# COMPUTER STORAGE OF TERRAIN BOARD DATA

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An objective of the CAL Off-Road Mobility Research program was to develop analytical and experimental tools for the prediction of the mobility performance of an off-road vehicle system. This system encompasses the vehicle, driver, and environment. Specifically, the objective of the Human Factors Task of the program was to develop techniques to analyze driver-vehicle problems related to off-road mobility. One of the tools under development within the program was a man-in-the-loop driving simulator with which the driver performance in an existing or postulated vehicle could be examined in the laboratory without resorting to extensive field testing.

The simulator configuration is shown in figure 1. It consists of a three-degree-of-freedom motion platform on which the "driver" sits, a television virtual image display system, and a scale model terrain board, and a servo-driven television camera which generates the television display. The motion of the platform is determined by the responses of the driver, the vehicle characteristics, and the terrain. These three components are inputs to the vehicle dynamics model (developed in another phase of the program) which computes the correct motion input signals for the motion platform and television camera servo-drives.

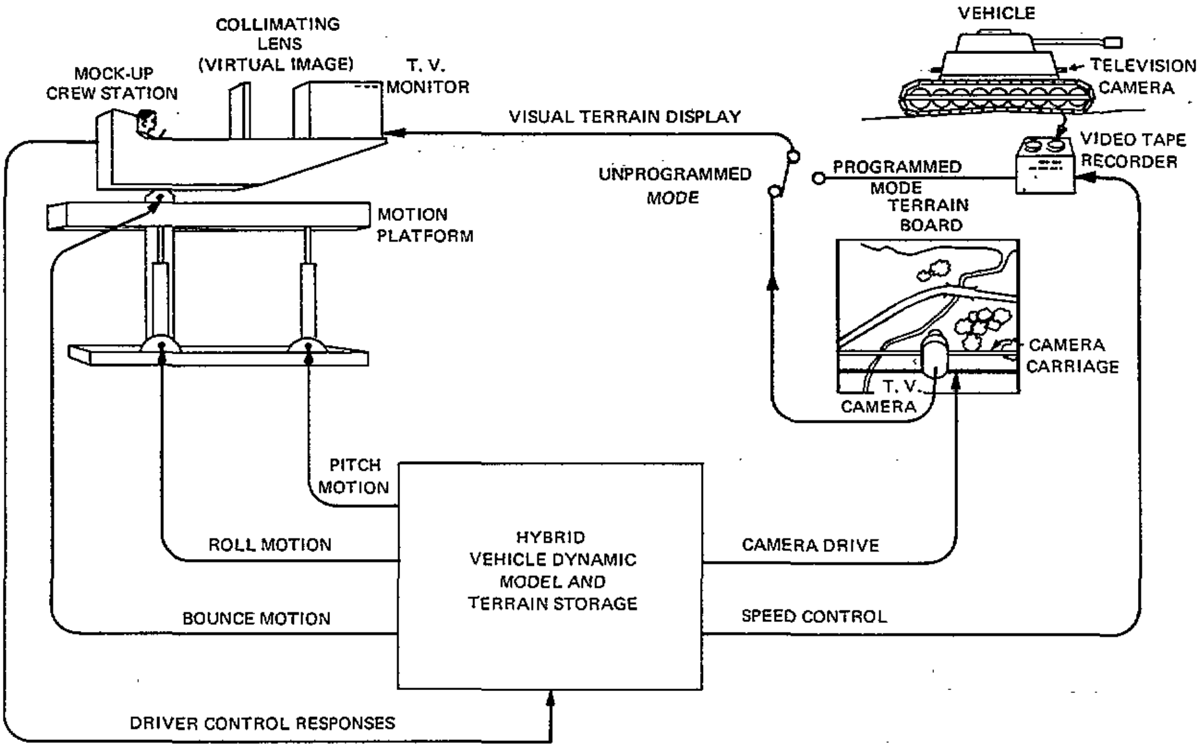


Figure 1. Off-Road Driving Simulator. Conceptual Sketch for a Moving-Base Simulator With Programmed and Unprogrammed Visual Display Capabilities

The unprogrammed mode allows the driver to choose any path along the model terrain. In the programmed mode the visual display and motion signals may be stored from motion sensors and a video tape recorder, or motion picture camera mounted on an actual vehicle.

