A COMPARISON OF TWO EUROPEAN REFLECTOR ANTENNA CODES

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Abstract - **Two computer programs for the analysis of reflector antennas are evaluated for the purposes of establishing their general capabilities and, more specifically, accuracy and computational efficiency. Both programs were used to analyse a number of test cases and the results obtained are compared.**

I. INTRODUCTION

As the analysis of reflector antennas beyond simple cases, including such effects as surface distortions, is not trivial a number of computer programs have been written that comprehensively address this problem. It is therefore of interest that these programs are verified and compared with both measurements and other existing software. In general, it is easy to compare the program against standard reflector configurations e.g. those that have an analytic solution, symmetric cassegrainian systems and others. It is however harder to validate software for more complex cases e.g. shaped systems, multi-feed contoured beam antennas, etc as there is no exact analytic solution.

One other problem is that generally only one software program will be available for use in any one company and hence it is difficult to compare the results for similar computations. Even if more than one program is available, great care must be taken in ensuring that the test cases are identical.

Currently, this latter point has been receiving increased attention [1] as the number of antenna analysis programs has become larger. This leads to a greater need to quantify each program in terms of its strengths and weaknesses in relation to the other programs.

The European Space Agency (ESA) has been active in antenna analysis for some time [2,3] and is interested in evaluating alternative software programs. Therefore, a small contract was placed with European industry to compare two reflector analysis programs [4].

The purpose of this paper is to summarise the work undertaken in [4]. Specifically, the work was concerned with comparing the general capabilities of the two programs and evaluating their respective accuracies and computational efficiencies. Some proposed reasons for the comparative differences found are given but the work was not designed to be a fully comprehensive comparison of both softwares, when a detailed study of the mathematics and computer codes would be made.

The two programs being evaluated are TICRA's (Denmark) GRASP program and British Aerospace's IAAC program. Both have been under active development and use for a number of years and are broadly similar in capability. GRASP (General Reflector Analysis Software Program) is widely used throughout European industry and has been extensively modified by industry for various specialist applications. The IAAC (Integrated Antenna Analysis Capability) program has been developed and used in-house and is not therefore as widely known.

It is ESA's intention to propose the test cases used here as a benchmark for comparing reflector analysis programs. This is because the cases considered are well defined and representative of the range of such antennas found in practice. It is therefore possible to supply further details as required.

II. THE PROGRAMS

Both programs are very general in their capabilities and can be used to analyse a wide range of different configurations. Table I contains a summary of those facilities that are common to both programs and Table II a summary of those that are unique to each.

The IAAC program employs a modular construction with, for example, separate modules for the calculation of main and sub reflector fields, while GRASP is one program except for the contour plotting part. Both programs can accommodate user supplied routines to enhance the existing capabilities.

GRASP has become the de facto European standard since it was first developed in 1977. Numerous updates and enhancements have been made to the original in the light of theoretical advances and practical experience and many companies have included their own specific routines for non-standard reflector types eg dichroic sub reflectors, gridded reflectors, etc. The GRASP program is part of a suite of programs (COBRA) used to generate contoured beam reflector antennas including the excitation coefficients. The program has been verified by extensive comparison with measured results which has confirmed its accuracy [5,6].

The British Aerospace IAAC program has also been developed over a number of years but for internal use only and is hence not as widely known. However, comparison with measured data has been made and the accuracy verified [7]. The IAAC suite of routines is also able to generate reflector antennas and excitation coefficients.

The two programs are basically similar in terms of the mathematical techniques employed. Briefly, Physical Optics (PO) is used to analyse the main

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Table I Summary of Common Program Facilities

- single and dual reflector configurations
- Physical Optics calculation of main reflector far field patterns
- GTD calculation of scattered fields from main and sub reflectors
- GO calculation of main and sub reflector fields
- either analytically or numerically defined main and sub reflector surface and rim
- inclusion of random and systematic surface distortions
- calculation of near or far field radiation pattern
- aperture blockage calculation
- inclusion of direct feed radiation in the far field
- forward scattered field from the sub reflector into the far field
- wide choice of analytic feed models or inclusion of a measured feed radiation pattern
- output options include line cuts and contour data of the radiated field, sub reflector field and feed radiation
- calculation of main reflector aperture field
- calculation of feed spillover

Table II Summary of Unique Program Facilities

- GRASP - analysis of the effects of sub reflector support struts
- IAAC - feed near field effects on the sub reflector

reflector scattered field with the addition, if necessary, of the Geometrical Theory of Diffraction (GTD) for edge effects and either GTD or Geometric Optics (GO) and GTD for the sub reflector scattered field.

The Physical Optics solution is expressed as a surface integral that models the scattering from a reflector surface and can only be solved numerically for most practical antennas. The solution is achieved by dividing the antenna surface into a number of grid points and integrating the surface electric current over these points due to the incident magnetic field.

There are a number of different ways of performing the numerical integration and the two programs use alternative techniques. GRASP uses the well known Ludwig integration method [8], while IAAC uses a fourier series of integrals to describe the surface electric current [9].

