DYNIS: A DYNAMIC INTERACTIVE SIMULATION PROGRAM FOR THREE-DIMENSIONAL MECHANICAL SYSTEMS

Gordon J. Savage & Gordon C. Andrews
Lecturer, Dept. of Systems Design
Assistant Professor, Dept. of Mechanical Engineering

University of Waterloo
Waterloo, Ontario N2L 3Gl

ABSTRACT

This paper describes the interactive computer graphics techniques involved in the DYNIS digital computer program which is being developed at the University of Waterloo. The name DYNIS is an acronym derived from the program's purpose, which is the DYNamic Interactive Simulation of the response of three-dimensional mechanical systems. The user of the DYNIS program is able to simulate and visualize the response of such systems (composed of masses, springs, dampers, force drivers and position drivers) simply by describing them to the computer interactively. The program generates and integrates the equations of motion for the system described and the system's dynamic response is displayed on a computer graphics screen for observation. At any point in the simulation, the user is able to interrupt the simulation to alter the various system and display parameters or to stop the program. The DYNIS program is based on recent research developments in graph theory and is intended as the first step towards a comprehensive computer-aided design program for use in the design of dynamic machinery.

ABRÉGÉ

Dans cette communication on décrit les techniques de la représentation graphique interactive, incorporées dans le DYNIS qui est en cours de développement a l'université de Waterloo. Le nom DYNIS est tiré du nom de la fonction du programme qui est DYNamic Interactive Simulation de systèmes mécaniques tridimensionnels. L'utilisateur du programme peut simuler et représenter la réponse de tels systèmes (composés de masses, ressorts, amortisseurs, forces et trajectoires) en les décrivant à l'ordinateur selon la méthode interactive. Le programme formule et intégre les équations de mouvement du système puis il décrit et représente la réponse dynamique du système sur l'écran. À n'importe quel moment pendant la simulation l'utilisateur peut l'interrompre pour changer des paramètres du système ou de la représentation. On a basé le programme DYNIS sur les résultats récents en théorie des graphiques, et on le considère comme première étape vers un programme d'étude par ordinateur des plans de machines dynamiques.

1. INTRODUCTION

The development of a self-formulating computer program for the simulation of the response of dynamic mechanical systems has been a subject of interest to mechanical design engineers for many years. A program which would show the designer the response and dynamic loads on a machine part under design would have an obvious use in the iterative process of mechanical design. The first such program was DYANA, developed in 1959 and extended in 1961 [1, 2]. The development of the DAMN program in 1970 was a significant improvement, since this program simulates realistic machinery moving in two-dimensional plane motion [3], and a third program of this type, called MEDUSA, was developed in 1971 [4]. The DAMN program is based on Lagrangian concepts, and the MEDUSA program uses a new "bond-graph" technique as its theoretical base. An alternate (and, it is believed, somewhat simpler) technique was developed in 1971, and has been used as the basis for self-formulating dynamic simulation program. This new approach established the relationship between graph theory and well-known vector methods, and is called the "vector-network" modelling technique [5]. A computer program called VECNET, based on the vector-network technique, was written in 1971, and simulates the response of three-dimensional mechanical systems composed of masses, springs, dampers, force drivers and position drivers, given only the system description as input [6].

Early in 1972, the VECNET program was interfaced with parts of FILMIT, a computer animation program [7], permitting observation of the mechanical system's response on a cathode-ray tube (CRT) display screen. This combination dramatically increased the usefulness of the VECNET program since errors were immediately obvious and the dynamic response was evident without interpreting reams of figures. It was apparent that a fully interactive simulation program was possible, and the DYNIS program is the result of this development. Although the vector-network technique is still the foundation of the self-formulating procedure, DYNIS permits DYNamic, Interactive Simulation of three-dimensional mechanical systems.

2. THE SIMULATION PROCEDURE

The DYNIS program can be divided into three separate parts, or "stages", which perform different operations. These stages could be summarized briefly as follows:

Stage I: Creation and modification of the description of the mechanical system to be simulated. This stage creates a data file describing the system, which is read by stage II.

