SUMMARY

This paper presents a short introduction to the computer programs which have been developed to assist in the design and analysis of mechanisms. A survey of the various types of programs which are available is given, and the most widely used programs are compared. The way in which the programs are used is discussed, and demonstrated with an example.

INTRODUCTION

Traditional mechanism design methods, both graphical and analytical, can be very complex and time consuming for all but the most simple mechanism systems. Computer software packages facilitate the automation of the trial-and-error process inherent in the design of mechanisms. Instead of cranking through equations by hand, the mechanism designer or analyst can specify characteristics of the mechanism and use the computer to calculate the kinematic and/or dynamic quantities of interest. Two-dimensional pin and paper models used to visualize the operation of proposed designs can be replaced by two- or three-dimensional dynamic visual models shown on a graphic computer terminal. The effect of design changes can be easily seen, and so the time required to develop the desired mechanism is greatly reduced.

Since the late 1960's, many computer programs for mechanism analysis have been developed. A number of these programs have been developed within particular companies and so are proprietary and not generally available. Other programs have been developed for a very specific application and thus are not very useful for general mechanisms work. There are, however, a handful of general programs which are enjoying widespread industrial use, and are actively marketed and maintained commercially. These programs are the subject of this paper.
Table I presents a summary of the characteristics of several of the most commonly used general-purpose mechanism analysis programs. At present, the programs which appear to be in widest use for general kinematic and dynamic analysis are known as ADAMS (for Automatic Dynamic Analysis of Mechanical Systems), DRAM (Dynamic Response of Articulated Machinery) and IMP (Integrated Mechanisms Program). These and other analysis programs operate on similar, but different, analytic principles, the details of which may be found in Reference (1). Of these programs, only ADAMS and IMP have been implemented for three-dimensional systems. A "two-dimensional" package, however, does not require that all of the links of the mechanism being designed must be contained completely in a single plane, but rather that all motions of the mechanism take place in parallel planes. For a large number of mechanisms, this is not a serious restriction, and the two-dimensional formulation provides advantages in computing speed and model simplicity.

ADAMS, IMP, and DRAM are used for the analysis of a mechanical system which has already been designed. These programs are distinctly different from packages which have been developed to assist in the synthesis of mechanisms. Table II compares three of these programs, KINSYN (Kinematic Synthesis), LINCAGES (Linkage Interactive Computer Analysis and Graphically Enhanced Synthesis Package), and MECSYN (Mechanism Synthesis). These programs provide the designer with a "family" of possible solutions to a design problem involving mechanisms which may be modeled as four-bar linkages (pin and slider-jointed planar mechanisms). They do not, however, lend themselves to more general mechanism systems.

Table III is provided as a summary of other more specialized mechanism programs. While these types of programs may be very useful for particular types of analyses, they do not lend themselves to more general mechanism systems. This paper will discuss the most widely used programs, ADAMS, IMP and DRAM, in more detail.

In comparing mechanisms programs, one should first attempt to determine for what types of problems the program selected will eventually be used. A three-dimensional program may be necessary for some applications, but a two-dimensional analysis may be sufficient for a wide class of problems. Of course, it is important to determine whether the intended use is one of design analysis or design synthesis, since both types are available.
Beyond distinctions in type, there are other more subtle differences. The most general programs, IMP and ADAMS, offer certain advantages. IMP is less expensive, but ADAMS appears to be more powerful, especially with respect to graphic capabilities. IMP is particularly good in detecting "lock-up" configurations. Both offer a similar menu of joints which may be used to connect the system components. The languages used in IMP and ADAMS to input the geometry of the model are similar. In contrast, programs such as DYMAC use standard computer languages (e.g., FORTRAN).

A major difference in the way these programs operate is that IMP is formulated to analyze systems composed of linkages comprising "closed" kinematic loops, while ADAMS permits open loops. Dummy loops, with masses and stiffnesses equal to zero, may be used in IMP to connect free links to ground. For some types of analyses, the use of dummy loops may not be desirable because of the resulting increases in model complexity and computing time. For aerospace applications, the requirement that all components be connected to ground is particularly inconvenient.

