PARADES Structural Design System Capabilities

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Design approaches, program capabilities, problem formulation, and user options are outlined for the PARADES program. PARADES is a new computer program for the analysis and design of parabolic antenna-reflector structures.

I. Introduction

PARADES is a special-purpose structural design computer program that is being developed for JPL by the Philco-Ford Western Development Laboratories, Palo Alto, California. The name is an acronym for Parabolic Reflector Analysis and Design Subsystem. The primary function of this program is to perform structural analysis of an initial reflector design, assess a selected measure of performance efficiency, and then improve the efficiency by redesign.

Since the task of PARADES is to improve the design of a structure with respect to some pre-established measure of efficiency by means of automated mathematical procedures, the program can be classified as operating within the field of Optimum Structural Design. This field began its contemporary development within the last decade and is a logical extension of rapidly expanding technology and computer implementation for the evaluation of structures by means of analysis of independently established designs.

Although structural optimization is currently an emergent field of technology, there is a host of widely differing mathematical approaches that have been developed. These range in sophistication from extremely simple trial-and-error solution searches to the much more complex methods of mathematical programming. A brief review of some of the more prevalent methods is given in Ref. 1.

As yet there is no clear definition of which method is preferential for any specific application. In the present context, "preferential" is a qualitative concept since it implies a subjective evaluation of the design efficiency attained as well as the effort expended for the attainment. Furthermore, since applications are so diverse, it may never be possible to establish a universally suitable method for all applications.

Consequently, the PARADES program has adopted the practical philosophy of implementing a solution method that has been demonstrated as effective for the antenna design problem. This bypasses the alternatives of developing a new method, or extending an existing method unproven for the problem at hand. Therefore, the attendant risks of little effectiveness or even uselessness are avoided.

Another practical attitude adopted within PARADES is the recognition that design optimization, in the global sense, is a tenuous concept that is often either not achievable or, if achievable, not worth the ultimate extra effort. Although the word "optimization" has been accepted to characterize a broad technological field, a more realistic interpretation with respect to structure design would invoke the word "improvement." Accordingly, PARADES addresses itself to the task of attaining effective design improvement without specifically attempting to find an abstract mathematical optimum.

Although the solution approach adopted by PARADES has been previously established by Von Hoerner with his concept of "homologous design" (Ref. 2), many features of implementation, program scope, and user options that are incorporated are advanced and innovative. It is anticipated that these features will make PARADES an effective program that will be used for analysis only, and when it is not also required to employ its design capability.

II. Design Approach

The design task entails reassigning values of design variables to generate an admissible design of improved efficiency. The design variables are defined to be the cross-sectional properties of the structural members of a parabolic reflector. An admissible design precludes overstress, buckling failure, and excessive deflections with respect to limits and loadings established by the program user. The measure of efficiency is the rms of half the difference in pathlength of the RF energy beam in traveling from a deformed reflector surface to the focal point, compared with the pathlength from a surface that is a perfect paraboloid. The reflector surface of interest is equivalent to an infinite set of points for which pathlength differences exist; in practice, the surface is replaced by a finite set of "target" points, which are taken to be a representative sample of the entire set.

The deformations that are considered within PARADES for efficiency evaluation are the repeatable elastic surface deformations that result from the gravity loading of the weight of the structure plus other nonstructural supported components. Although this loading has constant magnitude, the direction of the gravity vector with respect to the antenna surface can change as the antenna elevation angle changes from the zenith to the horizon operational pointing positions. Consequently, there is an infinite set of gravity loadings for efficiency evaluation—one for each attitude in the continuous spectrum of elevation attitudes.

However, by using formulations developed from the rigging angle concept (Ref. 3), it has been shown (Ref. 4) that loading at one particular elevation attitude is sufficient to characterize the efficiency of a particular design over the entire elevation range. This concept implies that the gravity loading at the so-called "rigging angle" attitude is compensated by adjustment of surface panels and the loading at other attitudes is effectively the net loading in moving away from the rigging attitude. Therefore, one of the innovations of PARADES, which permits the substitution of a single design loading condition, is to compute the optimal rigging angle associated with a particular structural design. Adjustment of the surface for the optimum rigging angle can be a major step toward efficiency improvement even if no other structural design changes are developed.

Homologous design, the primary design approach of PARADES, was defined by Von Hoerner (Ref. 2), as a design that would force the surface to respond elastically under loading by deforming from one perfect paraboloid into an alternative perfect paraboloid that could possibly have a different focal length, plus up to three independent rigid-body translations and two independent rigid-body rotations. In ideal situations, and also within minor approximation in many practical situations, the focal length change and the rigid-body motions of the alternative perfect paraboloid would have no effect on gain loss from surface distortion. If any of these "homology shifting parameters" were unacceptable from an RF standpoint, they could be suppressed during the mathematics of defining the alternative paraboloid. Then again, there would be no gain loss, provided that an homologous design could still be achieved.