Stage II: Formulation and integration of the equations of motion for the system. At each time-step of the integrating subroutine, the response data is provided to stage III.

Stage III: Graphic display of the symbols representing the mechanical system for observation on the CRT screen.

The first stage of DYNIS is an interactive package that permits the user to select, locate (in three dimensional space) and describe to the computer the characteristics of the mechanical elements that comprise the system. These elements may be masses, springs, dampers, position drivers or force drivers. Interaction is obtained through a CRT display terminal with the aid of a function box with eleven buttons.

The data file created by stage I, containing the specified system description, the graphic display data, and the numerical integration parameters, is read into the second stage of DYNIS, which is adapted directly from VECNET. The second stage formulates the equations of motion, and then integrates the equations to determine the dynamic response of the mechanical system. The response data is passed to the third stage of the program which generates a three-dimensional picture of the system using a standard set of representative symbols, and then converts this picture into a two-dimensional perspective representation which is displayed on the graphic display unit for observation. This third stage contains an option for triggering a camera which records the simulation on motion-picture film. It also contains a procedure for storing the CRT pictures on disc. These pictures, or "frames", may be replayed if desired at 24 frames per second, so that the simulation may be viewed in real time.

3. THE THEORETICAL BASIS OF DYNIS

The vector-network modelling technique, an extension of the concepts of graph theory to include three-dimensional mechanical systems [5, 6], provides the theoretical basis for the VECNET algorithm used by stage II of DYNIS.

The construction of the vector-network model for a given system consists of identifying the "nodes" or points of interconnection of the elements in the system, and then replacing the mechanical elements in the system (on a one-to-one basis) with displacement vectors that span the appropriate nodes. The resulting network of displacement vectors describes, precisely, the order of interconnection of the elements in the system. For example, consider the simple mass-spring-dashpot system in Figure 1. The vector-network for this system is shown in Figure 2. Assembling the input data to describe the vector-network properly is a simple, but somewhat tedious task. The development of stage I of DYNIS makes this construction simple and efficient, and the user is not required to understand or use the vector-network theory. Given the description of the vector network, stage II (which is basically the original VECNET program) can proceed with the simulation.

4. STAGE I: DESCRIBING THE MECHANICAL SYSTEM

(a) Man-Computer Communication: Stage I of DYNIS is a program which contains a systematic procedure for creating the data file describing the mechanical system. (This data file is then read by stage II.) In order to eliminate problems of format, and to minimize the knowledge of graph theory required by the user, while ensuring that certain graph-theory constraints were obeyed, it was decided to lead the user through a series of systematic decisions by the use of "menus" which offered certain possible choices. An example of such a menu is shown in Figure 3. This method of presentation has been tested in earlier research projects [8, 9] and was found to be very effective.

The menu options are arranged in two rows of five items as shown in Figure 3, and a continuous dialogue between the user and the computer takes place through these menus which are displayed on the CRT. After a user selects an item, the "page is turned", and a display of the next hierarchy of choices appears, until, at the final level, data is entered for storage or processing.

At appropriate levels of input, feedback headings and values are displayed at designated locations. These "cues" keep the user informed of the current area and level of input.

(b) Sub-Divisions of Stage I: As the needs of the user were analyzed, it became evident that stage I would be broken conveniently into three distinct sub-divisions: "CREATE", "REVISE" and "MODIFY". These subdivisions are evident in the simplified flow-chart of stage I shown in Figure 4, and are further explained as follows:

i) CREATE: This sub-division creates a complete data file by requesting, through the use of menus, the magnitudes and order of interconnection of all elements, the visual (or graphic) data, and the integration parameters.

ii) REVISE: This sub-division permits mechanical elements to be added to or deleted from the data file which describes the mechanical system.

iii) MODIFY: This sub-division permits all parameters to be changed except those that affect the order of interconnection of the system elements.

