Computer-aided ILS site evaluation is deemed practical

Results can be achieved in hours, rather than months; costs can be reduced substantially...

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THEORETICAL MODELS for instrument landing system (ILS) site evaluation are becoming accurate enough to compete with measurements and may soon replace them altogether; the availability of accurate models could revolutionize landing system installation programmes and yield significant savings in cost and time.

The ILS has been a cornerstone of the navaid complement at major airports of the world for over three decades. At the time of its induction, it represented a major breakthrough in the enhancement of safety and air traffic capability of airports under most general conditions of weather and visibility, and it has retained its importance over the years. Even today, with the new generation microwave landing system (MLS) in the offing, fresh ILS installations are being planned and implemented around the world.

The standard ILS has three major subsystems — the glide path, localizer and marker beacons, which respectively provide vertical and horizontal guidance, and discrete information on distance to go for touchdown on landing. A computer generated schematic of the glide-path generation principle is shown in Figure 1.

Two directed beams at a carrier frequency in the 328-336 MHz band are generated by the antenna system, staggered from each other in elevation, and modulated with 90 and 150-Hz signals, respectively. On the plane defined by the intersection of the two beams, a receiver would encounter a null in the difference between the two signals. Elsewhere, a non-zero differential depth of modulation (DDM) provides guidance information to the pilot regarding fly-up/down manoeuvres.

The localizer also operates on the null-ddm principle, with 90 and 150-Hz signals, but with a carrier frequency in the 108-112 MHz band. The localizer provides fly-left/right information to the pilot. The intersection of the two null-DDM planes electronically defines the glide-path line, which typically has an elevation angle of 3 degrees.

Marker beacons located along the extension of the runway centre line provide fixed 75-MHz vertical fan beams, which generate pinpoint fixes as the aircraft flies through them.

The null-DDM surfaces are designed to be planar under the idealized sitting requirement that the ground in front of the antenna system be level and perfectly conducting. Neither of these conditions are completely valid in practice. Typical planarity requirements extend up to 1,500 metres from the antenna location.

Since, in a majority of cases, the bulk of this stretch lies outside the airport property,

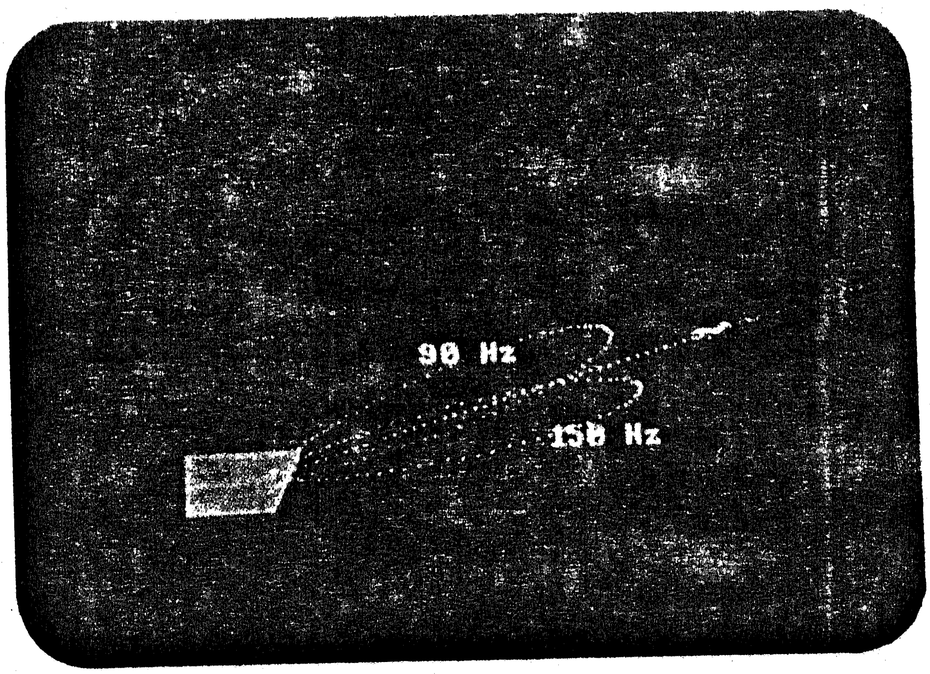


Figure 1. Computer-generated schematic of ILS glide-path principle.