DRAM is similar to ADAMS, mainly because these two programs were developed by the same people. DRAM is two dimensional, however, and so has considerably greater computing speed. It is also a good deal less expensive. A unique feature of DRAM is its generalized impact modeling capability.

PROGRAM USAGE

ADAMS, IMP and DRAM rely heavily on interactive graphics for presenting the results of the design session. In using programs such as these, however, it is first necessary to model the system geometry using alphanumeric program statements. This geometry is not the physical geometry of the system, but rather the kinematic geometry. The distinction is that many details of the physical geometry may be unrelated to the way the mechanism behaves kinematically. The kinematic "shape" of a linkage is defined by the points at which it is connected to other system elements and by its inertial properties. The actual physical shape of the linkage is unimportant unless the shape would cause a condition such as interference.

In addition to describing the kinematic geometry, specification of the forces and constraints which act on the system is necessary to complete the system model. This includes the types of joints which connect the system components, spring stiffnesses, damping constants, and externally applied forces and torques. A wide variety of joints may be used to connect the system components. For example, ADAMS allows the following types of connections: ball joints, U-joints, revolute (pinned) joints, translational contact, cylindrical joints, gear contact, screw joints, flat sliders, and rack-and-pinion gears. IMP offers a similar menu of joints.
Since DRAM is two-dimensional, it is limited to translational and rotational contacts. Cam-and-follower-type contact is not currently available in any of the programs; however, this and other special situations may be simulated with user-written subroutines.

Forces and torques may be input as constants or as "conditional" values which only act under certain conditions. In this way, it is possible to model compliant members or simulate impact by specifying that certain forces act only when specific members are within a certain distance of each other.

The development of the system model and entering it into the computer comprises most of the work required to use the programs. The language used to describe the model is "user oriented," in that familiar terms are used to describe the system. For example, the ADAMS statement:

```
JOINT/3, REVOLUTE, I = 21, J = 14
```

defines a rotational joint, numbered 3, which connects previously defined points numbered 21 and 14. By using familiar terms such as this, it is intended to minimize the amount of computer programming experience which is required by the user. Once the system geometry is described, the program user is required to enter the initial conditions (displacements, velocities, etc.) for the mechanism, and define the time interval over which the analysis is to be performed. When the system has been fully described, the designer may run the program.

After the program has been run, the user may request a wide variety of graphical and alphanumeric outputs. The most descriptive output feature for kinematics is the computer graphics which is available; however, it will be shown that many other types of useful results can be obtained.

**EXAMPLE**

As an example of computer-aided mechanism analysis, consider the automobile suspension shown (without its tire or the automobile frame) in Figure 1. An ADAMS model of the suspension was created to examine the kinematic and dynamic properties of the suspension. The model consisted of five major parts with twelve degrees of freedom. Compliance effects were included by modeling the tire stiffness and damping effects, and two mechanical stops, four bushings, a spring and a shock absorber. Also included in the model were three ball joints, one universal joint and rack-and-pinion steering. Figure 2 depicts the computer graphics model created for this suspension. The graphics serve two purposes: verification of the correctness of the input model, and easier interpretation of the simulation results. By combining suspension models with a rigid body model of a truck body, it is possible to model the total vehicle, as depicted in Figure 3. Using the computer graphics model, it is possible to determine the response of the total vehicle without ever building a prototype.
The graphic output may be manipulated in a number of ways. The
graphic model shown at various times may be superimposed on one view as
in Figure 3, or each interval of time may be viewed individually. The
view may be rotated, or zoomed in or out. It is also possible to show
three orthographic views, either at individual time increments, or super-
imposed. This is demonstrated in Figure 4 with a robot arm. By using
cameras which are computer controlled to take pictures of the graphics
display at each time increment ("frame-by-frame"), it is possible to
produce motion pictures which allow the response of the system to be viewed
continuously throughout the time increment analyzed. This type of motion
picture will be demonstrated at the symposium. Recently, new technology
in computer graphics has made it possible to produce a similar graphic
display directly on the computer terminal.