The normal polar integration grid used in GRASP to discretize the reflector surface is modified to take account of a non-circular reflector edge by using triangular patches, which has been found to be more accurate [10]. The user specifies the angular size of the central polar patches and the program then generates the integration grid and performs the PO integration.

IAAC always uses a rectangular grid but modifies the field value of patches at the reflector edge to compensate for the fact that the patch is not rectangular. An FFT algorithm is then used to evaluate the aforementioned fourier integrals to produce the far field. The user must specify the number of terms to be used in the integral but experience has shown that one term is usually sufficient.

PO is used only to model the main reflector by both programs as the computation becomes extremely time consuming if it is used for the sub reflector too. Generally, there is also no advantage in terms of accuracy in modelling the sub reflector with PO.

The Geometrical Theory of Diffraction accounts for the rays that are diffracted from the reflector edges and then contribute to the field at the point of interest. This problem is generally solved by using Keller's formulation [11] but a correction is required near the shadow and reflection boundaries as the field here becomes singular and cannot be evaluated. Both programs use the Uniform Asymptotic Theory (UAT) [12,13] to provide the correction to prevent singular field values near caustic points for the diffracted rays.

GTD is used for the sub reflector scattered field calculation and can also be used for the main reflector, but not close to boresight because of reflected ray caustic problems. As the calculation is considerably faster than the equivalent PO calculation it is recommended in the GRASP program to use it whenever possible, which usually means beyond the first few sidelobes. However, in some cases, especially when the antenna is shaped or defocussed, PO must always be used at all times as caustic regions outside the main beam region may appear. It is possible to use GTD in IAAC but this is not generally done as the PO technique used is sufficiently quick and it also simplifies the user interface.

Geometric Optics is the calculation of directly reflected rays from the source to the desired field point via the reflector surface(s).

IAAC uses the formulation of Lee [14] for the sub reflector field analysis.

A previous study was undertaken [15] to compare an older version of IAAC with an older version of GRASP (GRASP 2), when both of these were then the current version.

III. TEST CASES

A total of nine test cases were analysed, involving a representative cross-section of reflector antenna types. These are summarised as follows.

1. Single offset reflector with feed at focus.

The INTELSAT V west spot antenna with the characteristics:

$d = 42.781\lambda$
$f/d = 1$
$\Theta_o = 29.31°$

was taken for case 1, where d is the antenna diameter, f is the focal length and Θ_o is the offset angle. The feed is a gaussian model with a -7dB taper at 20°, giving a reflector edge taper of -14dB.

The far field was generated in a 64x64 grid to cover ±10°. GRASP was run using PO to 3.2° and GTD thereafter, while IAAC only used PO. One additional run using PO only was made covering ±3.2° in a 32x32 grid, which is a more typical range for most applications (Case 1a).

2. Single offset reflector with feed offset.

This reflector configuration is identical to case 1 but with the feed offset by 5.0729λ in the plane of asymmetry, corresponding to a beam shift of 4.6 beamwidths. In this case the near field of the main reflector was calculated on a 32x32 grid as well as the far field in the principal plane cuts. The latter had the same PO/GTD ranges as case 1. Similarly, a further run was made with a reduced angular range of ±3.2° using PO only (Case 2a) to calculate the principal plane patterns.

3. Single offset reflector with multiple feed array.

A reflector designed to illuminate Europe with a 16 element feed array and the following characteristics was analysed:

$d = 51.09\lambda$
$f/d = 0.86$
$\Theta_o = 38.45°$

The feed model used was a smooth walled circular horn supporting the TE11 mode with a radius of 0.55471λ. The far field pattern was generated on a 64x64 grid, with both GRASP and IAAC calculating the total incident field from the feed array at the reflector surface and then the far field pattern using PO.

4. Dual offset reflector with feed at the focus.

A compensated dual reflector to cancel cross-polarisation from MELCO (Japan) with

$d = 120\lambda$
$f/d = 1.82$
$\Theta_o = 98.27°$

was taken for the this case. To illuminate the sub reflector a smooth walled square horn of sides 1.248λ supporting the TE10 mode was used, based on the model of Silver [16]. The output was generated for this case only in principal plane cuts. Both programs use GO to calculate the incident field from the sub reflector on the main reflector, while GRASP uses PO to 1.2° and GTD to 8° and IAAC PO at all times to calculate the far field pattern. A further run was made with IAAC also using GTD for the sidelobe calculation.

This case was then analysed with the feed offset from the focus by approximately 24λ and a reduced output range of ±4° (Case 4a).

5. Dual offset shaped reflector.

Designed to cover Spain with an elliptical beam from a dual shaped reflector, the main reflector has the following dimensions:

$d(\text{major}) = 64.8\lambda$
$d(\text{minor}) = 35.2\lambda$
$f = 63.88\lambda$
$\Theta_o = 42.123°$

The shaping consists of analytically distorting the hyperbolic sub reflector and numerically defining the main reflector surface. The incident field on the main reflector is calculated by GO and GTD and the far field pattern, on a 64x64 grid, by PO only, by both programs. This antenna system is shown in figure 1 as an example of a typical antenna system.