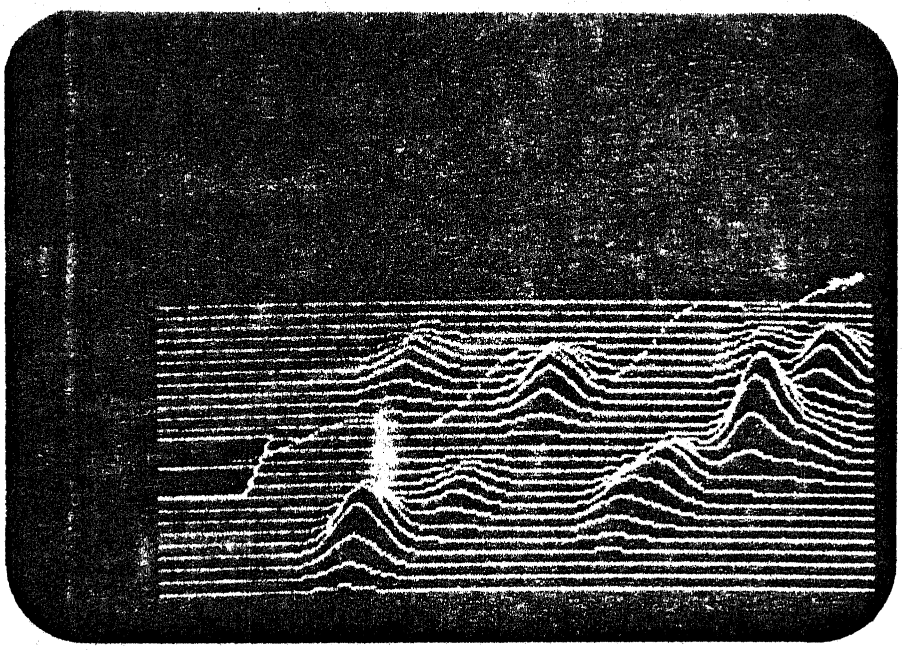


Figure 2. Computer-generated schematic of imperfect terrain and glide-path aberration, amplified for clarity.

there is no control over the nature of this terrain. In many airport locations around the world, the terrain is so undulating that it is not feasible to level it to specifications even if it is within the control of airport authorities.

ILS course bends

The primary effect of terrain undulations in the influence zone forward of the antenna is to warp the null-DDM surfaces. The intersection of such nonplanar surfaces would no more be a straight line, resulting in kinks and bends in the glide path. The schematic of such a situation, amplified for clarity, is shown in Figure 2.

Glide-path aberrations make the aircraft execute unnecessary manoeuvres to stay apparently on the glide path. This leads to uncomfortable landing and, in extreme cases, to accidents. In several air accidents around the world, ILS aberrations have been implicated as a significant cause. More importantly, perceptible departures of the equipment from its expected performance leads to loss of pilots' confidence in the system, which has an adverse effect on air traffic operation and safety.

Although the presence of terrain features affects the performance of both the glide path and the localizer, the effect on the former is considered more significant. This is because most reflectors in the vicinity of the antenna have a predominantly horizontal orientation. Also, errors in vertical plane are more critical than those in the azimuthal plane, especially in obstruction clearance and close to touch down. For these reasons, greater efforts has been devoted to the study and minimization of aberrations in the glide path.

One approach to the problem of minimizing glide-path aberrations has been through the design of sophisticated antenna systems. Special end-fire and flush-mounted antennas are examples of this class. However, due to a high level of complexity and the attendance problems of maintenance, especially in the less developed parts of the world, such systems have not found widespread usage.

The most commonly used antenna configurations are the null reference, sideband reference and quadrature array, in order of usage. The main differences among these configurations lie in the number of arrays, feed reference, sideband reference and quadrature array antennas have decreasing order of susceptibility to site effects. However, in each case, the site sensitivity remains significant.

Estimation of the extent of the aberration of glide paths due to terrain effects, therefore, is an essential part of ILS system planning. Prior knowledge of site effects helps planning at three levels: site selection, site development and choice of the antenna system.

Need for modelling recognized

Initial site evaluation for ILS installation is currently done using experimental means. This involves the installation of temporary glide-path equipment and extensive measurements using instrumented aircraft. This procedure involves large delays and expenditure; and quite often retards the spread of ILS installations in many developing countries of the world.

Another major limitation of the experimental approach is that it can only evaluate the performance of the current combination of antenna and the terrain. It does not provide information on the corrective action, such as the extent of site development and/or antenna reconfiguration, to be taken to improve glide-path quality.

The possibility of theoretical evaluation of terrain effects on ILS glide-path has therefore remained a very desirable goal. This would not only cut down the time and expense of evaluating a given site, but can readily provide insight into the improvement possible by altering sections of the terrain in a controlled manner.

