ACCURATE ILS AND MLS PERFORMANCE EVALUATION IN PRESENCE OF SITE ERRORS

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ABSTRACT

A powerful and versatile analytical approach is outlined for performing the site evaluation of Instrument Landing Systems (ILS) and Microwave Landing Systems (MLS) without resorting to the current experimental methods. The problem is treated as one of scattering, using a ray-theoretic approach. A multiwedge model of the terrain ahead of the antenna assembly is generated from standard survey data and an exact ray tracing procedure is evolved to trace all the rays between the antenna elements and approaching aircraft. The power of the current uniform diffraction theory (UTD) to evaluate scattered fields from wedges is extended to include the impedance and roughness of the wedge and the theory is applied to the multiwedge terrain model for evaluating the field. The results are reduced to a form compatible with ICAO-specified tests and compared with experimental data from real airports.

INTRODUCTION

As demands for accuracy and fail-safety become more stringent in modern avionic systems, the effects of site errors on performance of navigational aids are being recognized as being ever more critical. One important navaid whose performance may be seriously affected by site effects is the Instrument Landing System (ILS). In the past, serious aircraft accidents have been attributed to degradation in the quality of landing guidance offered by ILS. Although the Microwave Landing System (MLS), the ultramodern landing aid, is designed to be less susceptible to site effects, it is not entirely free from such effects. There exists the clear possibility that even relatively low levels of interference from unwanted scatterers may be significant for MLS performance in the dense traffic conditions that the MLS is designed to handle. With the MLS beginning to find operational use, and the ILS still the major landing aid globally, there is a strong need to evaluate site effects on these systems accurately.

Currently, such site evaluation is generally done through experimental methods. However, experimental methods are cumbersome, costly, time-consuming and do not provide estimates of system performance expected after proposed site developments. Analytical and/or computational methods have the potential of providing such estimates with little expense of time and money. This paper presents an outline of a powerful formulation which provides an accurate estimate of site effects on ILS and is readily applicable to the MLS.

The approach combines a multiwedge model for the terrain with a systematic and exhaustive ray tracing technique and a versatile and accurate formulation for estimating the electromagnetic fields due to the array antenna in the presence of the terrain. It can model generalized site effects, including effects of the undulation, the roughness and the impedance (depending on the soil type) of the terrain at the site.

Initial discussions leading to the visualization of terrain effects are based on the ILS which is the more familiar system and for which experimental data are available for comparison. Considerations for the more modern MLS are then presented.

ILS SITE EFFECTS

The ILS has been in service for about four decades and is well described in literature, e.g. [1]. The system has three major subsystems providing guidance information along three orthogonal directions. The subsystems are the glideslope, localizer and marker beacons, and their typical locations are shown in the layout of Figure 1.

The vertical plane guidance (fly-up/down) is provided by the glideslope subsystem operating in the 328-336 MHz band. Aircraft are to descend along designated glideslopes (typically inclined at about 3 degrees with respect to horizontal) as shown in the computer-generated Figure 2(a). The glideslope is established electronically by the intersection of two shaped beams carrying 90 Hz and 150 Hz modulations, respectively, as shown in Figure 2(b). Information regarding any departure from the designated glideslope in the vertical