6. Single offset reflector with surface distortions.

An inflatable reflector of Contraves, Switzerland, was manufactured and the surface measured to give the distortions with respect to the nominal paraboloid, in a regular rectangular grid. The nominal paraboloid is defined by

$d = 36.3\lambda$
$f/d = 0.78$
$\Theta_o = 49.57°$

A gaussian feed model is again used, with a taper of -20.671dB at 27.4°. Both programs use PO only to generate the 64x64 far field grid.

7. Single reflector with non-circular rim.

This case is the same as case 1 with the exception that the rim is a super-elliptic given by the following equation:

$$\left(\frac{x}{2}\right)^{m/2} + \left(\frac{y}{2}\right)^{m/2} = 1 \qquad (1)$$

where, for case 1 m=4, and for this case m=7. PO is

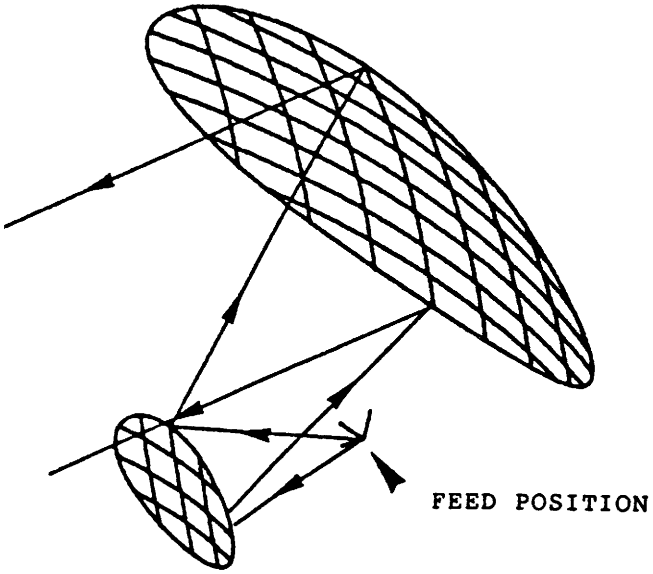

Fig.1. Example of a typical dual reflector antenna system

used by both programs to calculate the 64x64 point output grid.

8. Shaped single reflector.

Here, a single shaped reflector is used to provide a contoured beam illumination of Europe, with

$d = 41.41\lambda$
$f/d = 1.32$ before shaping
$\Theta_0 = 29.79°$

fed by a gaussian feed model with a taper of -20dB at 20°. The 64x64 point output grid is generated by both programs using PO.

For all cases described two principal plane cuts were also calculated.

IV. RESULTS

The first verification to be undertaken is that for the various feed models because if these are not identical it is unlikely that the reflector patterns will be. The agreement was found to be excellent in all cases, as shown in figure 2, the smooth walled cylindrical horn of case 3.

A summary of the CPU time taken for each case is presented in Table III. This table also contains the number of main reflector integration grid points used in the PO integration. All runs were made on an empty VAX 11/750 computer with 4Mb of main memory, version V4.3 VMS software and FPS5205 floating point hardware.

As the IAAC program is optionally able to use the floating point processor for the PO integration, each run was repeated though the times are not presented. As would be expected, in all cases the times are quicker when using the processor but are only significantly improved when a large number of PO integration points is evaluated.

A comparison of the run times for the two programs shows that IAAC is generally faster than GRASP. This is particularly true when only PO is used to calculate the far field pattern for single reflector geometries with a large number of integration points eg cases 6 and 8.

However, for dual reflector geometries there is no significant difference as in this case the computation time is dominated by the modelling of the sub reflector. This form of modelling is essentially identical for the two programs and hence the computation times would also be expected to be more similar.

GRASP has an advantage when it is required to analyse to a wide angular range as it is normal to use GTD for the far out sidelobe calculation, which is comparatively very fast, whereas IAAC is generally only used with PO and therefore needs a higher number of integration points.

One reason for the difference in speed of the PO integration is that the Ludwig (GRASP) integration procedure ensures an accurate prediction of far out sidelobes, where the phase of the surface integral is rapidly varying, at the cost of a slower convergence rate.

One other reason for the quicker IAAC integration is the use of the FFT implementation as opposed to the direct summation of GRASP. In IAAC the number of computations required by the summation varies as $N\log_{10}N$ as compared to N^2 for GRASP, where N is the number of integration grid samples in the aperture and far field.