(c) Creating a Data File with the CREATE Option: The creation of a data file describing a mechanical system requires knowledge of the types of elements, their order of interconnection, their magnitudes, the graphic display data, and the numerical integration parameters. Before a system can be described to stage I, it is usually necessary for the user to have a preliminary sketch of the system configuration (unless it is a very simple system) with all of the elements identified by the element type and sub-number. (For example, the masses should be labelled M1, M2, M3, etc.) It is also necessary that the user know the initial positions and velocities of the masses, as well as the unstretched lengths of springs, and the characteristics of driving functions.

With this information at hand, CREATE leads the user through a programmed sequence of requests for information which are directed and monitored by the graphics display. CREATE begins by asking how many of each type of element are in the system. Then, for each particular element, CREATE asks how the elements are interconnected, the particular variation of an element type (for example, a force driver might be a step or a ramp function, etc.), the graphic symbol to represent the element, the size of the graphical symbol, and the colour of the symbol, if it is to be photographed. Some elements require more specific data, such as the initial conditions of masses, unstretched spring lengths, driving function parameters, and effective start and finish times for driving functions.

When all of the data has been assembled by CREATE into a data file, the file is given a unique name by the user so that it can be recalled later from disc by either stage I (for revision or modification), or by stage II (for execution).

(d) Revising a Data File using the REVISE Option: If the occasion should arise when it is necessary to add or delete elements from a mechanical system, the user may enter the REVISE section of stage I.

In general, REVISE is a bookkeeping routine that edits the data file. It is, therefore, sufficient for the user to identify the element to be deleted, or indicate the type of element to be added when a change is required. In the case of the "add" feature, the user is led through the same sequence as CREATE so that all of the data for the element is entered. As an aid to the user, a graphic display of the system with all of the elements identified with alphanumerical tags is always available.

(e) Modifying a Data File using the MODIFY Option: The MODIFY option (unlike the REVISE option) permits any parameter to be altered except those parameters that define the order of interconnection of the mechanical elements. Parameters which can be altered by MODIFY include the element magnitudes, the graphic data and numerical integration parameters. A data tableau of all the elements and their parameters is presented to the user by MODIFY. This tableau is used for an overall comparison of parameters, or as a quick reference to the system situation.

MODIFY exists in both stage I and stage II; however, in stage I it is used mainly for corrections to the system being created. It is in stage II where MODIFY may be accessed at simulation time, and it is this feature which makes DYNIS a truly interactive program, since it permits interruption and alteration at any time during execution. The user can specify a different driver variation, stiffen a spring, increase the magnitude of a mass, or perhaps change a symbol for a better graphic display. Any of these file modifications can be permanently saved for future use.

After modifications are made, the user may continue the simulation at either of two values: the next logical time-step value, or back at time zero. If time zero is requested, provision is made for the user to re-set the initial conditions of the masses; however, it may be convenient to restart at time zero using the present position and velocity conditions of the masses. This would be particularly true for a system that has reached an equilibrium position,because it is now possible to activate forcing functions from an "at rest" attitude. These features are illustrated in Figure 5, which is simplified flow-chart for stages II and III.

5. STAGE III: COMPUTER GRAPHICS OUTPUT

(a) Computer Graphics Packages: Stage III is the graphic output stage of DYNIS. The computer graphics software was adapted in part from the earlier FILMIT program [7] and relies on the basic graphics software repertoire of the Engineering Computing Center at the University of Waterloo. The graphics features of DYNIS can be lumped into four sub-sets or "packages": a perspective package; a display file control package; a replay and film package [10]; and an alphanumeric and menu generation package [9].

(b) Three-Dimensional Symbols: The interface between stage II and stage III establishes a simple method of representing elements so that they appear to be solid in three-dimensions, stretch and contract with the motion, appear fore-shortened in perspective, and require a minimum of line segments to be easily recognized on the graphic display [11]. Basically, a series of two-dimensional symbols are oriented by vector mathematics so that they appear to be three-dimensional in the final view.