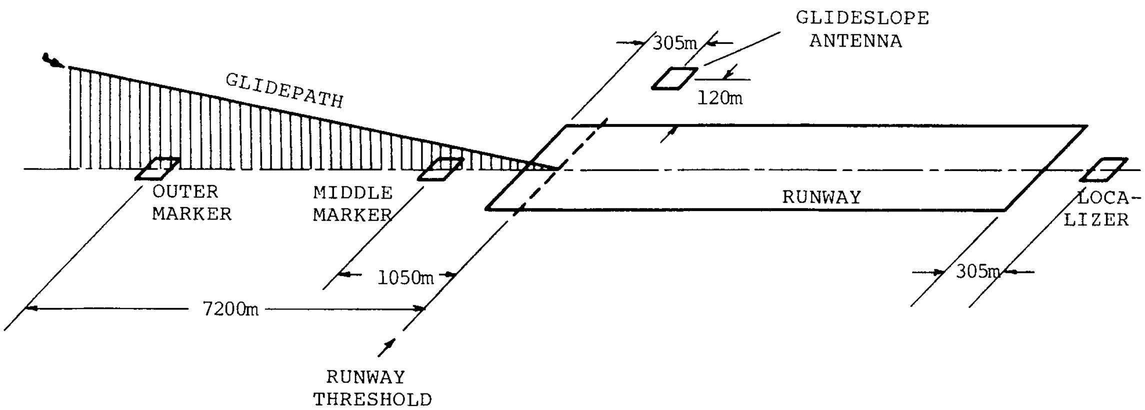


Figure 1 Typical location of ILS subsystem antennas in relation to a runway

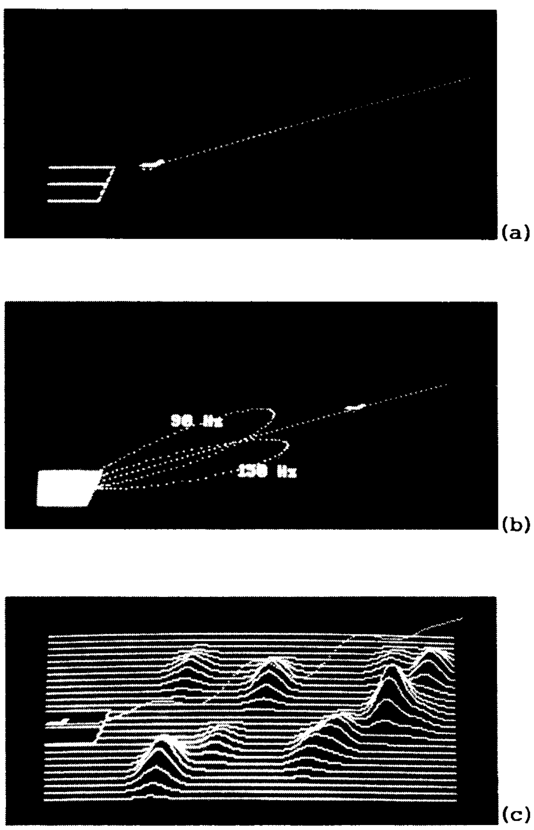


Figure 2 Computer-generated schematics of glideslope. (a) Ideal descent path, (b) Generation of glideslope by shaped beams and (c) Glideslope aberrations due to terrain undulations.

plane is obtained at the aircraft by sensing the differential depth of modulation (DDM) between the two modulations.

For horizontal guidance (fly-left/right), the subsystem responsible is the localizer, in which a separate pair of relatively wide beams (6-10 degrees wide), with a carrier frequency in the 108-112 MHz band, are made to intersect. Ideally, the 90 Hz and 150 Hz signals are expected to balance out along a vertical plane passing through the runway center line, and any departure from the vertical plane is sensed by measuring the DDM. The third dimension of landing guidance is along the approach direction, in which discrete distance information is obtained when the aircraft passes through the fixed beams of 75-MHz marker beacons, typically two in number.

Under ideal conditions, the null-DDM surfaces of the glideslope and localizer are planes, and their straight-line of intersection is the glidepath that the aircraft is supposed to follow. However, This assumes that a long stretch of ground (about 5 km) ahead of the antennas is perfectly level, smooth and conducting. Any undulations and features such as buildings and hangars reflects electromagnetic energy from the antennas, which interferes with the beams. The net result is to warp the null-DDM planes, and their intersection no more remains a straight line. An aircraft flying down the glidepath by holding the DDM values zero then actually flies a crooked descent path in space. The result is a bumpy descent, as schematically depicted in Figure 2(c). If the interference is strong, the kinks and bends in the glidepath are deep, and the aircraft may either lose control or hit an obstacle.