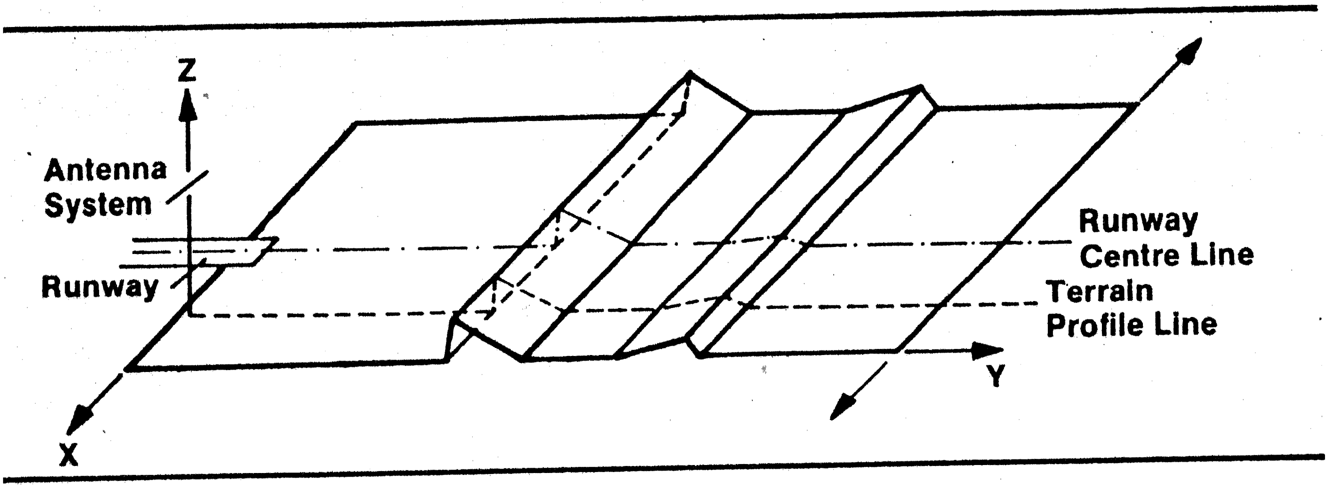
However, to be practically useful, theoretical models must be tractable and provide consistently accurate results over the most general type of terrain configurations encountered in practice. Until fairly recently, such accurate models had not been available; but, over the last few years, powerful formulations have been evolved to achieve this goal.

Modelling approaches vary

Early attempts at terrain modelling for glide paths were based on physical optics. In this method, fields along the glide path are evaluated from assumed ground currents through a process of integration. This requires heavy computational effort and cannot model obstructions and shadow effects. Variants of this model, incorporating half-plane diffraction were next proposed, but these also suffered from limitations regarding the type of terrain handled.

The more recent approaches to terrain modelling have relied on ray theory. The simplest of such models considers only the direct rays from the antenna to the aircraft, and the rays reflected from the terrain. The drawback of this model is that it predicts discontinuous fields in the presence of terrain drop-offs; this is against physical reality.

Perhaps the largest quantum jump in the search for accurate ray-theoretic field prediction around a wedge was contributed by J.B. Keller in 1962 through his geometric theory of diffraction (GTD), which considered diffracted rays in addition to reflected



gure 3. A seven-plate wedge model for a typical ILS terrain.

d direct rays. This theory predicted the ld nearly everywhere with high accuracy cept in two narrow sectors, where infinite lds (singularities) were predicted. The plication of this theory to idealized ter- in models was straight forward, but the ld singularity problem persisted and, in ct, appeared in multiple sectors.

ore recent theories have been available to ckle the singularities. The best known nong them are the uniform theories. At e present time, these theories hold the est promise for accurate estimate of the elds for ILS applications. The uniform eory of diffraction (UTD) and the uni- rm asymptotic theory (UAT) are the ost developed members of this class.

ll theories using the diffraction pheno- enon, including the GTD, UTD and JAT assume a wedge as the basic element. Diffraction occurs at the edge between the wo plane faces of the wedge. To be able to arness these theories for ILS terrain nodelling, the most convenient approach, herefore, is to visualize the terrain as a uccession of plane surfaces, forming vedges pairwise. Clearly, the number of uch planes required to model the terrain aithfully would depend on the extent of ndulation present in the terrain and would be based on a compromise between accuracy and tractability.

A good way of arriving at a multi-wedge approximation is to obtain the terrain profile along a vertical plane parallel to the runway centreline and passing through the antenna location, to approximate the profile by straight-line segments, and finally to translate the line-segmented profile laterally to obtain the wedge structure. Figure 3 shows a seven-plate wedge model of a terrain.