A total of eight frequently-encountered symbols was found to be sufficient for simple systems. These include four "line-symbols" that produce a spring, a damper, a vector (arrow), and a simple straight line; three "point-symbols", a circle, a square, and a triangle used for masses and fixed points; and one "force symbol", a large arrow used to represent externally-applied forces. Examples of most of these symbols can be seen in Figures 1 and 2.

6. THE COMPUTER HARDWARE

The computer "hardware" used in this research consists of DEC 340c precision CRT display unit driven by a PDP-9 digital computer with 32 K words of core storage, an RB09 disc, and four DEC tape transports as secondary storage. In addition, a computer-controlled Bolex 16 mm camera is used to record the dynamic sequences.

7. SOME CONCLUDING REMARKS

Although the interactive first stage of DYNIS is still being developed, the VECNET and FILMIT programs which form the second and third stages have been in use for some time [11]. Using these two latter stages, a seven-minute film has been produced, consisting of dynamic sequences of some simple non-linear systems such as double and triple pendulums, and "3-body" and "4-body" gravitational systems [12]. (Figures 1 and 2 are, in fact, frames from this film.)

The development of these interactive techniques are the first of a series of modifications intended to make the vector-network modelling technique into a practical tool for computer-aided mechanical design. The first results, although not conclusive, are certainly encouraging.

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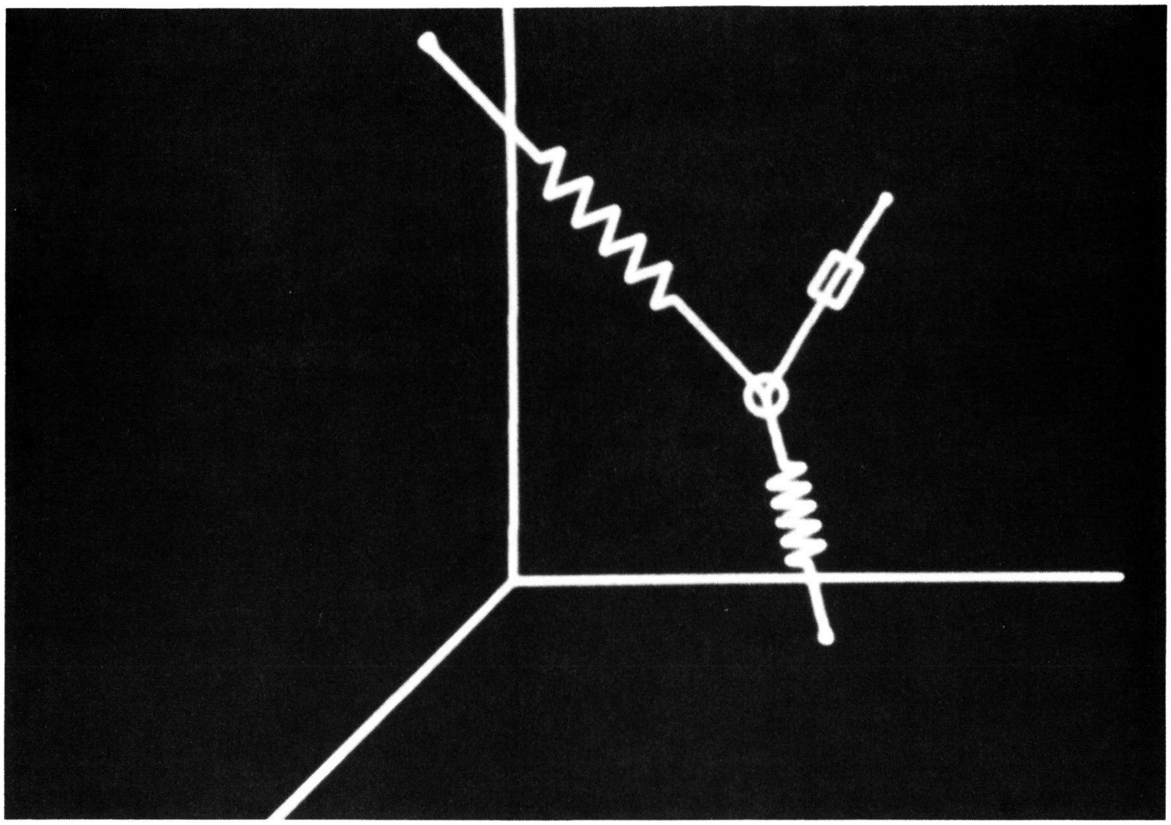