Homology is theoretically achievable as long as there are as many design variables (member sizes) for selection as there are target points. This follows because one equation can be written for each point in the surface target set of points to express the deflection of the point from the alternative paraboloid. Therefore, the homology design procedure is to solve these equations for the values of the design variables that make the deflections zero. Since these equations are nonlinear, they are solved in approximation by means of influence vectors developed to find the gradient changes in deflection for changes in the design variables. Consequently, as is characteristic of all practical problems in the field of structural optimization, linear approximations used in the solution of essentially nonlinear equations require that the design process must be iterative.

The iterative process entails repeated application of two operations until some measure of convergence or limit placed upon the allowable amount of computation is reached. These operations are:

(1) Analysis of the starting design, or of the design that has currently been developed. This operation is mathematically "exact."

(2) Redesign, which consists of selection of new member sizes. This operation is approximate because of the nonlinear relations between the design variables and the deflection response.

In many practical cases, perfectly homologous designs will not be achievable for one or more of the following reasons:

(1) There are not enough design variables.

(2) There are not enough free homology shift parameters.

(3) Selections of the design variables are restricted, e.g., by side constraints such as overstress or excessive deflection for some other loading condition, by a minimum size restriction, by a requirement that certain members be assigned to groups with common sizes, by a limited candidate list of discrete sizes from which member sizes must be selected.

In these cases, PARADES will automatically solve the target point deflection equations in the least-squares sense. This will result in a minimum rms solution for the resulting design. Like the homologous design mode, this is also an iterative process.

In addition to the reflector design solution modes of homology and minimum rms, PARADES has a third mode of fully stressed design. This option was introduced because of its general usefulness for many nonreflector-type structural designs either as a final design or as a feasible starting point for another design procedure. It is well known that fully stressed design is not really an optimization approach because no efficiency measure is recognized. Also, fully stressed design is sometimes not achievable. Nevertheless, in some cases, it can produce the optimum weight vs. stress designs, or designs close to the optimum. It is also capable of rapid execution and convergence within few iteration cycles.

Mathematics and details of implementation of these design approaches are given at considerably greater length in Ref. 5. It should be noted that in either of the reflector design modes, PARADES constrains the structure weight to be invariant and takes the minimization of the rms performance measure as the objective. In the fully stressed design mode, PARADES seeks the smallest individual member sizes that will satisfy the stress constraints. This will tend to produce a relatively small, but not necessarily the smallest, total weight for an admissible structure.

III. Program Features and User Input

As the program incorporates analysis with the innovation of design capability, input data requirements are more extensive than for familiar programs devised to perform analysis alone. Nevertheless, because this is a special-purpose program directed primarily to antenna-reflector structures, user input requirements are simplified and operational efficiency is enhanced by taking advantage of the highly repetitive nature of this class of structures. Consequently, the amount of data to be prepared for input and the execution time for one cycle of design and analysis are each likely to be approximately the same or less than for standard programs that perform analysis only. Complete details and examples of input data preparation are given in Ref. 6.

As in customary analysis programs, the structure is defined by nodal grid intersection points, member connectivity, and property data, while the problem is defined by loading data and grid constraint lists. However, a distinctive feature of PARADES allows a substantial condensation of these data through its capability for modular input. This requires the user to define only one representative sector of the structure with respect to grids, connectivity, and loading. The program internally generates all sectors of the complete structure as defined by the user and assembles the correct number of replicate and mirror-image copies of the representative sector. The program also accepts special user input to define features of the structure that are not typical of the representative sector.

Formulating and solving of the load-deflection equations is done on a sector basis. Identical computations that are performed for one sector are not repeated for other sectors. As a further simplification, when structural symmetry, in conjunction with loading symmetry or antisymmetry, makes it possible to restrict the investigations to one-half or one-quarter of the full structure, boundary conditions can be generated automatically for the part structure.

The structural connectivity as defined by the user consists of line elements. Elements can be offset from the terminal grid points, and slip and hinge joints can be specified. Direct stress, shear, torsion, and bending of these elements are considered in the analysis. Design is based upon the cross-sectional area and the one-to-one relationship of weight and area.

New members for an improved design can be selected on either an "idealized" or "realizable" basis. The idealized basis allows the program to compute the member size (area) from a continuous spectrum of sizes. The realizable basis restricts the choice of members to a discrete candidate list supplied by the user. The candidate list can contain any of eight classes of cross-section types. For each type, the user supplies the dimensions of the cross-section required to define the specific geometry, and the program computes all the necessary elastic and inertia properties for analysis and design. Figure 1 shows the cross-section classes available and the defining dimensions that are to be specified. The selection of particular members can be assigned to groups, with all of the members in each group being required to have a common size. From a practical standpoint, grouping often permits worthwhile economies in procurement, tooling, and fabrication that can overcome associated penalties in the design efficiency.

Reflector design for gravity rms is based upon two specific loadings applied parallel to the antenna aperture plane. The total loading, consisting of the weight of the structure and specified invariant external weights, is assembled by the program. Design admissibility is verified for any additionally specified loadings. Stress checks for design admissibility are based upon principal stresses computed at the end of the member with the highest strain energy density. The critical buckling stress is determined from the length and cross-section and included with direct stress in an interaction formula to account for beam-column effects.

