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Apollo Water Impact

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Abstract

This report describes (a) the status of the computer program being developed to simulate the impact of a right circular cylinder on a smooth water surface and (b) the experimental equipment and methods.

APOLLO WATER IMPACT

Introduction

Hydrodynamic impact has been simulated by impacting a stationary, rigid, right circular projectile with a viscous incompressible fluid initially at velocity V_o. The initial velocity of the fluid corresponded to the impact velocity of the falling projectile. A diagram of the simulated physical model prior to the instant of impact is shown in Figure 1.

This problem has been attacked numerically using the original Marker-And-Cell (MAC) code with the addition of a moving coordinate system. The MAC method was developed by Harlow and Welch (1, 2, 3) of Los Alamos Scientific Laboratory for studying transient fluid-flow problems involving free surfaces. The large number of details concerning its use can be found in the literature cited. Basically, the MAC method applies the finite difference form of the complete Navier-Stokes equations to the moving fluid and keeps track of the free surface by moving about massless fluid markers in accordance with average local velocities. Pressures are obtained from velocity initial conditions using an implicit technique. Using these pressures and velocities, the momentum equations are integrated explicitly yielding new velocities which are used to move the markers and to calculate pressures for the next time event. Results of the MAC simulation contain pressure and velocity distributions beneath the projectile as well as a graphical representation of the deformed free surface.

Application to a Right Circular Cylinder

The computational grid system is shown in Figure 1. Many problems were encountered with the original MAC method during the course of this period. Computer results obtained using this method were more often than not physically impossible, such as, negative pressure fields, unrealistic velocity distributions, and a linear dependence upon time step. These poor results are brought about by the fact that the original MAC method does not reliably maintain continuity.

Several modifications have been made to the original MAC method of solution in order to obtain results which are of the same order as those obtained experimentally. The most important modification is consistently ensuring that continuity is being maintained throughout the fluid. An implicit method of solving for velocities has been included to make sure that the velocity field is compatible with the pressure field and at the same time ensure continuity. A brief general flow diagram outlining the computational procedure is shown in Figure 2. This procedure can be termed an implicit-implicit procedure due to the implicit calculation of both pressures and vleocities.

With this scheme, pressures and velocities have been obtained and a valid range of time steps established. Typical plots of projectile deceleration $\frac{dV_p}{dt}$ versus time for various time steps are shown in Figure 3. Time steps larger than those shown cause the implicit-implicit scheme to diverge. If the time step is much smaller than that shown in Figure 3, no advantage is gained because of the length of computer time required to obtain a solution. Any time step chosen within the acceptable range is too small to allow the markers to be moved a visible distance within a reasonable amount of computer time.

Several extensions to the previously described implicit method of solution are presently being considered. The first of these is being implemented at this time. These extensions are:

1) Calculate pressures and velocities implicitly for the first several time cycles until the pressure and velocity fields are sufficiently developed. The exact number of time cycles is yet to be determined. Change from the implicit method of calculating velocities to an explicit method. Experiments with the MAC method have shown that the explicit method of solution allows the use of larger time steps and thus larger marker displacements. The ability to use larger time steps makes larger time events more economically feasible.

2) Include air in the computational region to the side of and several radii beneath the right circular cylinder. The initial distance between the falling cylinder and the quiescent water surface depends upon the characteristics of the velocity and pressure fields and is yet to be determined. Assuming the air to be incompressible for the very low entry velocities studied, the implicit-explicit scheme described above will be used to evaluate pressures and velocities for air and water as separate fluids. The addition of air allows the free surface to deform before impact. The deformed free surface will theoretically verify the "colliseum effect" often noted in pressure distributions measured experimentally.

3) Follow the same procedure as in extension (2), except assume air to be compressible even for low impact velocities. With this assumption density becomes a variable which must be evaluated during the implicit solution of the pressure field. If the procedure outlined in extension (2)

yields results with engineering tolerances, extension (3) will not be necessary.

Development of a Parallel Program in Cartesian Coordinates

In June 1969, development was initiated on a computer program which applies the Marker and Cell technique in Cartesian coordinates. The analytical theory and numerical technique involved are essentially the same as in the cylindrical case, the major exception being that a stationary rather than moving coordinate system is used. The purpose of this parallel program are:

1) To simulate the dropping of a "block" of water on a smooth free surface in order to generate traveling surface waves.

2) To serve as a basic program which can be modified to simulate oblique impact of a vehicle on a free surface wave.

3) To serve as a basic program which can be modified readily to experiment with different variations of the Marker and Cell technique.

Initial values of pressures and velocities must be known throughout the fluid body before impact in order to carry out the present impact studies. Since such parameters are not known for surface waves, it is necessary to generate the surface waves artificially and hence, compute the required parameters by following through the process with this computer program.

The assumption of axial symmetry in the program dealing with cylindrical coordinates precludes the investigation of oblique impact, whereas the use of two-diemnsional Cartesian coordinates makes such investigations possible without undue difficulties.

The non-constant control volumes of cells of constant geometric increments in cylindrical coordinates often magnify and complicate errors resulting from using different numerical techniques. Control volumes do not vary with position in Cartesian coordinates, so that a program utilizing such coordinates is much more suited to experimentation.

To date, the program has been developed to a point where surface waves are formed and pressure and velocity values are computed, but problems of stability of such solutions still have to be dealt with. It is anticipated, however, that such stability problems are common to all the phases of the present numerical investigation, and that once such problems are solved for the generation of waves, the same technique can be applied to the other phases such as oblique impact.