Figure 1: A Simple Three-Dimensional Dynamic Mechanical System as Displayed on the CRT Screen

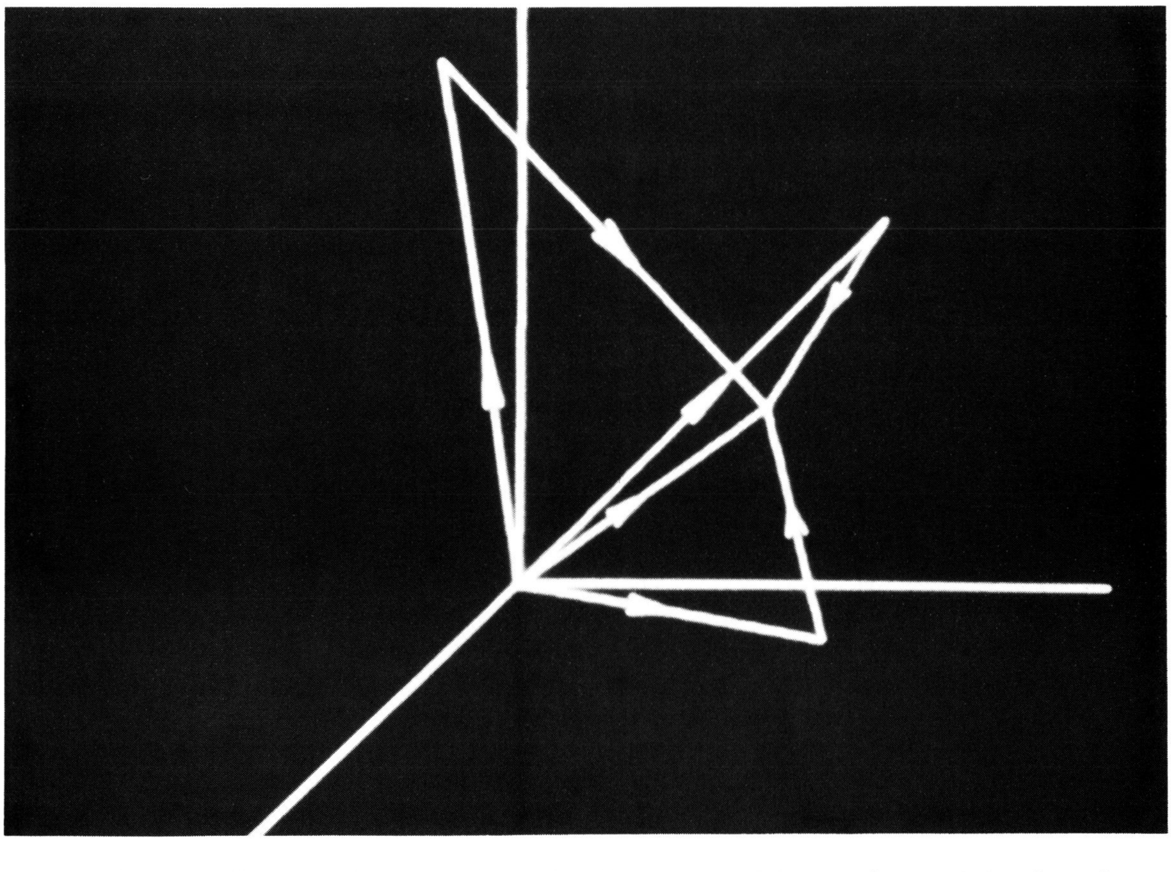

Figure 2: The Vector Network for the System in Figure 1, as Displayed on the CRT Screen

