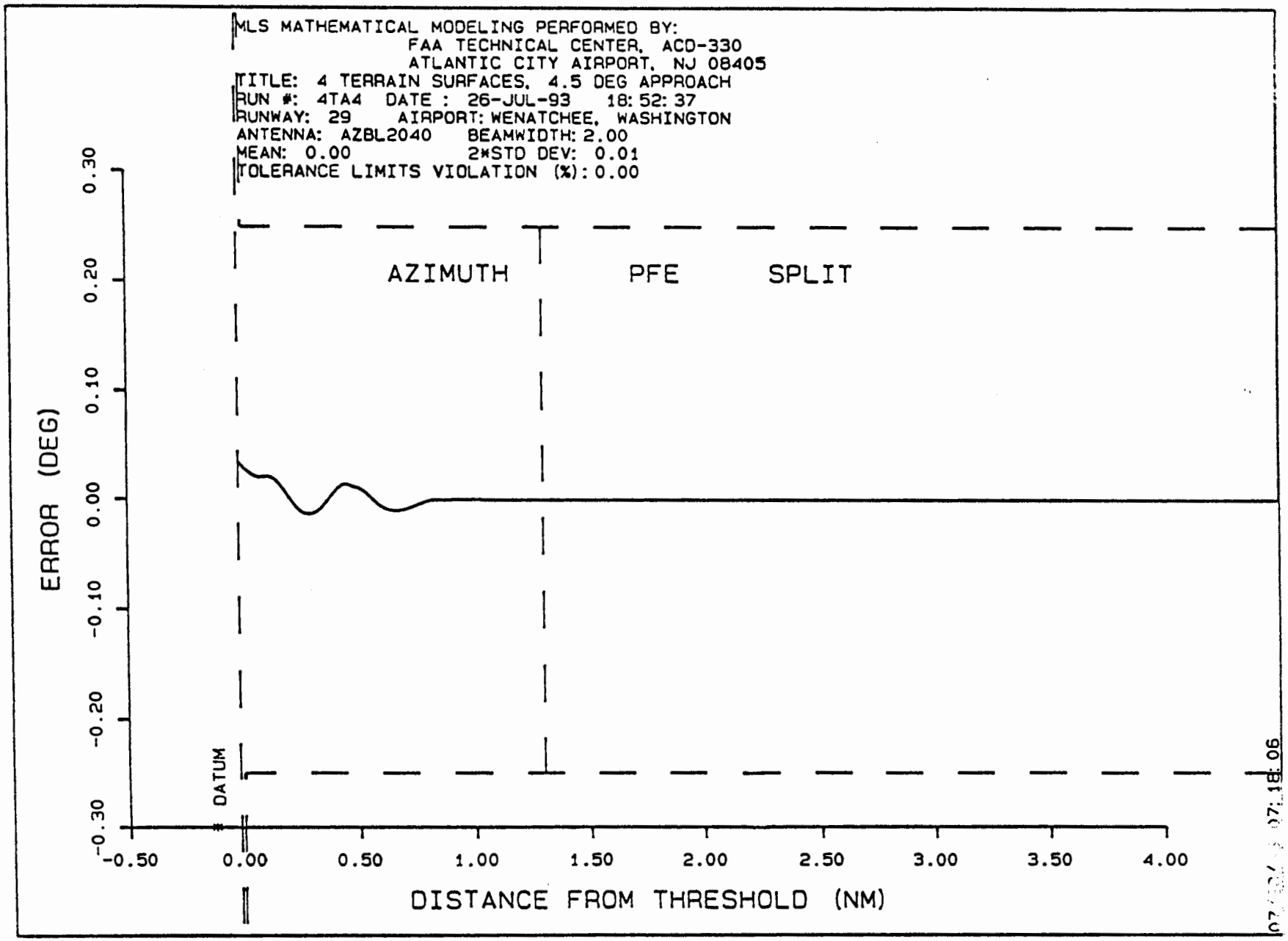


FIGURE 3. AZIMUTH SUBSYSTEM, 4.5 DEGREE APPROACH FLIGHTPATH, PFE ERRORS FROM TERRAIN

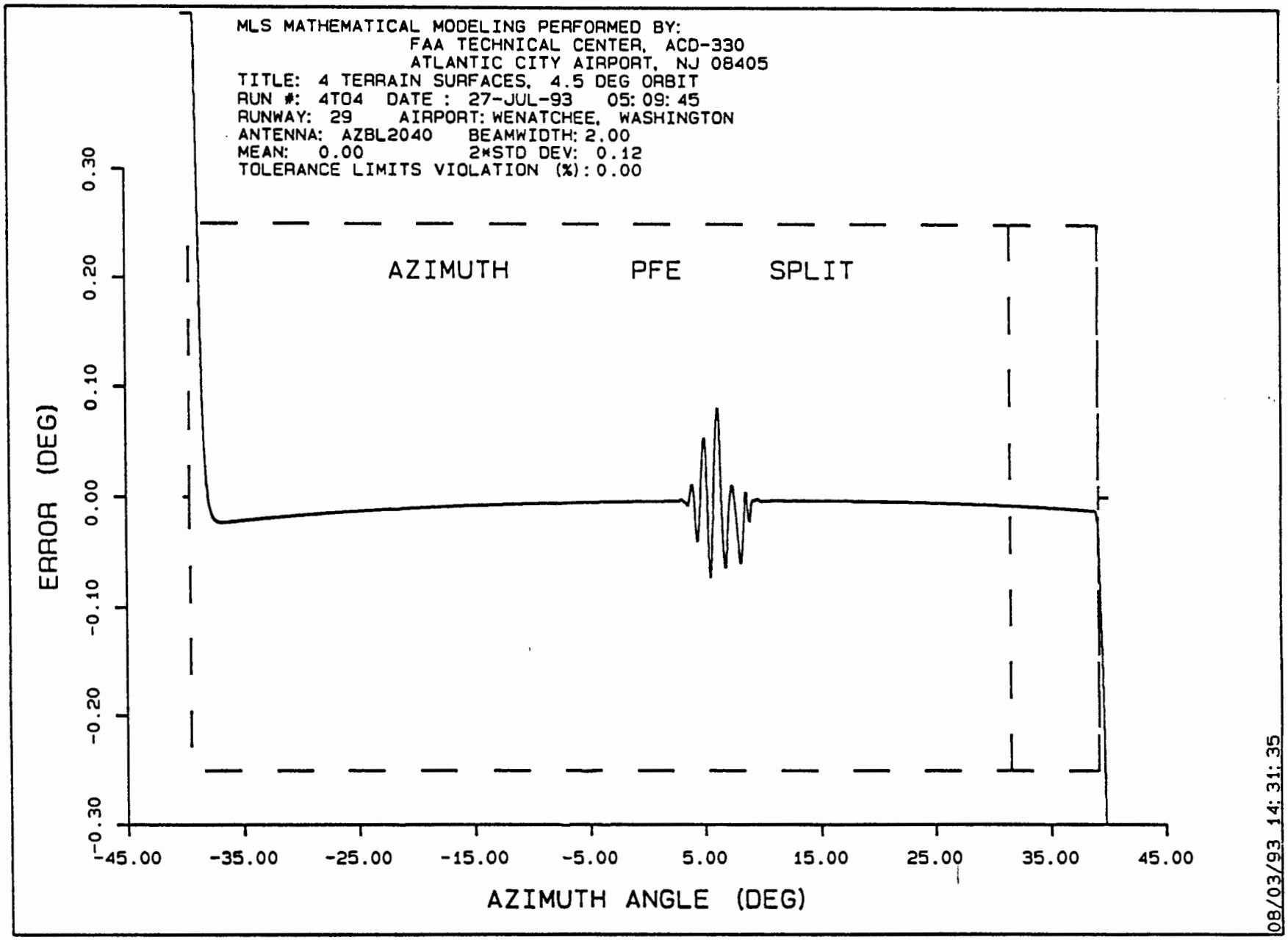