Table IV lists the peak directivities calculated for each test case. From this table it can be seen that the

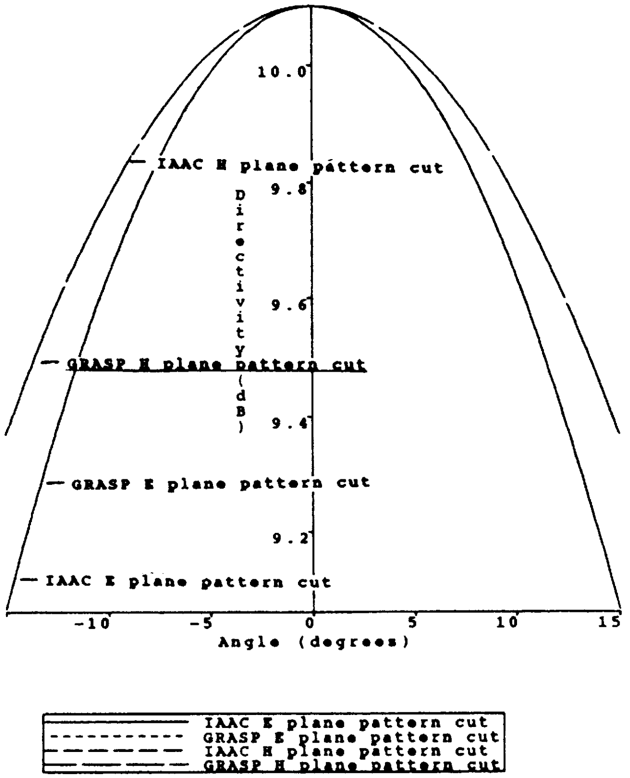

Fig.2. Comparison for TE_{11} cylindrical horn E and H plane cuts

Table III Summary of CPU Times

CASE		IAAC		GRASP	
		Number of PO Integration Points	Time (secs)	Number of PO Integration Points	Time (secs)
1	(cuts)	202	21.5	204	36.9
1	(contours)	202	26.0	204	141.6
1a	(cuts)	201	8.5	204	27.5
1a	(contours)	201	10.7	204	60.3
2	(cuts)	201	29.5	204	24.6
2	(contours)	201	73.6	204	292.2
2a	(contours)	201	9.4	204	28.6
3	(cuts)	804	66.1	1350	356.6
3	(contours)	804	119.2	1350	702.7
4	(cuts)	3217	280.9	216	117.8
4a	(cuts)	3217	352.4	216	137.2
5	(cuts)	1608	358.6	748	350.5
5	(contours)	1608	411.2	748	776.3
6	(cuts)	804	27.1	792	211.3
6	(contours)	804	30.7	792	785.8
7	(cuts)	804	45.0	444	90.2
7	(contours)	804	78.1	444	544.4
8	(cuts)	804	35.7	720	290.7
8	(cuts)	804	72.2	720	719.2

values calculated by GRASP are below those of IAAC by a small amount, the maximum difference being 0.26dB for case 2.

The probable reason is that GRASP has not fully converged for these cases, which on closer inspection are all single, unshaped antennas with no surface distortions. One possible explanation for the discrepancy is that relatively fewer PO integration points are taken for focussed, 'standard' configurations on the assumption that convergence requires fewer points, whereas more PO integration points are taken for other configurations. The results would indicate that this assumption is not generally true for GRASP but is for IAAC. In the other cases where a comparable number of PO integration points are taken the difference in peak directivity is in the order of 0.05dB (Cases 4,5,6 and 8), which is minimal.

Table IV Peak Directivities

CASE	PEAK DIRECTIVITY (dBi)	
	IAAC	GRASP
1	41.67	41.48
2	41.12	40.86
3	32.97	32.72
4	43.58	43.55
4a	41.78	41.73
5	41.40	41.33
6	39.04	39.03
7	42.40	42.19
8	30.48	30.43

In order to investigate the convergence of the single, unshaped reflector cases a number of runs were made to evaluate the convergence of both accuracy and computation time. The results are given in figures 3 and 4 for case 1. These show that IAAC converges more quickly than GRASP with respect to both the time taken to produce the converged directivity and the number of PO integration points required, as also indicated by examination of tables III and IV.

Convergence testing is one area where IAAC has better defined guidelines than GRASP. For IAAC this involves having a recommended sampling rate for the integral dependant on the complexity of the antenna, while the manual for GRASP suggests an integration grid angular size. The latter, however, does not guarantee convergence, which then needs confirmation by further computer runs.

As well as the peak directivities, of importance is the accuracy of the overall pattern computation. Examples of cases 1a,2,3,5,6 and 8 are shown in figures 5 to 11. These representative pattern cuts and contour plots illustrate the range of agreement found. For those