Of the two lateral guidance subsystems, the

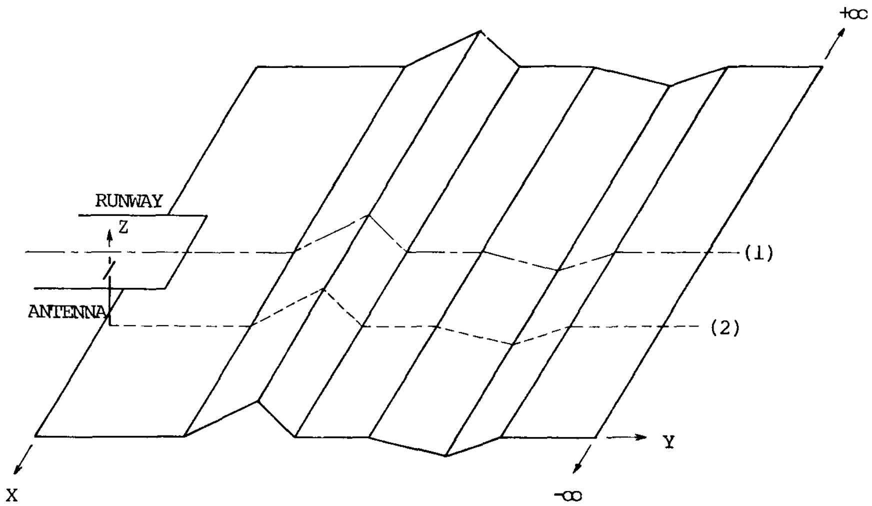


Figure 3 Multiwedge model of airport terrain: (1) Runway center line (2) Terrain profile line.

glideslope and the localizer, the former is more susceptible to interference due to terrain scattering. This is because of the predominantly horizontal orientation of ground features in terrain considered fit for airport location. Also, vertical plane guidance errors are more critical in terms of obstacle clearance and maneuvering.

The evaluation of the suitability of a site for ILS installation is currently done experimentally. Temporary equipment with parameters similar to the proposed facility is first installed and the quality of the glideslope is tested by actually measuring DDM variations in the space controlled by the ILS. The measurement is carried out by flying instrumented aircraft along flight paths, and according to procedures, stipulated by the International Civil Aviation Organization (ICAO).

The experimental procedure usually takes several months. It often takes even longer, especially in less developed countries which have limited experimental hardware and expertise in this area. It costs hundreds of thousands of dollars to perform validation of one site. Finally, the experimental procedure cannot predict the improvements in glideslope after certain postulated ground developments are carried out. Such developments must actually be carried out, at expense of time and money, and then the experimental procedure repeated to determine the new glideslope quality.

If the glideslope could be determined analytically or computationally with enough accuracy, it would be possible to get over the difficulties associated with the experiments. The following paragraphs outline developments in such a direction.

MODELING THE SITE

Interference due to the terrain is viewed essentially as a problem in electromagnetic scattering. Since the ground has a large extent, and individual features that are much larger than the operating wavelength are considered, a ray-theoretic approach is taken for analyzing the scattering problem.

A basic canonical shape for which the scattering problem is well understood, and the theory well developed, is the straight-edged wedge. It is therefore advantageous, from the point of view of analysis, to model the ground undulations as a succession of wedges. A pictorial view of such a terrain model is shown in Figure 3. To construct the model, the following steps are followed:

1. From the contour plan of the airport site, the profile of the terrain is obtained along a vertical plane parallel to the runway center line and passing through the location of the antenna.

2. The profile line is approximated by straight line segments. The number of segments depends on the severity of undulations. A compromise between accuracy and computational effort is involved.

3. The straight-line segmented profile line is moved laterally parallel to itself to generate the multiwedge model.

The model of Figure 3 is a simple 2-D model, but is an adequate description of the terrain for the current purpose, since only a narrow strip of ground along the profile line has significant influence on the glideslope.

TRACING THE RAYS

In addition to the direct rays of radiation that reach the aircraft from the antenna elements, other rays may reach the aircraft after single or multiple reflection at the plane surfaces of the multiwedge model, single or multiple diffraction at the tips of the wedges, or a combination of reflection and diffraction. The direct, singly reflected and singly diffracted rays are called the first order rays. The other rays are called the higher order rays, the order of each depending on the total number of reflections and/or diffractions suffered by it before reaching the aircraft.

To be able to calculate the DDM at the aircraft location (at a point during the flight of the aircraft), it is theoretically necessary to determine all the rays that exist between the antenna elements and the aircraft. However, for a multiplate model there would be infinite number of rays, and a truncation must be made after a certain order of the rays to keep the ray tracing at a tractable level. Our studies have shown that in most practical cases, rays beyond the third order do not contribute significantly to the scattered energy reaching the aircraft.