FIGURE 4. AZIMUTH SUBSYSTEM, 4.5 DEGREE ORBIT FLIGHTPATH, PFE ERRORS FROM TERRAIN

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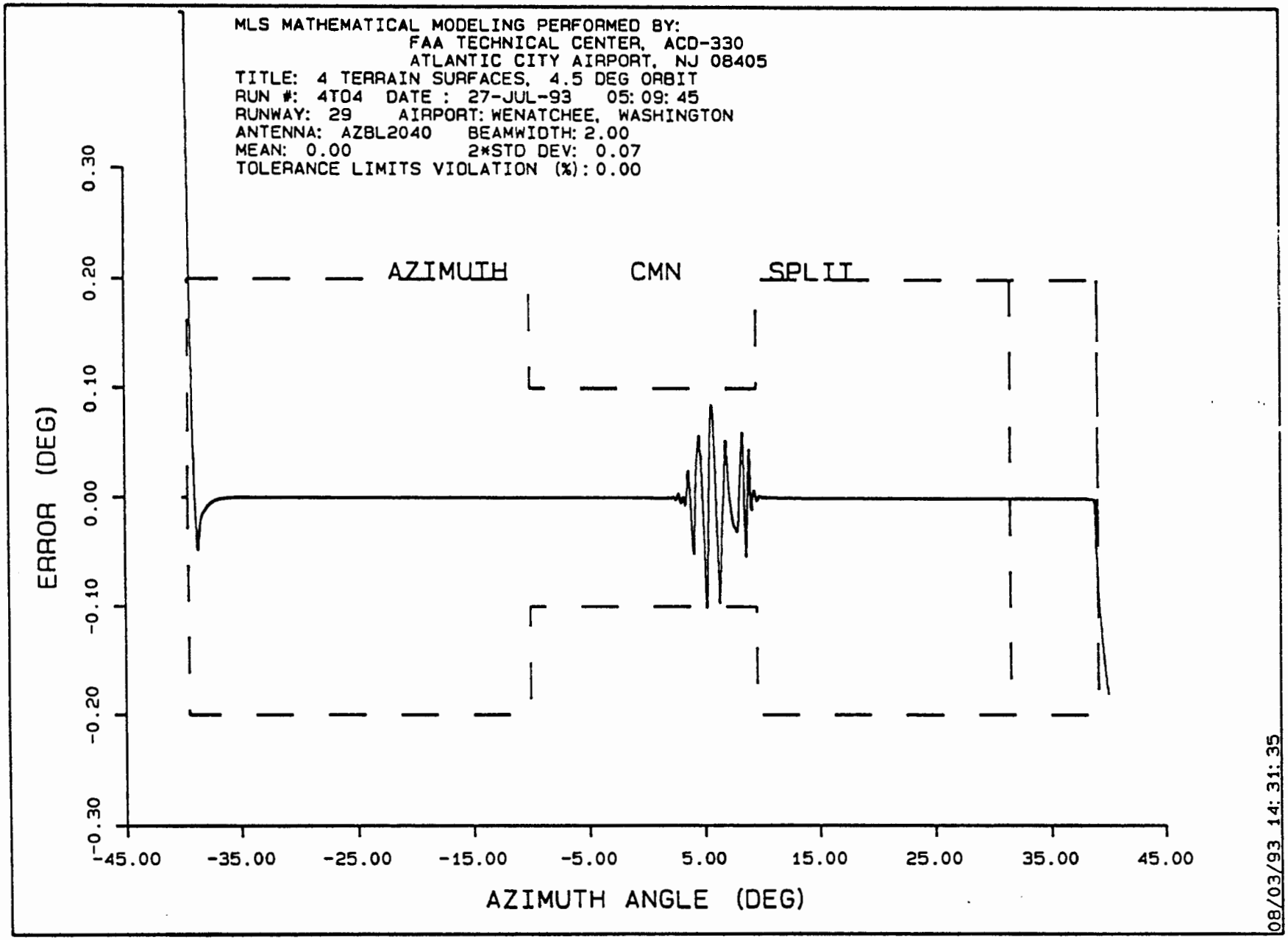