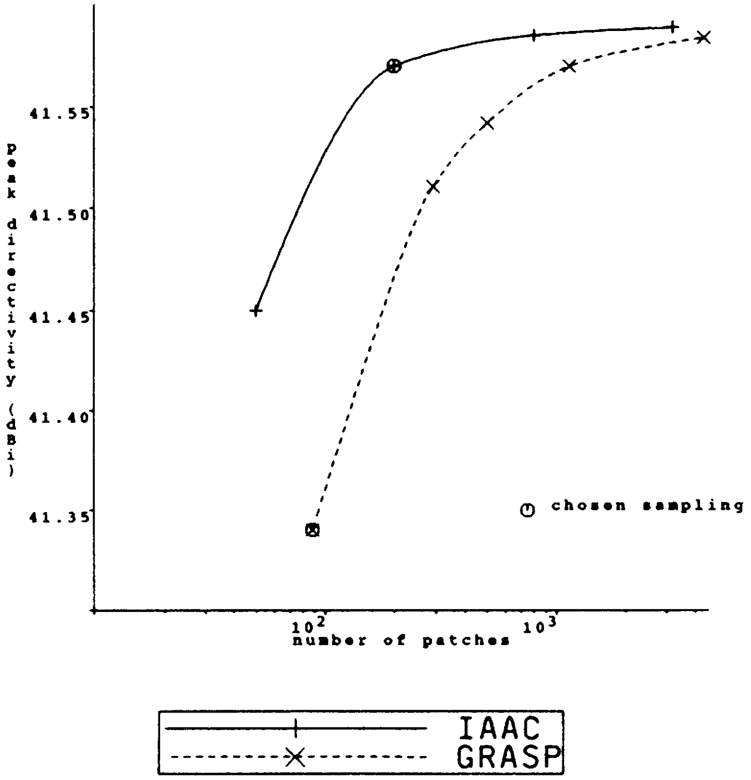

Fig.3. Comparison of convergence of boresight directivity and number of PO integration points for Case 1a

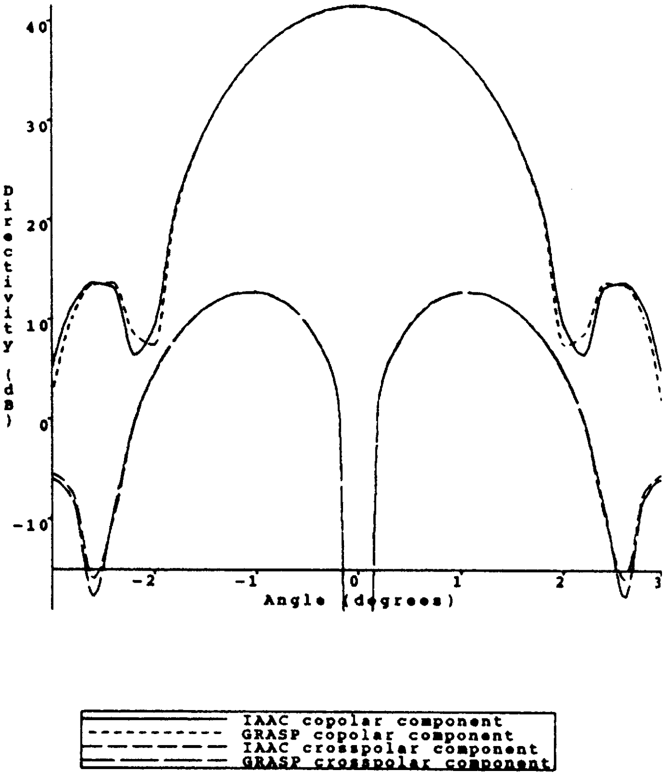

Fig.5. Comparison of far-field co and cross polar radiation for asymmetry plane cut of Case 1a

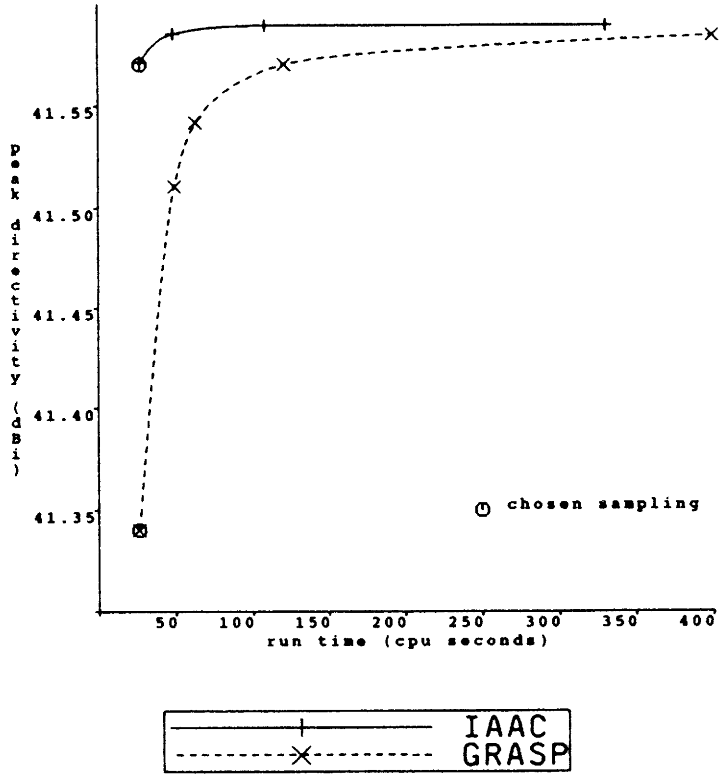

Fig.4. Comparison of convergence of boresight directivity and computer run time for Case 1a