To trace all the rays of a given order that may exist between the antenna elements and the aircraft is an involved task, and its complexity increases with the order of the rays. A straightforward approach, and one that has been commonly used, is to perform a numerical search for the points of reflection. However, the search is a multivariate one for the higher order rays, requiring heavy computation. We have developed an exact geometric method of ray tracing which can exhaustively identify and trace all possible rays upto any given order between the antenna elements and the aircraft. The geometries have been built up for each type of ray of each order, and some sample geometries are shown in Figure 4.

EVALUATING THE ELECTROMAGNETIC FIELDS

The next step is to evaluate the electromagnetic field contributed by each existing ray at the aircraft location. The best known theories to compute fields due to rays suffering diffraction are the uniform theory of diffraction (UTD) [2] and the uniform asymptotic theory (UAT) [3], but these assume the wedges to be perfectly conducting. Because of the grazing angles of incidence, such an assumption is valid for a large fraction of terrain. However, for special classes of terrain such as those with dry/sandy soil and those with high surface roughness, the assumption is not adequate.

We have extended the original UTD to include the effect of surface impedance and, through it, the surface roughness of wedges [4]. We have then used this extended theory to evaluate the field contributed by each ray. The extended UTD, however, requires much more computation. Hence, where the perfect conductivity assumption holds, we still use the original UTD for field evaluation. From the field contribution due to individual antenna subarrays, it is possible to calculate the DDM by using a simple formula derived in [5].

ICAO STANDARDS

Two major tests are specified by ICAO [6] to validate glideslopes based on flight tests: the 1000-ft level run and the low-level approach. The test aircraft is instrumented measure the DDM.

In the level run, the aircraft is flown at a constant height of 1000 ft (305 m) in a vertical plane through the nominal glideslope. The DDM is plotted with respect to the elevation angle. The elevation at which the DDM is zero is taken as the glideslope. The course sectors are contained within elevations corresponding to ± 75 microamperes.

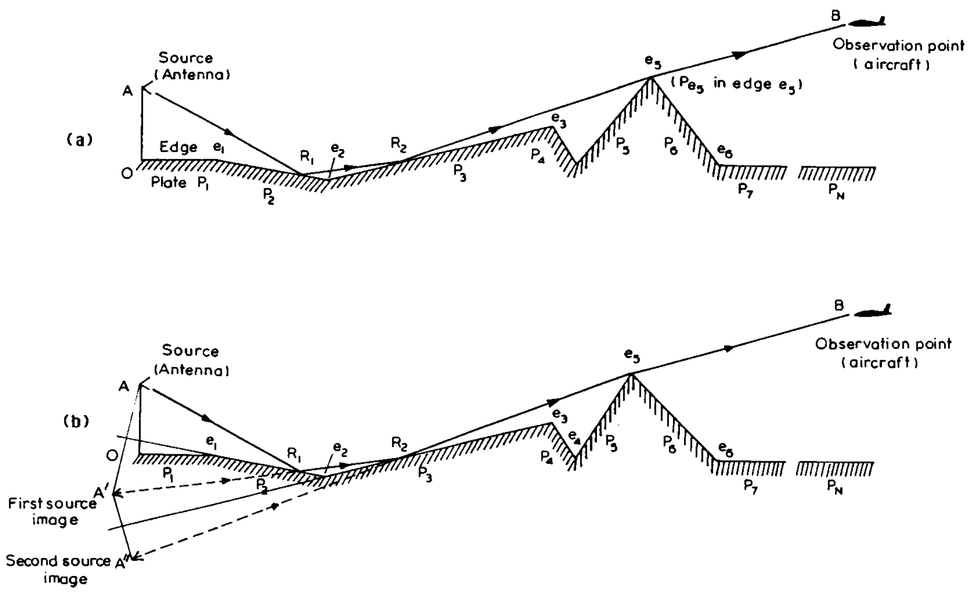
In the low level approach experiment, the flight is controlled to be along the nominal glideslope of the ILS. Any residual DDM, which should ideally be zero along this line, should not exceed ± 30 microamperes. The exact nature of variation of the DDM within these limits is not important.