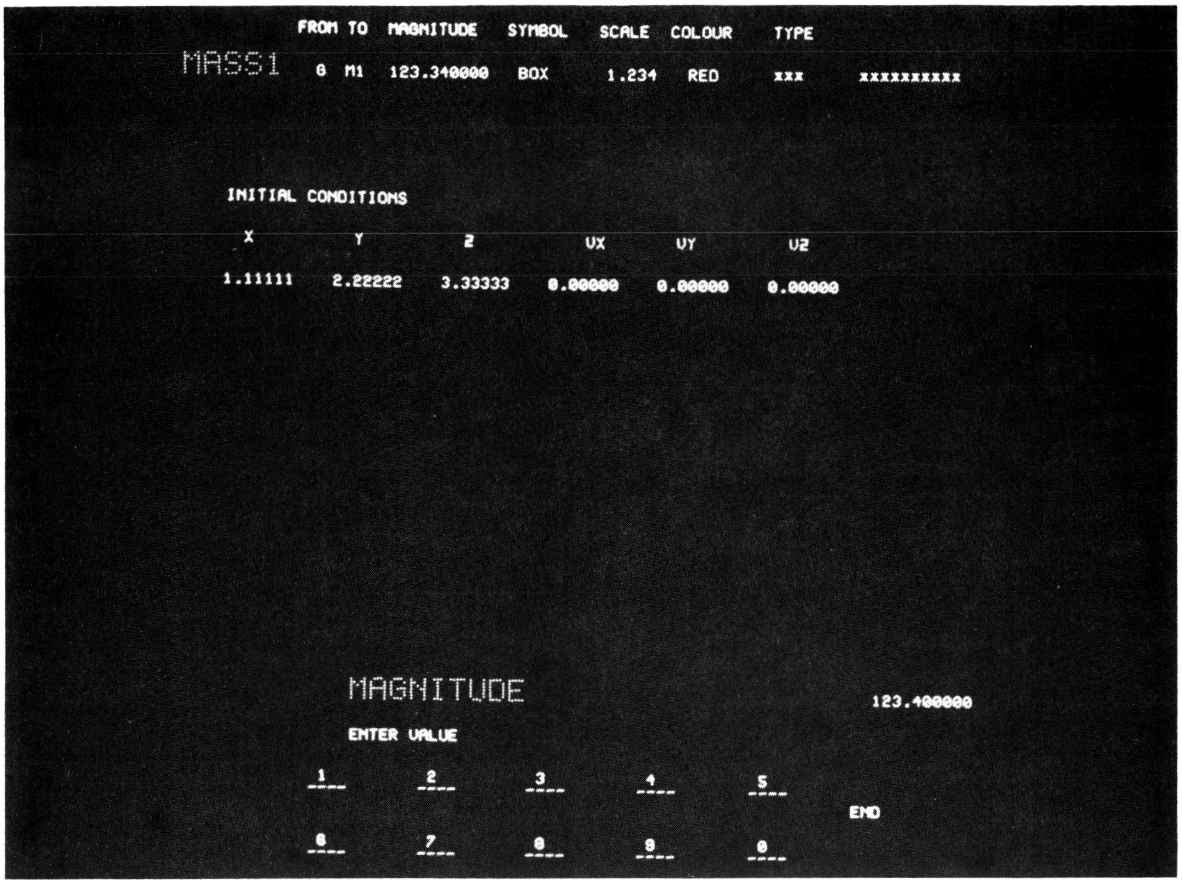

Figure 3: A Sample Menu Used in Stage I of DYNIS