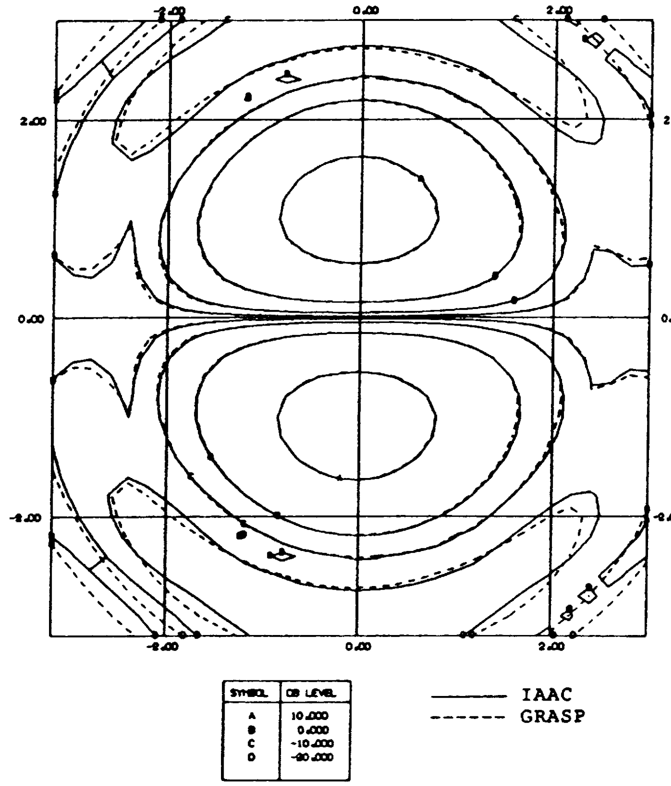

Fig.6. Comparison of far-field cross-polar radiation pattern in a contour plot of Case 1a

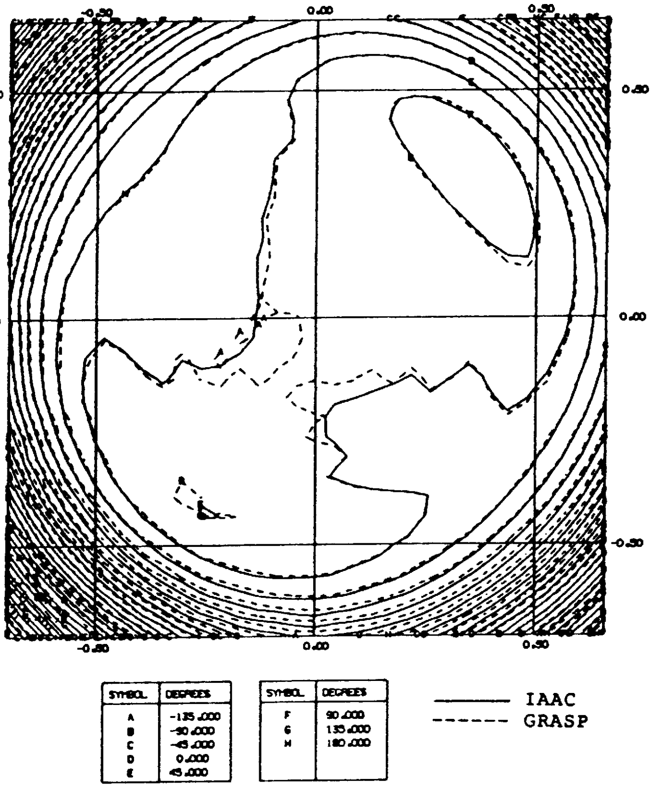

Fig.7. Comparison of near-field E_y phase pattern in a contour plot of Case 2

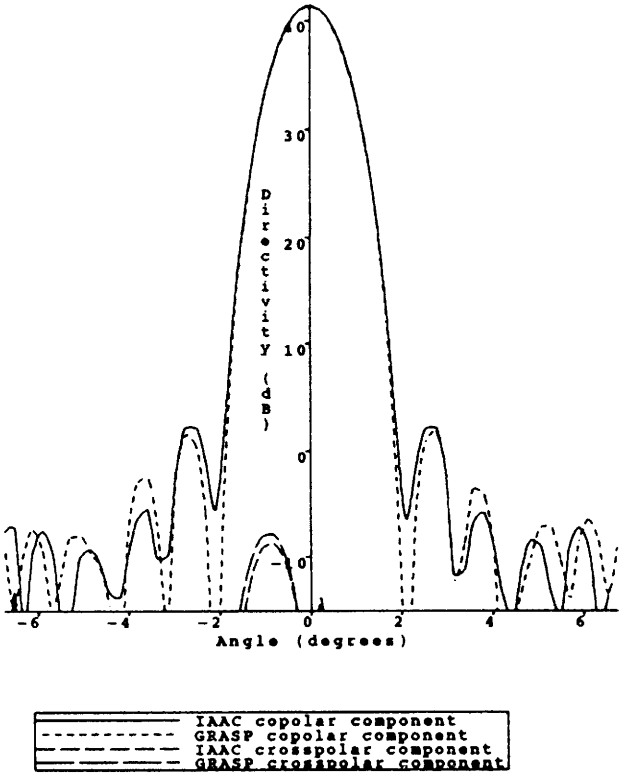

Fig.9. Comparison of far-field co and cross polar radiation patterns for asymmetry plane cut of Case 5