RESULTS

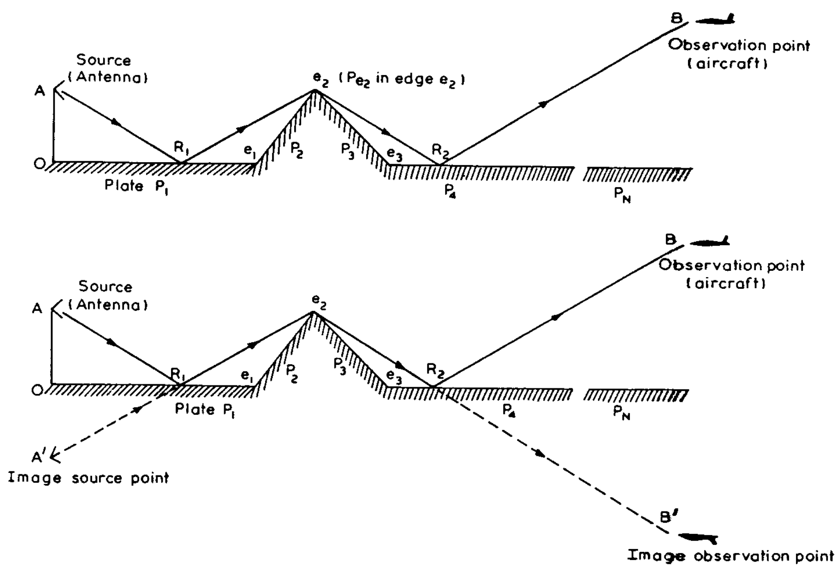
To validate the approach presented in the paper, two actual airports are considered, for which ILS calibration data are available. The experimental DDM is recorded along 80 points on both the level run and the low level approach paths. The analytical/computational method is also used to obtain the DDM at the same points, and these are compared with the experimental data.

The ILS parameters and the terrain geometries for the two airports are shown in Figures 5 and 6, respectively. The DDM values, computed as well as measured, for the two airports for the 1000-ft level run are given in Tables I and II. For Airport #1, the soil type permits the use of the original UTD and UAT. For Airport #2, the soil is dry and sandy, and the extended UTD, referred to earlier, is used for obtaining the computed values. The values obtained from the original UTD are also given alongside for comparison.

The general observation is that a combination of the powerful ray tracing technique with the original UTD/UAT is quite accurate for evaluating the glideslope parameters, but the use of the extended UTD enhances the accuracy even further.



(a)



(b)

Figure 4 Sample geometries for exact ray tracing on multiwedge terrain model. (a) Reflected-reflected-diffracted ray (b) Reflected-diffracted-reflected ray. In each case, the top figure represents the basic ray geometry and the bottom figure shows the geometry for obtaining the points of reflection and testing the existence of the ray.

ILS PARAMETERS FOR AIRPORT #1

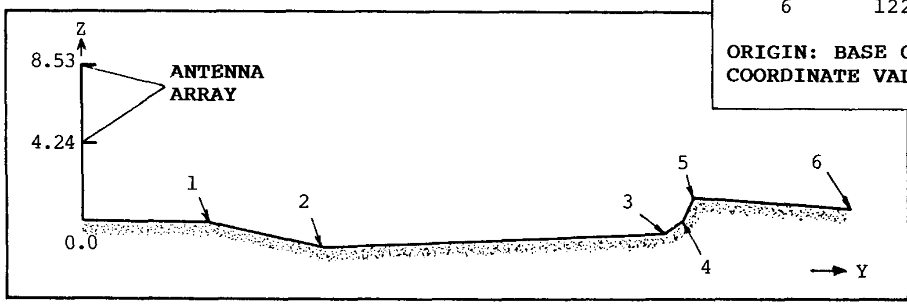
GLIDESLOPE EQUIPMENT FREQUENCY: 335 MHz
ANTENNA OFFSET FROM RUNWAY CENTER LINE: 135 m
NOMINAL GLIDESLOPE ANGLE: 3 Deg
SOIL TYPE: LOAMY, MOIST

(a)

COORDINATES OF CORNER POINTS:

POINT	Y	Z
1	212.0	0.0
2	419.0	-1.06
3	916.0	-0.51
4	965.0	-0.31
5	1015.0	1.2
6	1220.0	0.6

ORIGIN: BASE OF THE ANTENNA MAST.
COORDINATE VALUES ARE IN METERS.



(b)

Figure 5 Particulars of Airport #1. (a) ILS parameters (b) Six-segment model of the terrain.

Table I Measured and computed parameters in degrees for a 1000-ft level run at Airport #1.