FIGURE 5. AZIMUTH SUBSYSTEM, 4.5 DEGREE ORBIT FLIGHTPATH, CMN ERRORS FROM TERRAIN

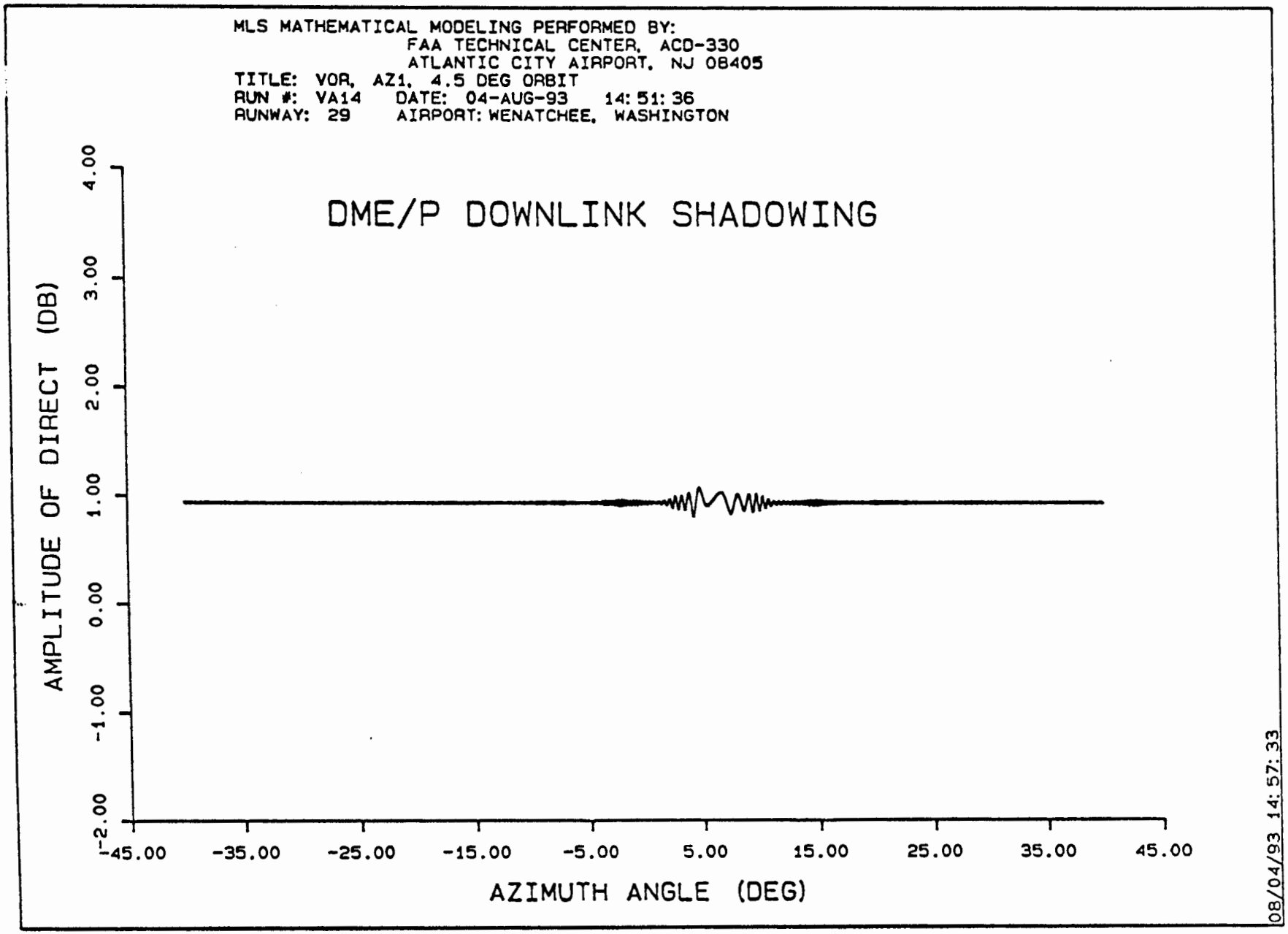


FIGURE 6. DME/P SUBSYSTEM, 4.5 DEGREE ORBIT FLIGHTPATH, EFFECTS OF SHADOWING

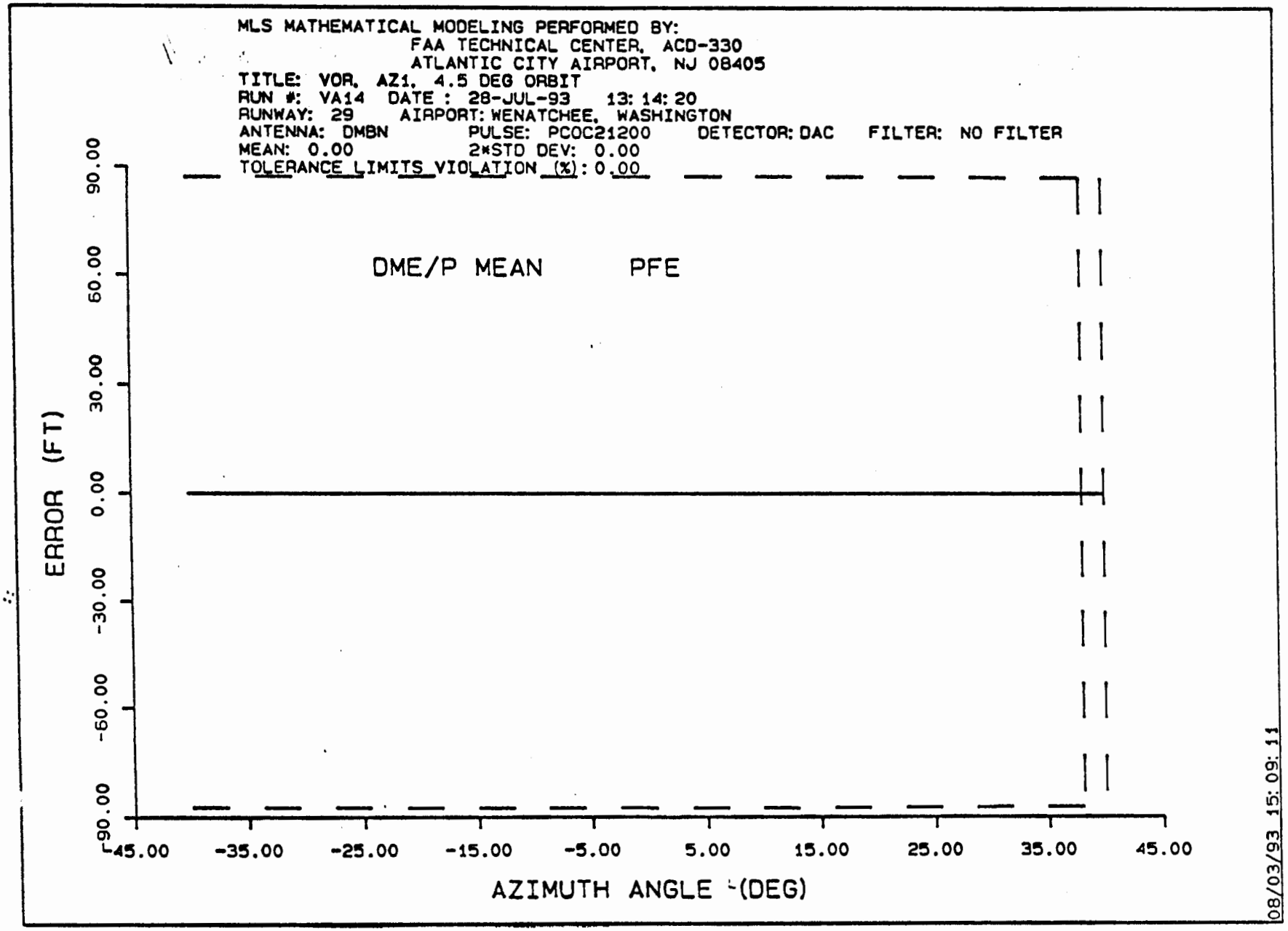


FIGURE 7. DME/P, 4.5 DEGREE ORBIT FLIGHTPATH, PFE ERRORS FROM VOR STRUCTURE

APPENDIX A - AN INTRODUCTION TO MLS

I. ANGULAR MEASUREMENTS

Azimuth

The AZ antenna generates a narrow vertical fan-shaped beam and sweeps it to and fro across the coverage area, as shown in figure A-1. At the beginning of the AZ time slot, the AZ preamble is transmitted. This sets up the processor in the receiver to decode AZ angle data. The "TO" scan starts. At the end of the scan, there is a pause before the "FRO" scan starts.

During a single scanning cycle, the aircraft receiver detects a "TO" pulse and a "FRO" pulse, and measures the time between the two pulses. As shown in figure A-1, it is the elapsed time between receipt of the TO and FRO pulses that determines the angular location of the aircraft, and thus its displacement from the selected course.

The antenna can actually scan out to +/- 62°, but courses within 2° of the edges of the service area are not used in order to avoid losing the signal and having to go through the acquisition cycle again. The normal scan of most installations is +/- 40°. Some locations may require a 60° scan to serve an additional runway or heliport, or to support curved approaches. On the other hand, some may scan as low as +/- 10° at locations where special siting or multipath problems exist.

Elevation

The same angular measurement principle used for determining azimuth is used for determining the elevation angle. The EL antenna generates a narrow horizontal fan-shaped beam and sweeps it up and down through the coverage area shown in figure A-2.

During the elevation scan cycle, the aircraft receiver detects a "TO" pulse from the upward scan and a "FRO" pulse from the downward scan. The elapsed time between the two pulses establishes the elevation angle of the aircraft, and thus its displacement from the glidepath angle selected by the pilot.

Because the aircraft flight control system is considerably more responsive to changes in elevation than to changes in azimuth, the elevation scan cycle is repeated 39 times per second, as compare to 13 times per second for the azimuth cycle.

II. FACILITY SITING CONSIDERATIONS

General

The electronic equipment for the AZ and BAZ (back azimuth) stations

will be mounted inside the antenna enclosures. The EL and DME/P (precision distance measuring equipment) stations will be contained in weatherproof enclosures. Shelters for the EL and DME/P equipment will be provided at some severe weather locations.