Grid coordinates can be input either in rectangular or cylindrical form. The displacement output coordinate system is specified independently of the input form. For the antenna problem, the internal solution is performed in parabolic coordinates. This permits the reduction of the three customary displacements at each target node to the single component of distortion normal to the parabola. The target set for rms analysis is defined by a weighting factor assigned to the grid point.

The extent of structure that can be analyzed depends mainly on the numbers of degrees of freedom in any sector. If this is less than about 180, total storage for code and data can fit in one 65K bank of the 1108 computer. Large antenna structures could be treated by extending core if the representative sector size could not be made small enough. Adding a second bank of core allows about 380 degrees of freedom in each sector. An option of the program can be used to restrict the number of elastic degrees of freedom at each node to three, rather than six. This is usually appropriate for a reflector structure, so that there can be about 60 nodes per sector for a standard-size core execution, and about 125 nodes if two core banks are assigned. Formulas are given in Ref. 6 to determine the exact core size needed for each problem. The program makes and outputs its own core size computation and will not proceed if storage is inadequate.

In the design mode, homology and minimum rms designs are available for reflector structures. Fully stressed design is available for any general structure, including reflectors. The user can specify the maximum number of redesign cycles. The program can terminate before this number is reached, depending upon an internal parameter that tests the current rate of design convergence. The program will punch decks defining the design achieved for use either in restart or for some other analysis application.

For minimum rms design, the user can specify the objective of minimum peak rms over the entire elevation range, which is accomplished within the program by choosing the rigging angle to make the rms at zenith equal to the rigging angle at the horizon. Alternatively, the user can specify the minimum weighted average rms over the horizon/zenith elevation range, with a weighting function equal to the cosine of the elevation angle and rigging angles computed accordingly by the program. The cosine weighting function provides the minimum expected rms for observations uniformly distributed in the hemisphere between horizon and zenith.

PARADES can execute in an analysis-only mode if desired. The advantages here for reflectors, compared to other standard analysis programs, are the modular input, the included rms computation as opposed to a post-processor program requirement, the comprehensive stress and buckling effect computations that are not ordinarily available in other programs, and the structure cost estimate furnished by PARADES. This cost estimate is developed from user parameters specifying cost per unit length and volume of general structural material, and specific length and volume costs for particular cross-sections in each of the cross-section classes. In the analysis-only mode, user input can be condensed by deleting information associated with the design capability.

IV. Summary and Program Status

A summary of some of the distinctive features of program execution, data preparation, and optional usage is presented below.

(1) Modular input with automatic generation of identical or mirror-image modules of structure and loading.

(2) Automatic boundary-condition generation for half or quarter antenna structure investigation.

(3) Stress and buckling interaction determination.

(4) Line element properties determined from cross-section dimensions.

(5) Rectangular or cylindrical coordinates for input or output.

(6) Member offsets, hinges, slip joints.

(7) Rms computations included with deflection analysis.

(8) Design options for homology, minimum rms, or fully stressed design.

(9) Automatic determination of rigging angle for minimum rms design for minimum peak or minimum average rms over elevation range.

(10) Idealized or realizable design options.

(11) Cost estimate furnished for best design.

(12) Punched deck output for best design.

(13) Analysis only, without design, mode of execution.

(14) Grouping of members for common sizes.

A copy of the program has been delivered to JPL by Philco-Ford and has been compiled on our Univac 1108 computer. To date, the analysis capability of the program has been tested on a sample problem, and extensive testing of the design capability is currently in progress.

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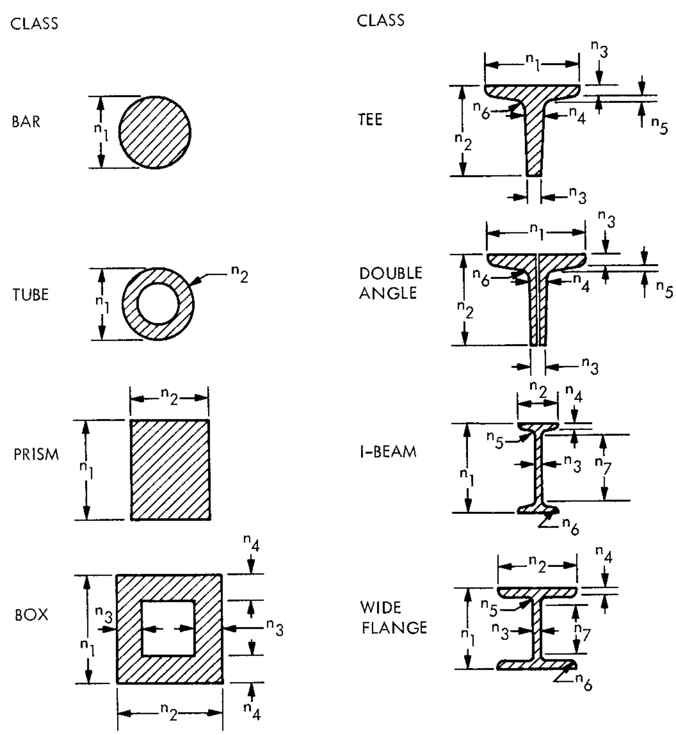

Fig. 1. PARADES line element cross-section classes