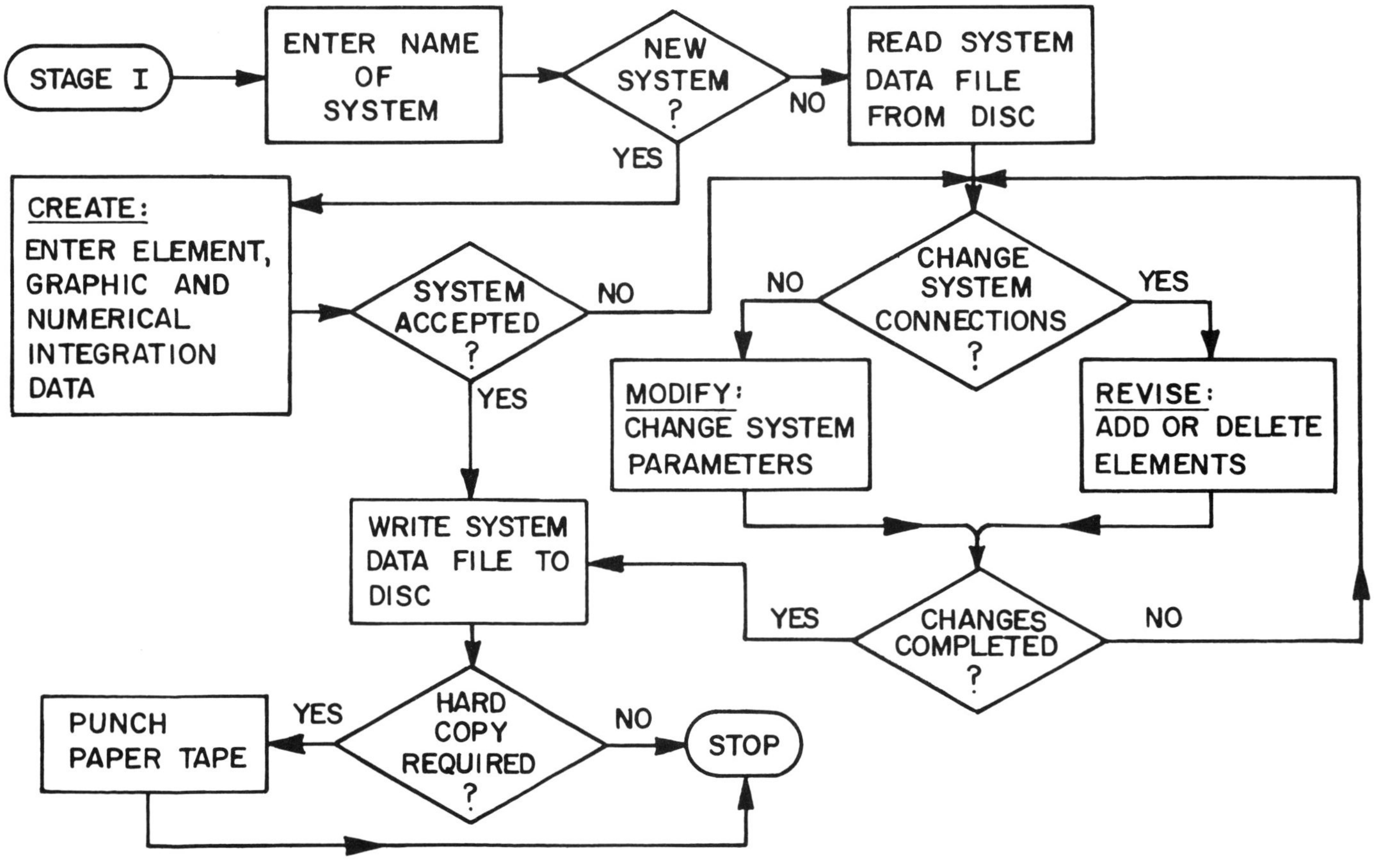

Figure 4: Simplified Flow-Chart of Stage I of DYNIS