By using video presentation in all modes of operation, the display may be derived from a wide variety of sources (including computer-generated displays) using fully compatible equipment. In this paper, we are considering the first mode, which is the unprogrammed terrain board system. The unique element of the conceptual design of the simulator is the use of a digital computer to store complex information about the terrain to be traversed, and yet allow a real-time retrieval of the information.

One of the important functions to be carried out during a simulation is to supply terrain information to the vehicle dynamics model. For aircraft simulators the terrain is typically a landing field, so that terrain sensing is simply a matter of determining whether the aircraft is on the ground or not. When not on the ground, the altitude and attitude are determined mathematically without reference to the terrain board.

The situation is much more complicated with ground vehicles where the height, roll, and pitch are determined primarily by the height of the terrain under each wheel or track. Modification of this information takes place by considering such factors as suspension characteristics and speed. Because a research simulator must be compatible with a wide variety of vehicles, it is necessary to have a terrain-sensing capability which can accommodate different numbers of wheels, different wheel bases, tracked vehicles, articulated vehicles, as well as novel running gear designs.

Typically, existing surface-vehicle terrain-board simulators derive information about the terrain by means of a scale model of the running gear apparatus. The model rides in contact with the board and transduces the vertical motions into electrical signals. Contacting sensors have the following disadvantages:

1. They must be scaled to the characteristics of the vehicle being simulated hence must undergo extensive change or replacement for each vehicle.

2. Being physical objects, they interfere with the television optics. This is particularly a problem if the forward-most running gear is well in front of the driver.

3. They may snag on certain terrain features.

4. They may mar the terrain board.

5. The sensitivity of these sensors for small elevation changes is limited by their response characteristics and by the detail included on the terrain board.

It was because of these inherent limitations that we felt that it was necessary to consider alternative techniques. Some of the disadvantages of contacting sensors are eliminated by using noncontacting sensors. Such sensors would be ultrasonic or capacitance probes and air pressure devices that measure the resistance to a stream of air. Other possibilities exist, but all of these suffer the disadvantages that a great deal of development would be necessary to apply a noncontacting sensor technique to terrain board use.

The technique that looks most promising in terms of the least amount of development time and most versatility involves the storage of elevation information in a high-speed digital computer. A preliminary study of such a technique has been made and can be described as follows:

The terrain board would be represented as a matrix of cells, each cell being equivalent to a square, ten inches on a side in the full scale world. For a scale factor of 1:100 and a 20 x 40 foot terrain board, this amounts to $11.52 \times 10^6$ cells. The average height of the terrain represented in each cell would be stored in the computer to a resolution of $\pm$ 1 inch (full scale). The storage requirements for this information are well within the capacity of one disk pack (e.g., IBM 2314). Along with each piece of elevation data, one could also store a code number which would represent a measure of friction and/or bumpiness. The code would be used to specify the parameters of random distributions of small bumps which could not be physically included on the surface of the terrain board. These small bumps would be computer generated and superimposed on the stored terrain heights.

In operation, the x, y coordinates of each running gear elements are computed so that the appropriate elevation and code may be read out from storage. Although the terrain elevation would be digitized, interpolations may be computed at a rate compatible with the operation of the vehicle in a real-time simulation. Smoothing functions could be carried out in an analog computer. Traction information would be entered into the vehicle dynamics model in order to accurately compute the response of the vehicle.

A method (see appendix 1) has been devised in which only a small portion of the terrain data is required in the computer's high-speed core at any one time. It is economical for computer use, and has a reasonable data transfer rate requirement. The advantages of digital computer storage are several: Many functions can be carried out with great speed (such as random bumpiness generation); the computer can be used to provide collision protection for the optical probe; no contact with the terrain board is required; the x, y coordinates of each running gear element may be computed for any vehicle by making simple software changes; and the codes used to generate arbitrary terrain conditions may be easily changed from one trial to another.