Azimuth

The desired location for the AZ will be on the extended runway centerline between 1000 and 1500 feet beyond the stop end of the runway, as shown in figure A-3. If a location on the centerline is not feasible, the AZ station should be located within the alternate siting area shown in figure A-3. The penalty will be a slightly higher decision height. Care must be taken to keep the AZ station clear of jet blast areas.

Elevation

The desired location for the EL station is 400 feet offset from the runway centerline. The range of offset distances for Cat I facilities is from a minimum of 250 feet to a maximum of 600 feet. At Cat II and III locations, the EL station must not be closer than 325 feet. As shown in figure A-4, the longitudinal displacement distance from the threshold of the landing runway is chosen to provide an approach reference datum (ARD) of 50 feet.

Like the ILS glidepath, the MLS glidepath has a conical characteristic. Because the elevation station is offset from the runway centerline, the glidepath along the runway centerline is a hyperbolic curve which flares slightly above the straight line path along the boresight of the antenna. This effect increases if the offset distance is increased or if a higher glidepath angle is selected for the MLS approach.

To minimize shadowing and multipath effects, the EL Station should, if possible, be sited on the opposite side of the runway from the entry taxiway, as shown in figure A-4.

DME/P

The preferred location of the DME/P is at the AZ site. However, the antenna can be moved up to 450 feet if necessary to avoid penetration of obstacle clearance surfaces and approach light planes. MLS facility configurations can be varied to meet operational requirements. For example, an MLS has been installed at Jasper, Alberta, Canada, with the DME element collocated with the EL instead of the AZ element, in order to reduce the shadowing effects of a nearby mountain. MLS installations for heliports may have their AZ, EL, and DME elements collocated.

Back Azimuth

The siting criteria for the BAZ is the same as that shown for the AZ in figure A-3.

Out-of-Coverage Indication (OCI) Signals

It is desirable for the MLS cockpit display to show a flag warning whenever the aircraft is outside of the normal service volume of the MLS. However, in some out-of-coverage areas, spurious MLS signals caused by terrain reflections or other anomalies may still be present. To prevent false guidance from this cause, provision is made to transmit out-of-coverage indication (OCI) pulses from directional antennas. This will result in a flag warning on the deviation indicator in the cockpit. OCI signals can be provided up to 8 regions outside the azimuth service volume, and 2 regions outside the elevation service volume, as needed.

Figure A-5, which is a magnified view of the AZ time slot, shows the location of the azimuth OCI pulses within this time slot. When the aircraft receives an OCI pulse which is stronger than the scanning signal, a flag warning indication appears on the MLS cockpit display.

The OCI feature is intended to be implemented only as needed, on a case-by-case basis. Figure A-6 shows a typical scenario where azimuth OCI signals might be required.

Clearance Guidance Signals

Although most MLS facilities will have a proportional coverage of +/- 40° in azimuth, a minimum installation would cover only +/- 10°. For any azimuth equipment which provided less than +/- 40° of proportional coverage, clearance guidance (fly left/fly right) signals will be provided to produce a minimum guidance sector of +/- 40°, as shown in figure A-7.

Within a clearance guidance sector, the azimuth guidance is not proportional to the angular displacement of the aircraft from the approach course, but is a full-scale left or right indication of which way the approaching aircraft should turn in order to enter the proportional coverage region.

The clearance signals are comprised of four pulses, two of which are transmitted in pairs from directional antennas, into the fly-left and fly-right clearance sectors. Figure A-8 shows the location of the clearance pulses within the azimuth function time slot, adjacent to the TO and FRO scanning beams. Pulses No. 1 and No. 4 are transmitted into Sector A. The wide time spacing between these two pulses produces a fly-left indication on the cockpit display. Pulses 2 and 3 are transmitted into Sector C. Their narrow time spacing produces a fly-right indication on the display.

Critical Areas

Critical areas are regions around the MLS stations wherein objects, vehicles, or aircraft may cause serious signal degradation as a result of multipath or shadowing. Care must be taken that roads and taxiways do not pass through these critical areas unless it has

been determined that the vehicular traffic will not interfere with the transmitted signals, or that traffic can be restricted during instrument approach operations. Definitions for MLS critical areas are now being developed.

Shadowing

To minimize the effects of shadowing of the EL beam by aircraft awaiting takeoff clearance, it is usually desireable to site the EL station on the opposite side of the runway from the entry taxiway, as shown in figure A-4. Another factor which should be considered is the shadowing of the EL beam by nearby buildings or other obstacles, as shown in figure A-9. In some cases the effects of shadowing can be reduced by adjustment of the EL station location in order to place the shadows in a non-critical portion of the coverage area. The simplicity of siting an EL station facilitates this solution.

Multipath

The MLS has to operate in an airport environment that is subject to multipath (reflections) from hangers, aircraft, and other objects in the vicinity. Potentially, these effects can introduce errors in the guidance signals. Therefore, careful attention has been given, in the design of the system, to resist the effects of multipath.

Because of the short wavelengths used by the MLS, relatively small flat surfaces can produce specular (mirrorlike) reflections of high intensity. However, these reflections are highly variable in amplitude, phase, and duration. The MLS angle (azimuth and elevation) receiver is designed with acquisition and validation circuits to select and process the strongest and most persistent signal. This allows the receiver to operate in strong multipath environments.

Three basic principles are used in the system design to reduce the effects of multipath:

1. Try to keep multipath signals from arriving in the receiver at the same time as the scanning beams;

2. If multipath signals do arrive at the same time, reduce multipath signal magnitude to a negligible value;

3. Average rapidly varying signal components.

The received MLS scanning beam may be distorted if interfering signals are present at the same time the direct scanning beam is received. This situation, known as in-beam multipath, is shown in figure A-10. It can occur if the separation angle between the aircraft and the reflecting object is within 1.7 beamwidths.

However, if the separation angle is more than 1.7 beamwidths, the

reflected signal will arrive at a different time than the direct signal, and therefore will not distort the beam envelope or cause a guidance error. This situation, which is shown in figure A-11, is known as out-of-beam multipath. One way to reduce in-beam multipath effects is to use an antenna with a narrower beam width. Another way to reduce multipath effects is to design the antenna patterns with the lowest possible sidelobe levels.

The vertical pattern of the azimuth antenna is designed with a rapid reduction in amplitude (a sharp cutoff) on the lower side. The reduction is approximately 6 dB per degree below the horizontal. This ensures that close-in reflections from the ground in front of the antenna are much weaker than the direct signal received in the aircraft.

If there is a strong reflector such as a mountain range on one side of the final approach course, the scan of the azimuth antenna can be tailored as shown in figure A-12 so that it does not illuminate the mountain. The horizontal pattern of the elevation antenna is designed with a rapid reduction in amplitude beyond 40° from the centerline.

Although multipath can be strong for short periods, it is not persistently stronger than direct signals. Fortunately, the high data rates (13 scans per second for azimuth and 39 scans per second for elevation) make it possible to average the direct and multipath signals. Averaging by the receiver filter serves to reduce the rapidly varying azimuth and elevation errors as the aircraft flies through the multipath interference region.