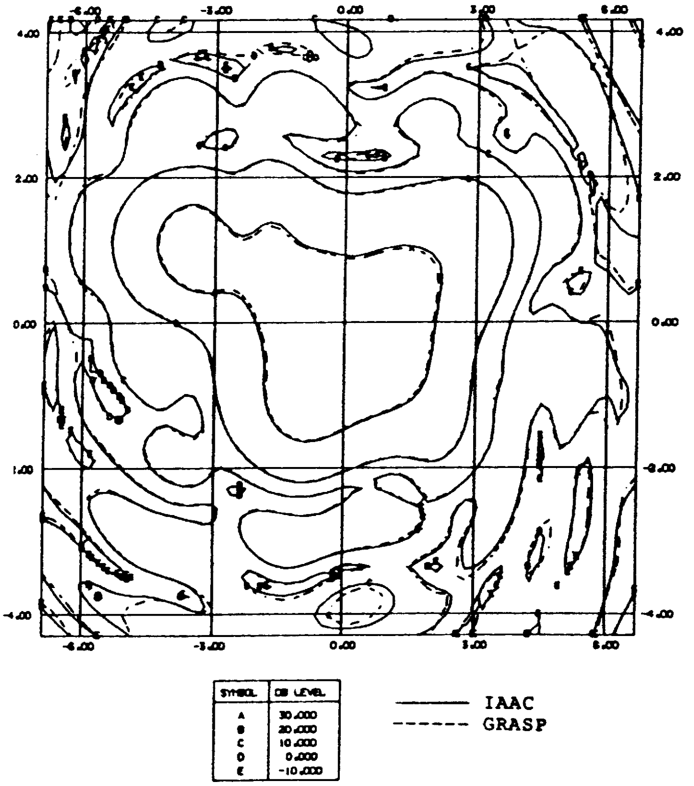

Fig.8. Comparison of far-field co-polar radiation pattern in contour plot of Case 3

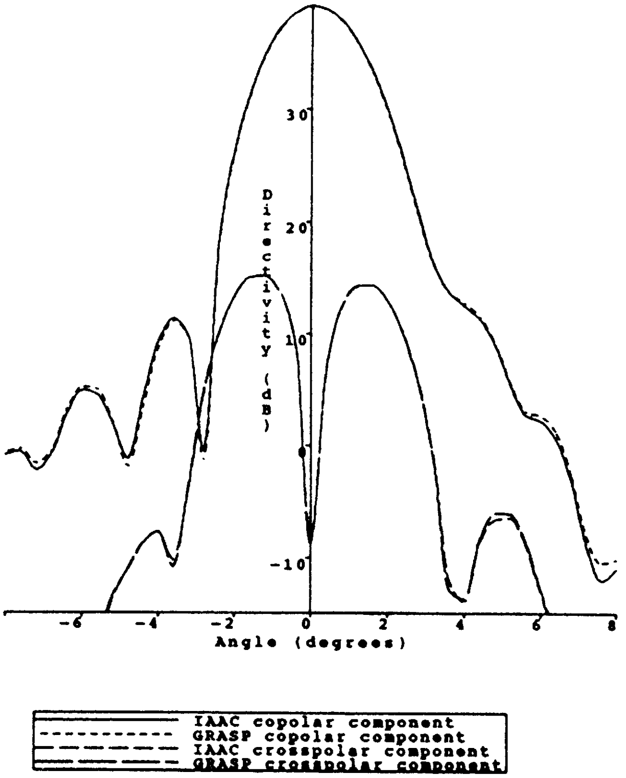

Fig.10. Comparison of far-field co and cross polar radiation patterns for asymmetry plane cut of Case 6