The primary step in applying the ray-theoretic approach to the multi-wedge model is the process of ray tracing. While, for a single wedge, only three kinds of rays — direct, reflected, diffracted — are recognized, in a multiple-wedge situation, each of these rays may further suffer reflection and diffraction at other planes/edges before reaching the point of observation. Such rays may be branded as reflected-reflected, reflected-diffracted-reflected, *etc.*, depending on the route taken by the ray, and are called higher order rays.

Ray tracing typically consists of determining all the possible ray paths that may exist between the antenna and the aircraft location. Owing to the large number of ray combinations possible, not all of which may exist in a given situation, ray tracing is a complex logical exercise.

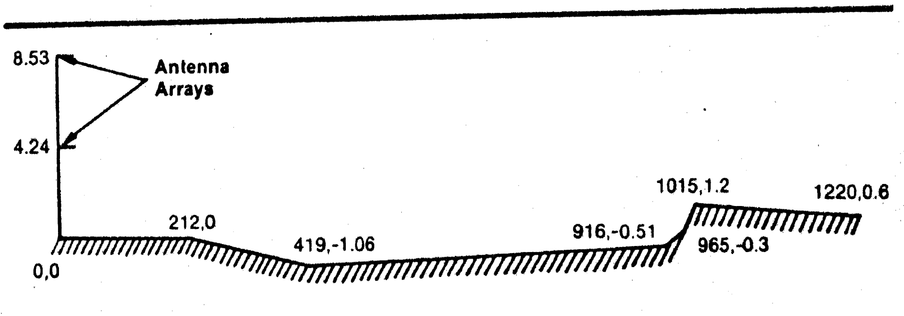


Figure 4. Six-segment idealization of the terrain profile line at an airport. Coordinates are in metres (not to scale).

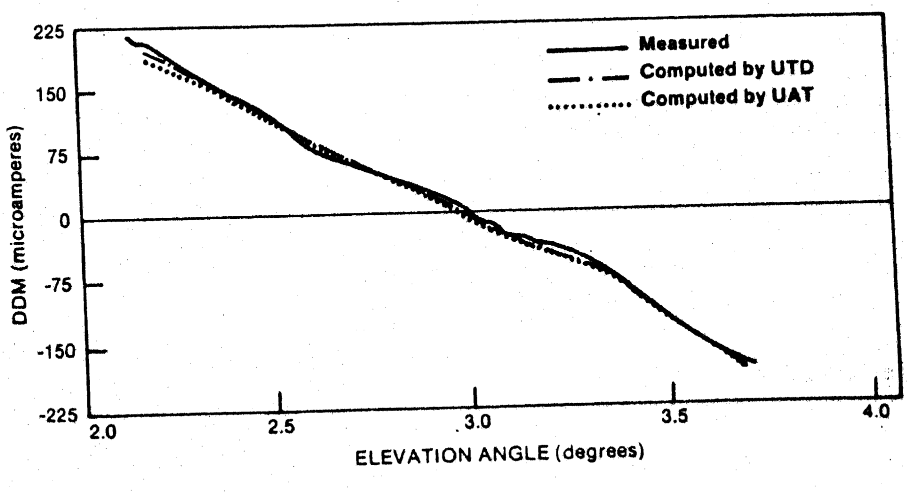


Figure 5. DDM at various elevation angles for a 1,000-foot level run at the airport profiled in Figure 4.