The distance-measuring portion of the MLS is designed to resist multipath effects which would otherwise introduce range errors, particularly when the aircraft gets down to a low altitude in the final part of the approach where range accuracy is most important. For this reason, the DME/P of the MLS uses a very accurate pulse processing method, more resistant to multipath effects, when operating within 7 nautical miles of the ground station. This mode of operation is called the Final Approach (FA) Mode.

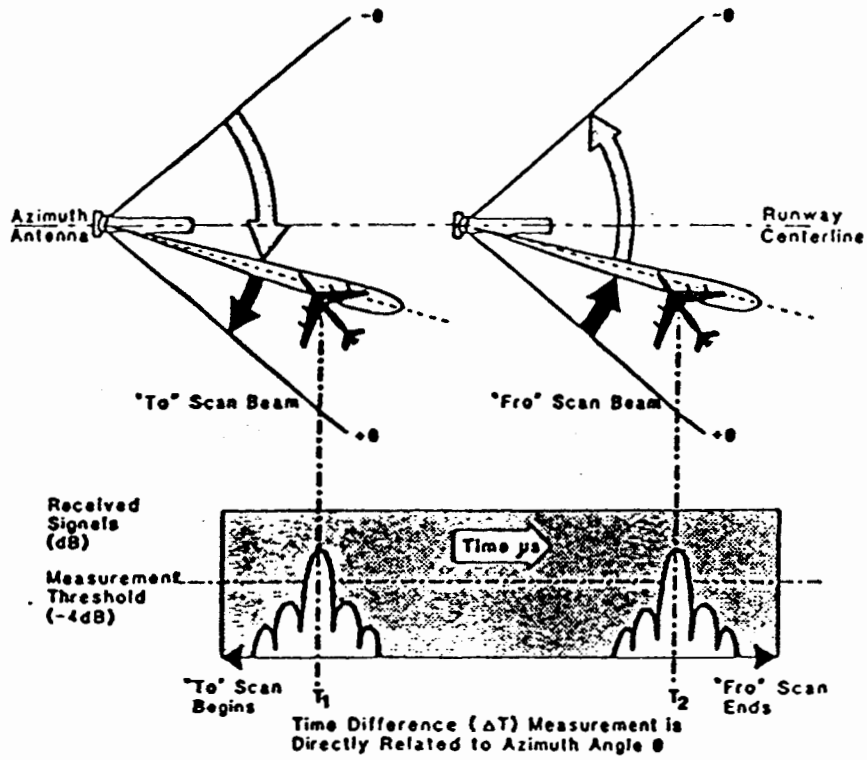


Figure A-1 Angular Measurement Principle

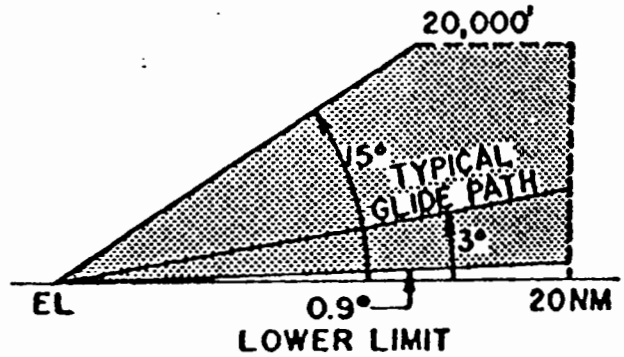


Figure A-2 Elevation Coverage

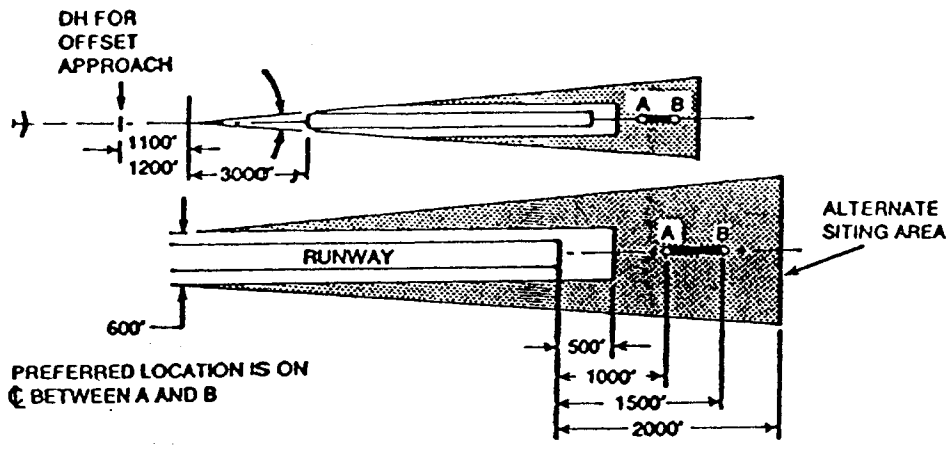