While graphic results are the most striking feature of these programs,
other types of useful information may be obtained. The user may request
plots or tabular listings of forces, displacement, velocities or acceler-
ations as functions of time. An example of a plot produced by the IMP
program is shown in Figure 5. These programs may also be asked to compute
relative velocities, torques, static equilibrium positions, natural
frequencies and the like. That these programs may be used with an alpha-
umeric terminal is an important economic consideration, since the cost of
one of these terminals is quite a bit less than that of a graphics terminal.

While the example discussed previously is from the automotive
industry, the use of mechanism analysis programs in aerospace applications
is particularly advantageous since the analyst is able to simulate con-
ditions of zero gravity. Since one can "turn off" gravity effects,
simulations of mechanical systems which could not be tested on the ground
can be performed. The programs have been used to analyze the performance
of numerous aerospace systems such as landing gears, ailerons, airplane
doors and deployable booms. The interactive nature of the programs allows
the designer to quickly determine if a candidate design is able to fulfill
the requirements of the desired mechanism. The kinematic properties of
the system are clearly seen and the effect of design changes are immed-
ately evident. Consequently, the time required to design a mechanism is
reduced and the number of options which may be examined is greatly increased.

CONCLUSIONS

An introduction to the types of programs which are available has
been given and some quick comparisons of the most widely used have been
made. It has been shown that ADAMS, IMP, and DRAM are the most complete
programs for mechanism work, and offer a comparatively wide range of
analysis capabilities. Each of the programs offers certain advantages to
the user, depending on the type of mechanism to be designed or analyzed.
For more details on the programs, the reader is directed to References 1
through 15.
<table>
<thead>
<tr>
<th>TABLE I</th>
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<tr>
<td><strong>GENERAL ANALYSIS PROGRAMS</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimensionality</th>
<th>ADAMS</th>
<th>DRAM</th>
<th>DYNAM</th>
<th>IMP</th>
<th>UCIN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capability</strong></td>
<td>3-D</td>
<td>2-D</td>
<td>2-D</td>
<td>3-D</td>
<td>3-D</td>
</tr>
<tr>
<td><strong>Available from</strong></td>
<td>Mechanical Dynamics, Inc., Ann Arbor, MI</td>
<td>Mechanical Dynamics, Inc., Ann Arbor, MI</td>
<td>B. Paul, U. of Penn. Phil., PA</td>
<td>Structural Univ. of Cincinnati Dynamics Research Corp. Milford, OH</td>
<td></td>
</tr>
<tr>
<td><strong>Graphics</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Availability</strong></td>
<td>Time-share or lease</td>
<td>Time-share, lease or purchase</td>
<td>Purchase</td>
<td>Time-share, lease or purchase</td>
<td></td>
</tr>
</tbody>
</table>

*See text*
<table>
<thead>
<tr>
<th></th>
<th>KINSYN</th>
<th>LINCAGES</th>
<th>MECSYN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensionality</td>
<td>2-D</td>
<td>2-D</td>
<td>2-D</td>
</tr>
<tr>
<td>Capability</td>
<td>Kinematics design synthesis</td>
<td>Kinematics design synthesis</td>
<td>Kinematics design synthesis, dynamics</td>
</tr>
<tr>
<td>Available from</td>
<td>Prof. Kaufman, George Washington, Washington, DC</td>
<td>Prof. Erdman, University of Minnesota, Minneapolis, Minneapolis</td>
<td>Prof. Myklebust, Florida Atlantic University, Boca Raton, Florida</td>
</tr>
<tr>
<td>Graphics</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Availability</td>
<td>Time-share (available Spring 1982) or purchase</td>
<td>Time-share or purchase</td>
<td>Purchase or time-share</td>
</tr>
<tr>
<td>Features</td>
<td>Interactive, small version to run on Apple computer being developed. Will handle 4-, 6- or 8-bar mechanisms</td>
<td>Interactive Device independence</td>
<td>Interactive Ringed data structure Can specify time-dependent properties 4-, 6- or 8-bar mechanisms</td>
</tr>
<tr>
<td>Limitations</td>
<td>No dynamics</td>
<td>No dynamics</td>
<td>Cannot display mechanism itself</td>
</tr>
</tbody>
</table>
### TABLE III