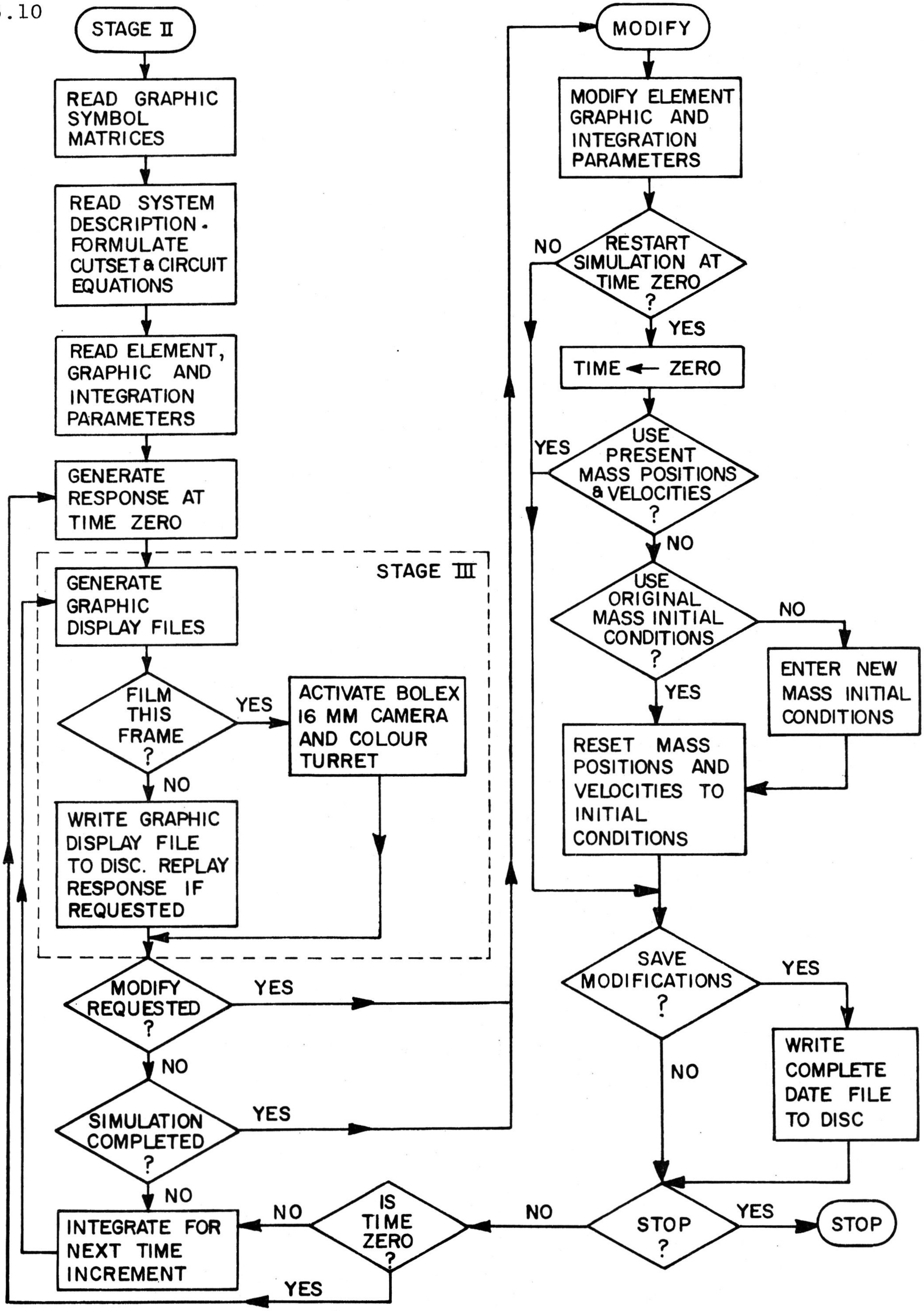

Figure 5: Simplified Flow-Chart of Stages II and III of DYNIS