The major disadvantages of this scheme is the initial storage of the terrain information. It was concluded that the best way to accomplish this storage is to construct the terrain board without features such as trees. A contacting probe would then be mounted on the gantry in place of the television camera. The gantry would automatically run across the board and perhaps enter the elevation information in analog form on tape followed by A-D conversion, or directly into digital form by automatic sampling of the probe. Next, the trees, etc. would be added. This requires updating the elevation storage by specifying the areas taken up by the new obstacles. This updating is not seen as a particularly difficult task.

There is an alternative scheme which may be possible for use in training simulators where the running gear specification requirements are less demanding. This scheme would use a modified computer storage technique along with elevation sensors (either contacting or noncontacting). Two sensors would ride at the front of the optical pickup (one for each side of the simulated vehicle), and enter their signals into temporary storage. Then for the calculated position of each element of the simulated running gear the elevation at those points would be recalled and entered into the vehicle dynamics model. After the vehicle has passed a point, the stored information for that point may be erased. The assumption is made that all the running gear elements along one side of the vehicle follow the same path. The implications of this assumption must be considered for each vehicle to be simulated. This concept is advantageous when any of the following conditions exist:

1. The computer storage capacity is limited.
2. Only one running gear configuration is to be used.
3. The x, y coordinates of the television camera cannot be read out with sufficient accuracy.

If the x, y coordinates of the camera can be read out, then codes may be used, as before, to represent terrain areas of certain characteristics (e.g., bumpiness and friction), and to generate "STOP" signals for crash protection.

Because this modified elevation storage concept greatly reduces the amount of information to be stored and the number and complexity of computations to be carried out, it is particularly attractive for use in training simulators (as opposed to the more elaborate scheme suggested for the off-road driving research simulator). The chief problem, however, would still be to develop a suitable terrain sensor.

# APPENDIX 1

## Disk Storage and Retrieval of Terrain Data

1. Assumptions:

Area covered is at least 4000x 4000 feet (full scale)
Sampling interval: 10 inches
Altitude least count: 1 inch
Maximum altitude change within any 50 ft horizontal distance: 21 feet
Surface traction data representable by a 4-bit (= 16 Value) code
Local bumpiness data representable by a 4-bit (= 16 Value) code
IBM-2314 Disc Pack used as storage. Some multi-programming system such as OS-360 used in central computer.

2. Data Storage Technique:

Altitudes: Each sample altitude stored as an 8-bit increment, least count 1 inch, above a local datum. Datum changes are possible every 50 horizontal feet.

Traction and local bumpiness data each stored as a 4-bit code. Total storage required per sample: 16 bits = 2 bytes.

Data organized into local rectangular arrays of 60 x 60 samples, corresponding to 50 ft x 50 ft full-scale region. Together with identification, control, and local altitude datum, this packs neatly into one track of a 2314 disc.

System capacity is thus equal to the number of tracks on a 2314 disc pack (2000), multiplied by 2500 $ft^2$, which is $10^7$ $ft^2$.

### 3. Data Retrieval

The program is organized to keep in the main core storage at all time 9 of the local data arrays, corresponding to the array containing the vehicle center of mass and its 8 nearest neighbors. As soon as the vehicle center of mass moves to an adjacent local array, three of the presently-in-core arrays are replaced by the three new ones required to maintain this condition. A conservative estimate of the time to position the disc heads and read the data is 75 milliseconds per array or a total of .225 seconds for the three local arrays. This means we can guarantee to keep up with any vehicle whose speed is less than 223 ft/sec. In practice, of course, the required data transfer rate is much lower, and represents a negligible load on the data channel of an IBM-360.

Core storage required is that for the 9 local arrays, about 65,000 bytes, plus processing programs, etc. A reasonable estimate, even if very elaborate processing is required, is 90,000 bytes total, well within the capacity of any IBM-360 likely to have a 2314 disc as peripheral equipment.

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