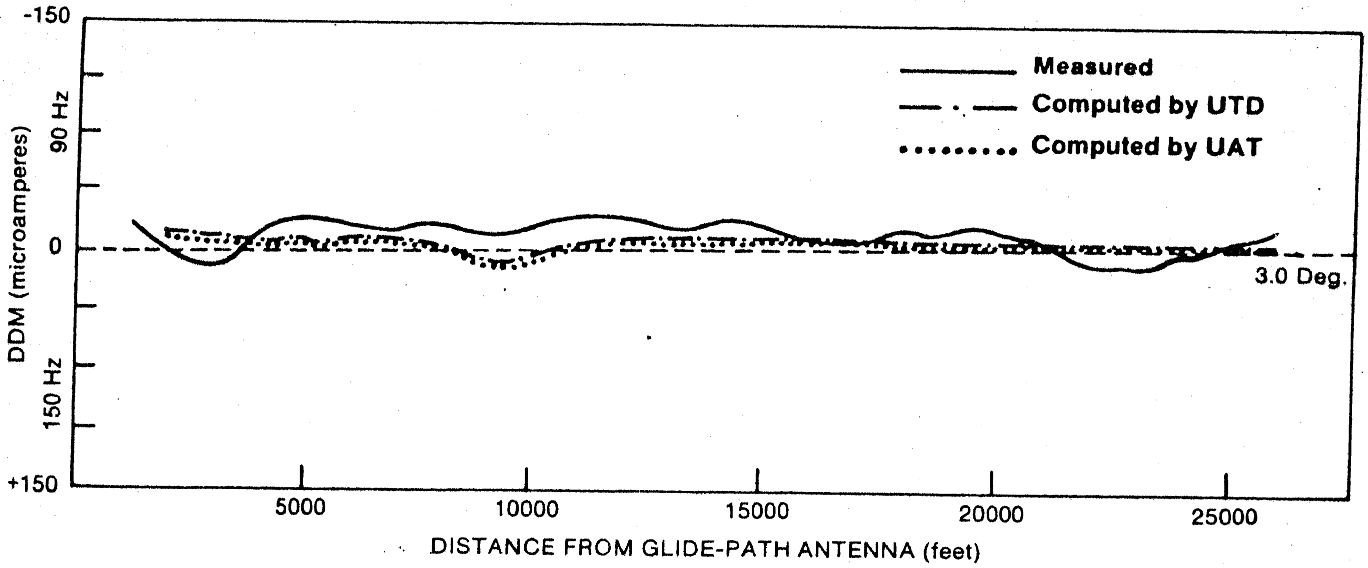


Figure 6. DDM along a nominal three-degree glide-path run at the airport profiled in Figure 4.

The authors have developed a computer algorithm for systematically checking for the existence of all ray combinations up to any specified order. However, it has been found in practice that rays beyond the third order have negligible contribution to the computed field.

Following the ray-tracing operation, the field contribution due to each ray that is found to exist may be computed using the UTD or the UAT. The authors have used both the approaches, the UAT for the first time, to the ILS glide-path problem.

The ray tracing and field evaluation programme has been applied to real airport sites in India for which measured data are available for validation. The starting point of the chain of computation is an aerial altimetry or a contour map of the site under evaluation. The profile line derived from such a contour is then used to generate the plate model.

Figure 4 shows the profile line for an existing airport approximated to a six-plate structure, up to a distance of 1,220 metres from the glide-path antenna. The ray tracing and field evaluation algorithms have been applied to this site, using both UTD and UAT, and the resulting fields are expressed in terms of equivalent DDM. These computed DDM values are compared with the measured values for validation of the theory.

Two common experiments routinely conducted for ILS calibration are the level run and the low-level approach, standard procedures for which have been laid down by the ICAO. Figure 5 is a plot of the DDM as a function of the elevation angle for a 1,000-foot level run. The measured values and the computed values using the two methods are plotted. The two computed values are nearly coincident, and are very close to the measured curve over the entire run.

The glide-path parameters derived from the level run are shown in the accompanying table along with measured values. The difference between the measured and the computed path angles is only 0.02 degree. The computed course width also agrees with measured values within an accuracy of 4 per cent.

The results for low-level approach run are shown in Figure 6. Here, both the computed DDM values along the nominal glide path remain throughout the run within the ICAO stipulation of 20 microamperes, as does the measured curve.

Benefits are numerous

Given the level of accuracy achieved by theoretical modelling, as illustrated by these examples, it is worth considering the saving in time and money by going in the modelling route, as compared to experiment. Actual costs and time scales will, of course, vary considerably over the world.

Glide-path parameters derived from level run.

Parameter in degrees	Measured	Calculated	
		UAT	UTD
Path angle	3.0	2.98	2.98
Total sector width	0.72	0.69	0.68

But, dealing with orders of magnitude, a typical experimental site evaluation may cost about US $100,000, whereas the computer evaluation, which typically takes about 30 minutes on a medium level mainframe computer for an 80-point run, would cost within $1,000.

An experimental sequence, including the installation of the temporary system, takes up to six months in remote parts of the world and somewhat less in places with better facilities. The computer approach, which can start right from the survey data stage, can yield results in matters of hours. This would make it possible to examine, right at the planning stage itself, alternative sites as well as sites at different assumed stages of development.

The last word on the accuracy of computer modelling has not yet been said, and scope remains for further refinement. One useful extension of the theory is to include the effects of terrain surface roughness and imperfect conductivity, which are related problems. The authors have devised generalized models capable of handling these factors and positive results are indicated.

The underlying theory for the model is valid over a very broad band of frequencies. With minor modifications, the theory developed for ILS can be readily applied to the microwave landing system and, indeed, to a broad class of radiating systems, including communication and navigation equipment, where terrain multipath is an important factor. □