Parameter	Measured	Calculated	
		UAT	UTD
Path Angle	3.00	2.980	2.980
Sector Width	0.72	0.690	0.676

MLS CONSIDERATIONS

At the higher carrier frequencies employed for the MLS, ray-theoretic approaches are more valid. The technique outlined for ILS is directly applicable to the evaluation of terrain effects on MLS. However, a few differences must be kept in mind.

The MLS utilizes a time referenced scanning beam (TRSB) technique [7] in which a narrow nodding beam scans the control volume in each direction (azimuth and elevation). An aircraft locates its position by the time difference between the TO and the FRO passes of each beam. The DDM and the nulling concept, as applicable to the fixed-beam design of the ILS, are not relevant to the MLS.

Because of the narrow beam width of the order of a degree employed in MLS, it is inherently more resistant to terrain effect. However, scattering due to sidelobes could be significant.

Certain aspects of MLS make terrain interference more important in the case of MLS than ILS. First, since MLS promises multiple approach corridors to aircraft, relatively small inaccuracies in the guidance information could cause conflict among aircraft sharing the approach corridor. For the ILS, with only one approach path, only large aberrations become hazardous. Second, the much smaller wavelength of the MLS means that relatively small obstacles such as automobiles and parked/taxiing aircraft within the influence zone behave as electrically large bodies, causing considerable interference. Finally, although the main lobes of the two nodding beams do not normally hit the ground, if the ground features are large or if the ground has significant slope, the main beams may illuminate the ground, causing strong reflections.

Because of these factors, the interference immunity of the MLS cannot automatically be taken for granted, but must be ensured for each site. Since the difficulties with experimental validation, referred to earlier for the ILS, are likely to be more pronounced for the MLS because of its higher complexity and cost, there is a strong case for analytical evaluation of terrain effects

ILS PARAMETERS FOR AIRPORT #2

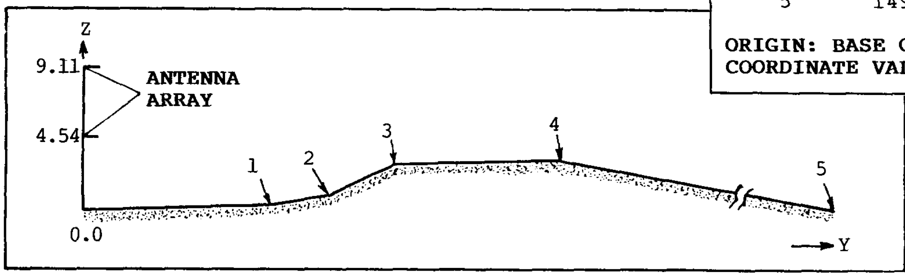
GLIDESLOPE EQUIPMENT FREQUENCY: 338.8 MHz
ANTENNA OFFSET FROM RUNWAY CENTER LINE: 122 m
NOMINAL GLIDESLOPE ANGLE: 3 Deg
SOIL TYPE: SANDY, DRY

(a)

COORDINATES OF CORNER POINTS:

POINT	Y	Z
1	381.0	1.37
2	487.7	2.59
3	609.6	6.315
4	944.9	7.92
5	1493.5	0.00

ORIGIN: BASE OF THE ANTENNA MAST.
COORDINATE VALUES ARE IN METERS.



(b)

Figure 6 Particulars of Airport #2. (a) ILS parameters (b) Five-segment model of the terrain.

Table II Measured and computed parameters in degrees for a 1000-ft level run at Airport #2.

Parameter	Measured	Calculated	
		UTD	Extended UTD
Path Angle	3.06	3.08	3.06
Sector Width	0.55	0.54	0.56

on MLS. Each of the three main elements of the current analysis -- terrain modeling, ray tracing and generalized evaluation of scattered energy -- are directly applicable to the MLS problem. However, we cannot at present validate the analysis for the MLS because of non-availability of detailed experimental data on actual MLS installations.

CONCLUDING REMARKS

A systematic analytical and computational approach to the problem of site effect evaluation for ILS and MLS has been presented. Specific results have been generated for ILS glideslopes located at actual airports for which experimental ILS calibration data are also available for comparison. The comparison shows very good agreement with experimental results. The computations are of a small enough magnitude to be performed on minicomputers and even on micro/personal computers.

The improved accuracy of the approach based on analysis and computation has brought such techniques closer to being a reliable alternative to the current expensive and time-consuming site evaluation through flight tests.

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