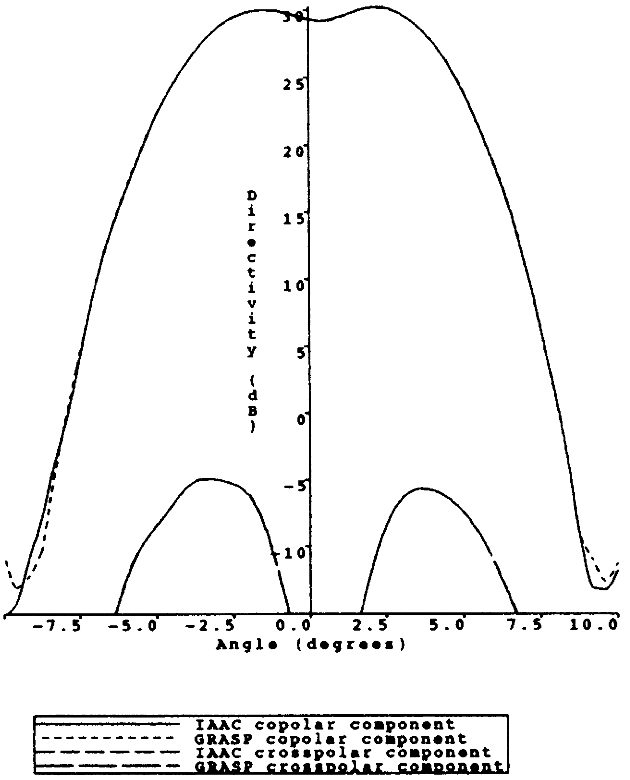

Fig.11. Comparison of far-field co and cross polar radiation patterns for asymmetry plane cut of Case 8

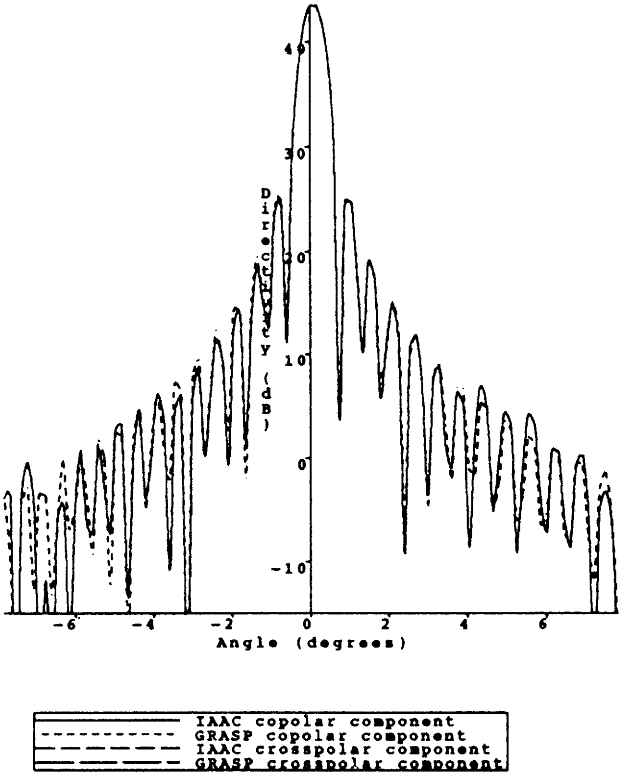

Fig.12. Comparison of far-field co polar radiation pattern for asymmetry plane cut of Case 4

cases where the results are not presented the agreement is no worse than the cases shown.

In general the figures indicate very good agreement and are consistent with the results found in comparing the peak directivity calculations. Some discussion follows on possible reasons for differences between the two programs.

As has already been shown, GRASP converges on the peak directivity less quickly for single, undistorted reflectors than IAAC, implying that the rest of the radiated field computation would be as correspondingly as accurate. This may account for the differences in figure 5 and also figure 9, when the GRASP analysis used 748 integration points and IAAC 1608.

In the latter case, however, the peak directivity values are very close (0.05dB) and hence one would expect the patterns to be similar. One explanation is that GRASP uses irregularly shaped triangular integration patches near the reflector edge, while IAAC uses weighted rectangular patches. The former would be more accurate in this case. Another explanation is that the convergence of the sidelobes is slower than that for the peak directivity and as GRASP uses fewer integration points than IAAC this may explain the difference. It should also be noted that the sidelobe levels for this reflector are at -45dB with respect to peak when implicit computer accuracy may start becoming important.

Referring to case 4 and figure 12, the first runs were made with IAAC only using PO resulting in a high run time as this case also has a high angular range (8°). GRASP used a combination of PO and GTD.

Comparison of the far field patterns showed a high discrepancy in the far out sidelobe region. In this case the discrepancy is because IAAC is using an insufficient number of terms in the fourier integral, which is a problem when analysing highly offset reflectors, as in this example. The problem has since been solved by increasing the array limits so that more integral terms can be included.

Following a second run with IAAC just using GTD very good agreement was found. This shows that even with a high number of PO integration points care must be taken to ensure that the calculation has converged. This result also confirms that the GTD calculation in each program is equally accurate.

V. CONCLUSIONS

The study has shown that both programs have similar capabilities, which enable a wide range of reflector antenna types to be modelled. Comparable accuracy has been demonstrated with agreement between the two different methods of evaluating the PO integral being high. Agreement between the GTD calculations is also good. The computation time on a general basis is similar with the exception of cases involving only PO where IAAC is substantially faster. In the latter cases, IAAC also converges more rapidly than GRASP.

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VII. ADDENDUM

It should be noted that since this comparison was made, the method used in GRASP to evaluate the PO integral has been altered to make it more efficient. This is because the original Ludwig integration was optimised for the far out sidelobe region calculations as GTD was at that time not implemented. This made the integration less efficient around boresight.

IAAC has also been extended to include a forward ray tracing algorithm for the sub reflector. This allows the analysis of severely distorted sub reflector surfaces.