Figure A-3 Preferred and Alternate Locations for Approach Azimuth Station

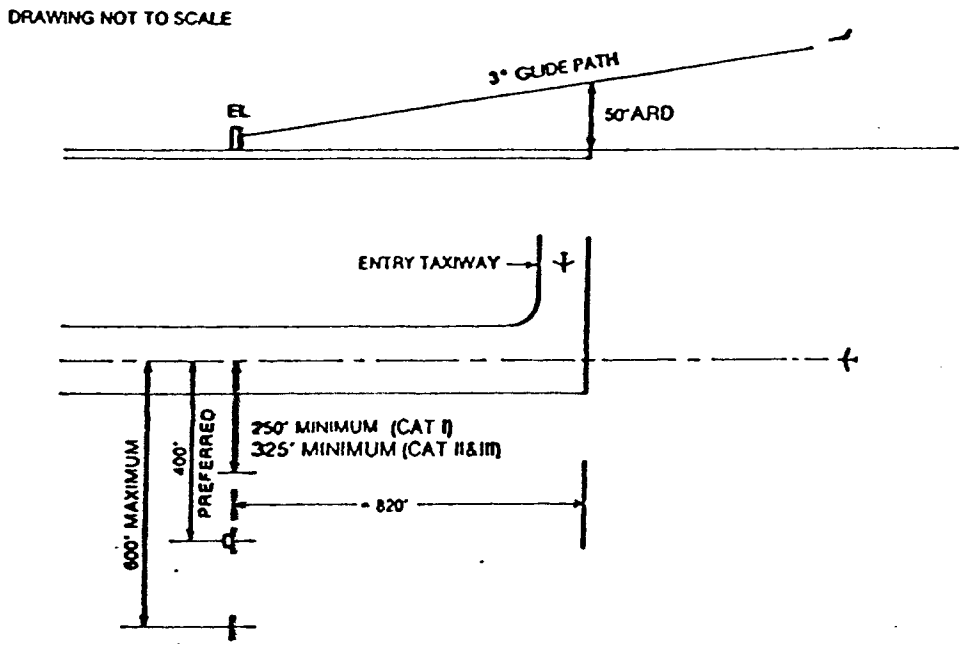


Figure A-4 Preferred and Alternate Locations for Elevation Station

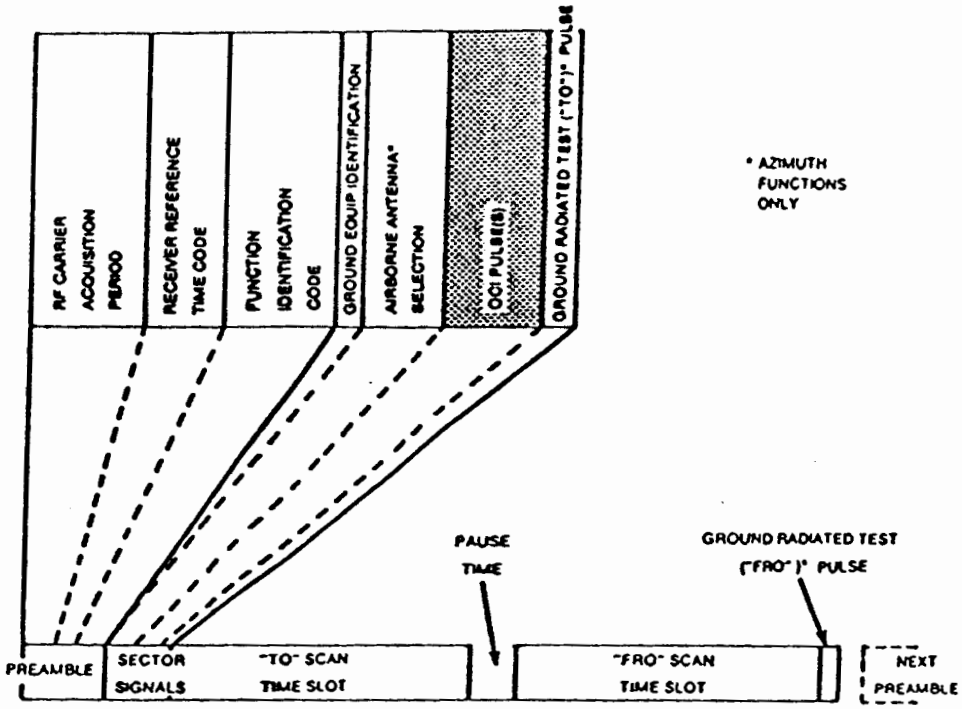


Figure A-5 Location of OCI Pulses in Azimuth Time Slot

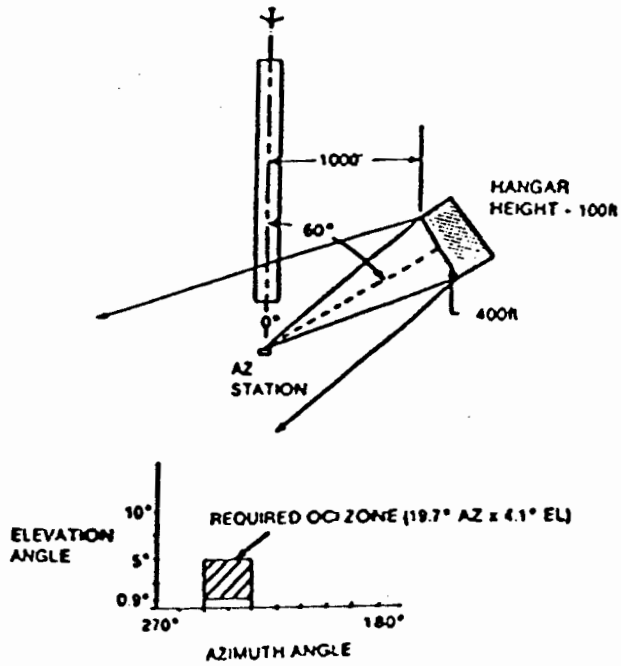
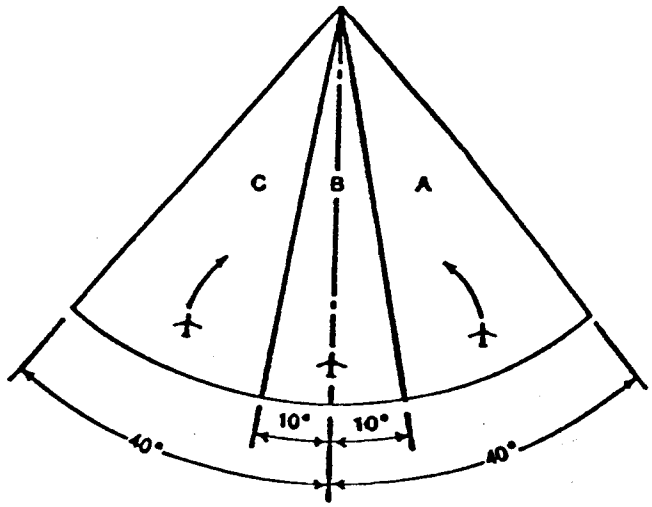


Figure A-6 Need for OCI Signals

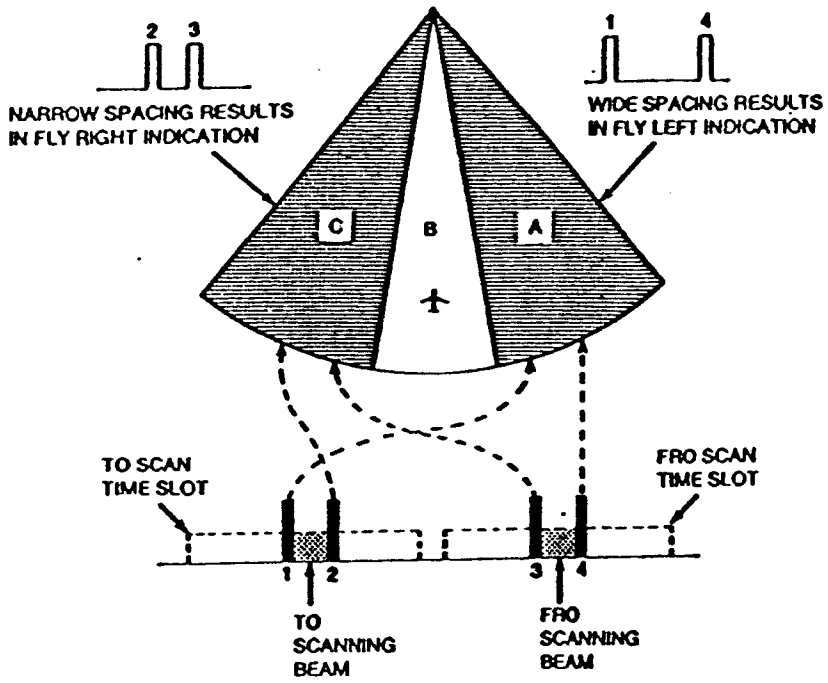


A - CLEARANCE GUIDANCE SECTOR
(FLY LEFT)

B - PROPORTIONAL GUIDANCE SECTOR

C - CLEARANCE GUIDANCE SECTOR
(FLY RIGHT)

Figure A-7 Clearance Guidance Sectors



A - CLEARANCE GUIDANCE SECTOR
(FLY LEFT)

B - PROPORTIONAL GUIDANCE SECTOR

C - CLEARANCE GUIDANCE SECTOR
(FLY RIGHT)