**SPECIALIZED MECHANISM PROGRAMS**

<table>
<thead>
<tr>
<th>PROGRAM NAME</th>
<th>APPLICATION</th>
<th>DEVELOPER AND/OR AVAILABLE FROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFL</td>
<td>Static force analysis of four-bar linkage system</td>
<td>Structural Dynamics Research Corp., Cincinnati, Ohio</td>
</tr>
<tr>
<td>CAMDES</td>
<td>Design of disk cams</td>
<td>K. W. Chase, Brigham Young Univ., Provo, Utah</td>
</tr>
<tr>
<td>CAMDYN</td>
<td>Design of plate cams</td>
<td>B. Paul, University of Penn., Philadelphia, PA</td>
</tr>
<tr>
<td>CAMPAC</td>
<td>Synthesis, analysis, and design of cams</td>
<td>Prof. D. Tesar, Univ. of Florida, Gainesville, Florida</td>
</tr>
<tr>
<td>COMMENT I</td>
<td>Generalized mechanical design system with linkage cam, gear, spring, shaft and timing-belt design programs</td>
<td>IBM Systems, Development Division, Rochester, MN</td>
</tr>
<tr>
<td>DYREC</td>
<td>Dynamic analysis of reciprocating machines with multiple sliders</td>
<td>Prof. B. Paul, University of Penn., Philadelphia, PA</td>
</tr>
<tr>
<td>FLYLOOP</td>
<td>Flywheel design</td>
<td>Prof. B. Paul, University of Penn., Philadelphia, PA</td>
</tr>
<tr>
<td>FORBAR</td>
<td>Kinematic and dynamic analysis of four-bar linkage systems</td>
<td>Structural Dynamics Research Corp., Cincinnati, Ohio</td>
</tr>
<tr>
<td>GODAS</td>
<td>Design of parallel axis gears</td>
<td>D. Hughson, Ford Motor Co., Dearborn, Michigan</td>
</tr>
<tr>
<td>IMAGE</td>
<td>Design and analysis of planar mechanisms</td>
<td>Reed and Garrett, University of Texas, Austin, Texas</td>
</tr>
<tr>
<td>ISD-FORSS</td>
<td>Force system structural synthesis of four-bar mechanism</td>
<td>Prof. Carson, University of Missouri-Columbia, Columbia, MO</td>
</tr>
<tr>
<td>KINAL</td>
<td>Kinematic analysis of planar multiple-loop mechanisms</td>
<td>Prof. B. Paul, University of Penn., Philadelphia, PA</td>
</tr>
<tr>
<td>SLIDER</td>
<td>Static and dynamic analysis of slider crank systems</td>
<td>Structural Dynamics Research Corp., Cincinnati, Ohio</td>
</tr>
<tr>
<td>STATMAC</td>
<td>Static analysis of planar machines</td>
<td>Prof. B. Paul, University of Penn., Philadelphia, PA</td>
</tr>
</tbody>
</table>

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FIGURE 1 - SCHEMATIC OF AUTOMOBILE SUSPENSION
(WHEEL AND TIRE NOT SHOWN)

FIGURE 2 - ADAMS GRAPHICS MODEL OF SUSPENSION

BUSHINGS
TIE ROD
LOWER CONTROL ARM
SHOCK/SPRING

UPPER CONTROL ARM

BUMP INPUT
FIGURE 3 - TOTAL VEHICLE SIMULATION

FIGURE 4 - SUPERIMPOSED ORTHOGRAPHIC VIEWS OF A ROBOT ARM
FIGURE 5 - IMP FORCE PLOT
REFERENCES


Mr. Knight joined The Aerospace Corporation in 1979 as a member of the Technical Staff in the Vehicle Engineering Division. He received his B.S. and Master of Engineering degrees from the University of South Carolina and is currently pursuing a Doctorate in Mechanical Engineering at the University of Southern California.