Figure A-8 Clearance Guidance Signals

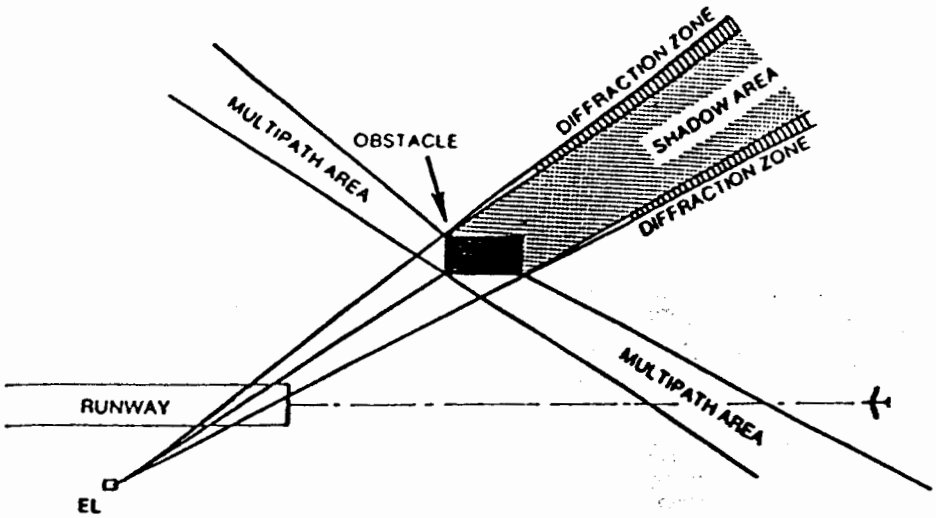


Figure A-9 Shadowing and Multipath Areas

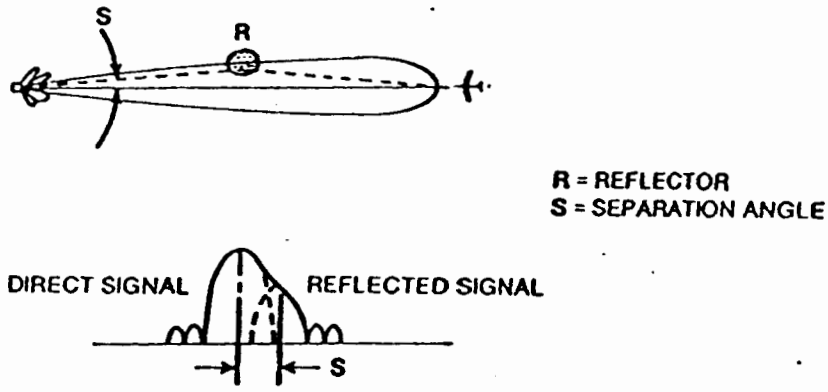


Figure A-10 In-Beam Multipath

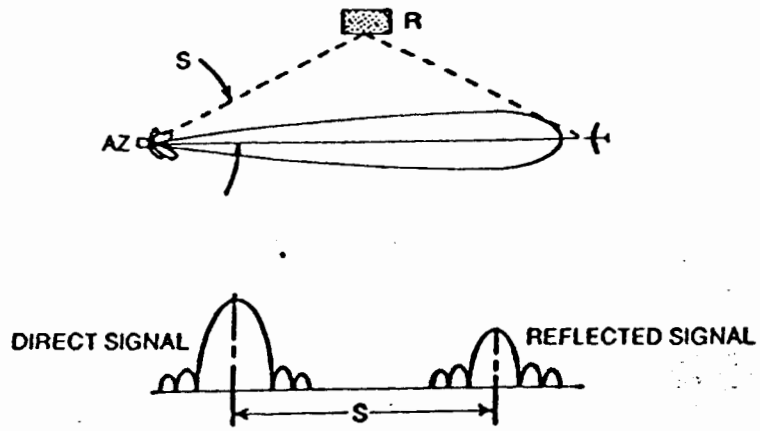


Figure A-11 Out-of-Beam Multipath

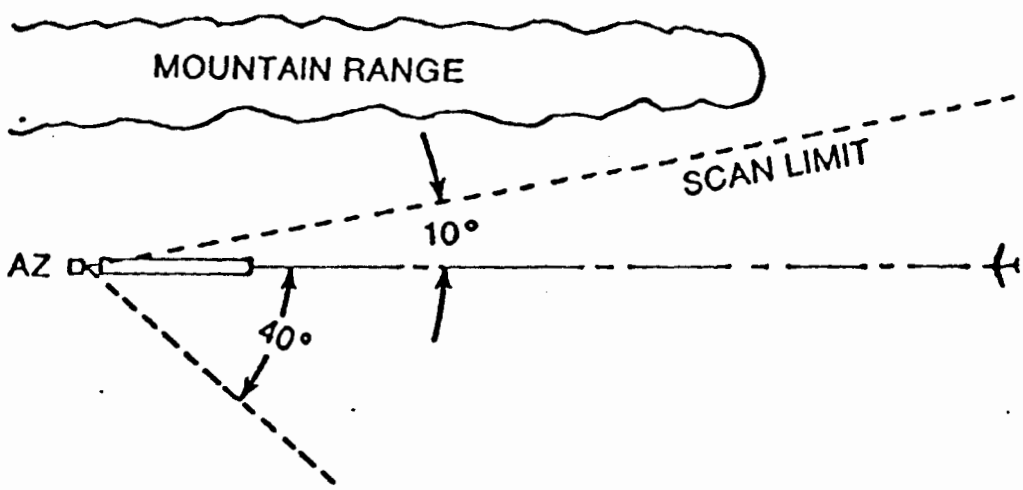


Figure A-12 Scan Limited to Avoid Multipath

APPENDIX B - AN INTRODUCTION TO THE MLS MATH MODEL

PURPOSE

This report introduces the Microwave Landing System (MLS) Mathematical Model for interested persons not familiar with the model's purpose and features. It discusses the format of the model, the input and output parameters, and additions and improvements planned for future versions of the model.

INTRODUCTION

The MLS Mathematical Model is a computer simulation of the effects of an airport environment on the MLS signal. It is used to provide guidance in the selection of MLS and siting configuration for a specific airport environment by predicting the errors due to multipath in that environment.

THE MODEL SOURCE CODE

The complete model consists of four computer programs. The flow diagram shows the relationships among these four programs. The source code, about 40,000 lines, is written in ANSI standard FORTRAN-77 and has been successfully implemented on a variety of mainframe and personal computers.

A complete site simulation is performed in two stages. The first stage is the execution of program BMLST. This is the propagation (or transmitter) model, a simulation of the signal in space as it interacts with objects in the airport environment. Output from BMLST is written to two files. One file provides plotting information to BPLOTT, a program that plots the multipath and shadowing effects on the signal from each of the ground stations--azimuth (AZ), elevation (EL), precision distance measuring equipment (DME/P). The second file is the input file to the second stage of simulation.

In this second stage, program BMLSR simulates the behavior of an MLS receiver. At each point along the flightpath, the system (or receiver) model evaluates the signal it is receiving in order to distinguish the direct beam from any caused by multipath. Once the receiver is confident that it has acquired the direct signal, it compares this MLS angle with the true position of the aircraft (as defined by the flightpath coordinates, discussed in the section on input parameters). The angular difference between these positions is the error at that flightpath point for that system (AZ or EL). This error is written to an output file which is used by program BPLOTR to plot the error data. BPLOTR also filters the error data with both path following error (PFE) and control motion noise (CMN) algorithms and plots the filtered data with appropriate error tolerances (discussed in the section on output). These plots allow the user to evaluate the receiver errors and determine whether or not they fall within acceptable tolerance limits.

INPUT PARAMETERS

The model accepts input from an ASCII text input file consisting of thirteen sections of input data. The input data fall roughly into three categories: (1) a description of the airport environment, (2) the configuration of the MLS and DME/P systems, and (3) a specification of the flightpath of the receiver.

The airport environment is described by coordinate information relative to the runway. The coordinate system assumes an origin at the centerline of the stop end of the runway and is a right-handed coordinate system with the positive X axis along centerline pointing toward the threshold and the positive Z axis pointing up. Each obstacle must be identified in separate sections of the input file as to its potential effect on the MLS signal---reflective (scattering) or diffractive (shadowing). Obstacles that can be defined include buildings, aircraft (Shadowing aircraft can be moving.), terrain features, and a runway hump. Obstacles are represented by simple geometric shapes such as rectangles, triangles, and cylinders. User input defines the location of the object and whatever additional information is required (vertical orientation, surface characteristics, velocity, etc.).

For the configuration of the ground systems, the user specifies the location of each transmitter and the type. The user can also indicate a frequency and scan angle limits for each transmitter. The appropriate data for representing the specified transmitter type are loaded into memory by program BMLSR and are used in the evaluation of the signal at the receiver. The receiving antenna is assumed omnidirectional. The propagation portion of the model (BMLST) assumes an omnidirectional transmitter pattern in its operation and does not consider the characteristics of the receiver other than its location in space.

Currently, the path of the receiver is represented as a set of two to thirty-six coordinate triplets (X, Y, Z) which define the locations of the flightpath waypoints. Multipath calculations are made for points between the waypoints depending on the velocity (in feet/second) and distance increment (in feet) defined by the user. These latter values are constrained by the model's assumption of a data rate of 5 hertz for the PFE and CMN filter algorithms.

OUTPUT

Output from the math model is provided in graphic form by the two plotting programs (BPLOTT for the propagation model, BPLOTR for the system model). Output from BPLOTT includes tables of data and plots (flightpath plots, airport map) that allow the user to verify the input data. In addition, a multipath plot shows the multipath/direct ratio in decibels for each point along the flightpath for each of the six highest multipath sources in the environment. This is accompanied by a plot of the separation angle in degrees (for AZ and EL) or the time delay in nanoseconds (for DME/P). If the user has specified shadowing obstacles, a shadowing plot shows the effect of the simulated shadowing obstacles on the

magnitude of the direct signal. For both scattering and shadowing, each transmitter is plotted separately, as requested by the user.

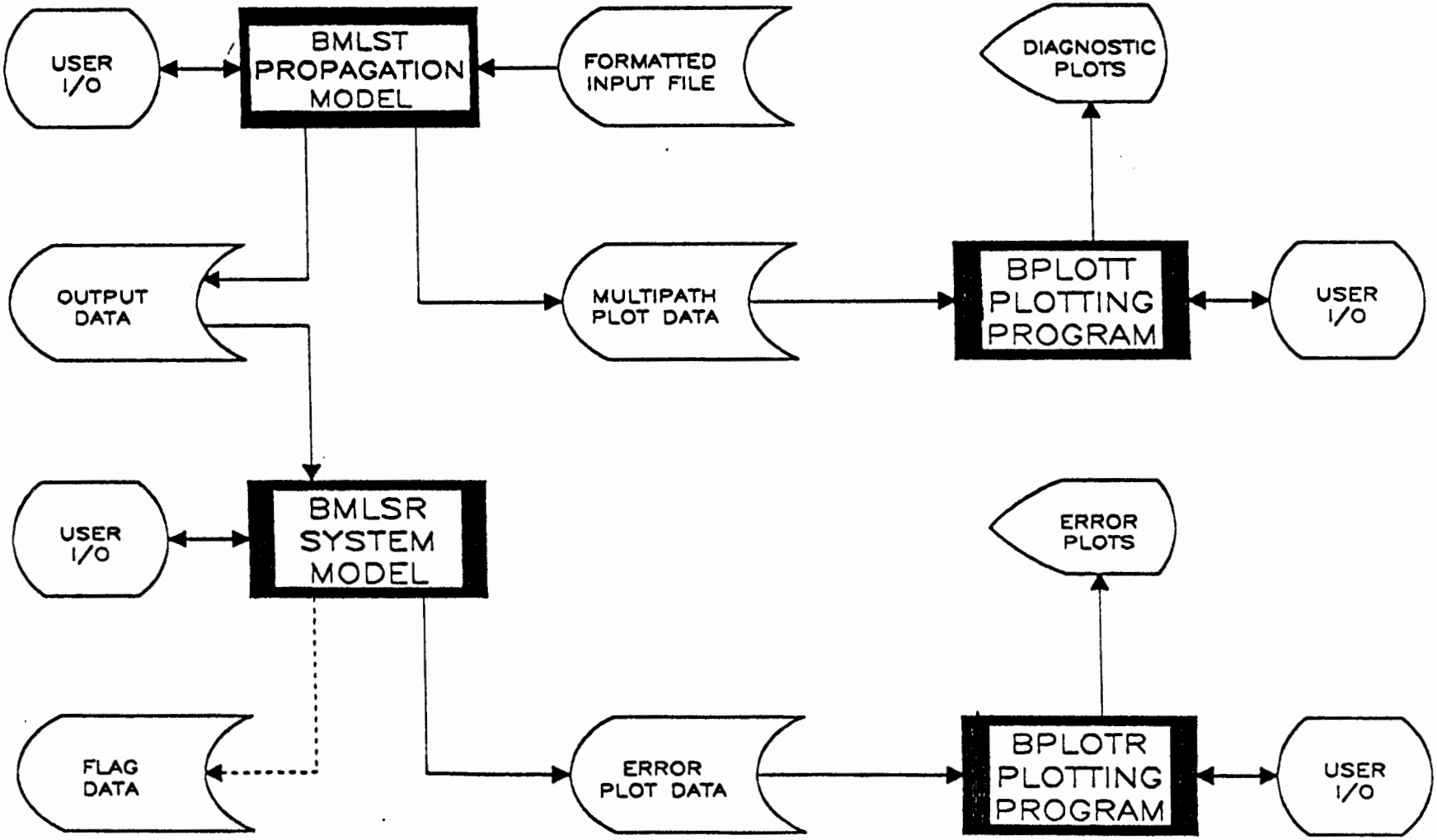
The output from BPLOTR is a plot of the angle error in degrees for each system. The DME/P interrogator is not implemented by the system model at this time. Error plots are provided in four formats. The static error shows the raw error at each receiver point. The dynamic error also shows the raw error with account taken of the movement of the receiver. PFE and CMN plots show the error as filtered by these algorithms respectively. In addition, tolerance and coverage limits are calculated based on Federal Aviation Administration (FAA) specifications and are displayed on the filtered error plots. The user can then see at a glance whether or not the MLS signal goes out of tolerance at any point along the flightpath. If it does not, it is reasonable to conclude that the airport environment, as defined, will not adversely effect the MLS signal.

THE FUTURE OF THE MLS MATH MODEL

The model as described above is the current version distributed by the FAA to users throughout the world. However, the model is not considered to be in final form. Plans are being made to release version 3.0 of the model which will include the following features:

1. implementation in the system model of a DME/P interrogator
2. implementation of a measured flightpath. This option will permit the model to read flightpath coordinates from a separate input file which might be created from actual flight data.
3. inclusion of additional transmitter antenna patterns
4. assignment of specific dielectric constants for each possible surface material for scattering building plates

Additions and improvements to the model will continue after the release of version 3.0. These additions and improvements will include implementation of an orbit flightpath option, improved algorithms for simulating runway hump shadowing and ground plate scattering, the addition of the ability to simulate shadowing by trees, and other features as required.



MLS MATHEMATICAL MODEL FLOW DIAGRAM