Experimental Work

A large lucite tank has been constructed and initial experiments performed to find suitable plastic particles. High speed color movie photographs have been taken of the motion of these particles when a spherical projectile is impacted vertically on the water surface. These are being examined frame by frame with a view to obtaining a time history of their velocity and acceleration. Attention has now been turned to the hydrodynamic impact of a circular cylinder.

Nomenclature

αR_p = radius of computing system (no. of radii)

βR_p = height of computing system (no. of radii)

γR_p = length of projectile (no. of radii)

R,Z = cylindrical coordinates

t = time

ρ = density of liquid

μ = dynamic viscosity of liquid

V_o = initial impact velocity (axisymmetric)

V_p = velocity of projectile

$\frac{dV_p}{dt}$ = deceleration of projectile

A = impact area of projectile

P = pressure

u = radial component of fluid velocity

v = axial component of fluid velocity

$\vec{W}$ = velocity vector

$\nabla \cdot \vec{W} = 0$ = divergence of velocity

$\nabla^2 = \frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{\partial^2}{\partial z^2}$ = Laplacian operator

$\frac{D}{Dt} = \frac{\partial}{\partial t} + u\frac{\partial}{\partial r} + v\frac{\partial}{\partial z}$ = material derivative

References

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2. Welch, J. Eddie, Harlow, Francis H., et al., The MAC Method, A Computing Technique for Solving Viscous, Incompressible, Transient Fluid-Flow Problems Involving Free Surfaces, LA-3425, UC-32, Mathematics and Computers, TID-4500, March 1966.

3. Harlow, Francis H. and Welch, J. Eddie, "Numerical Study of Large-Amplitude Free Surface Motions," The Physics of Fluids, Vol. 9, No. 5, pp. 842-851, May 1966.

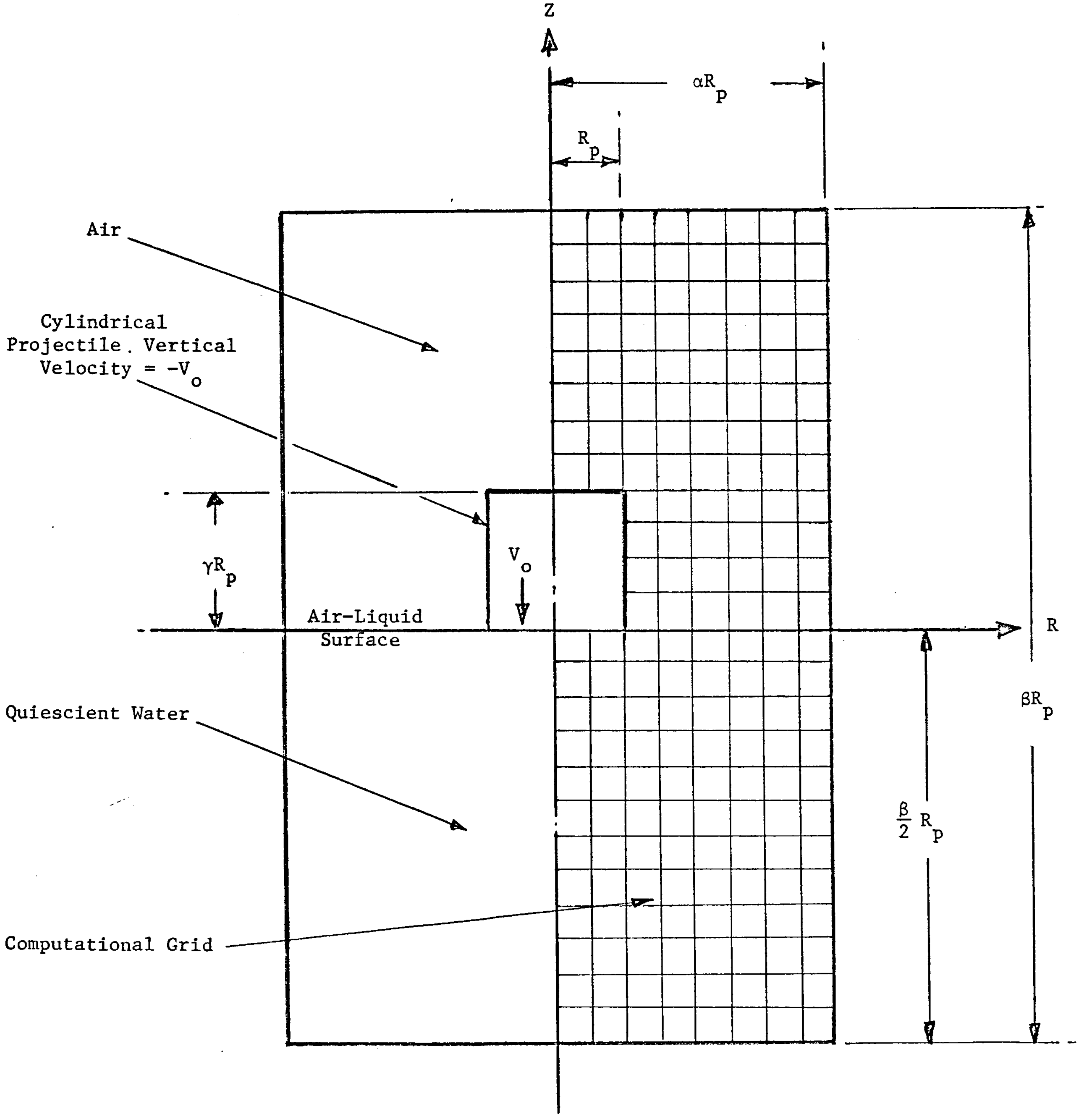

Figure 1. Diagram of Model and Computational Grid Assuming Axial Symmetry

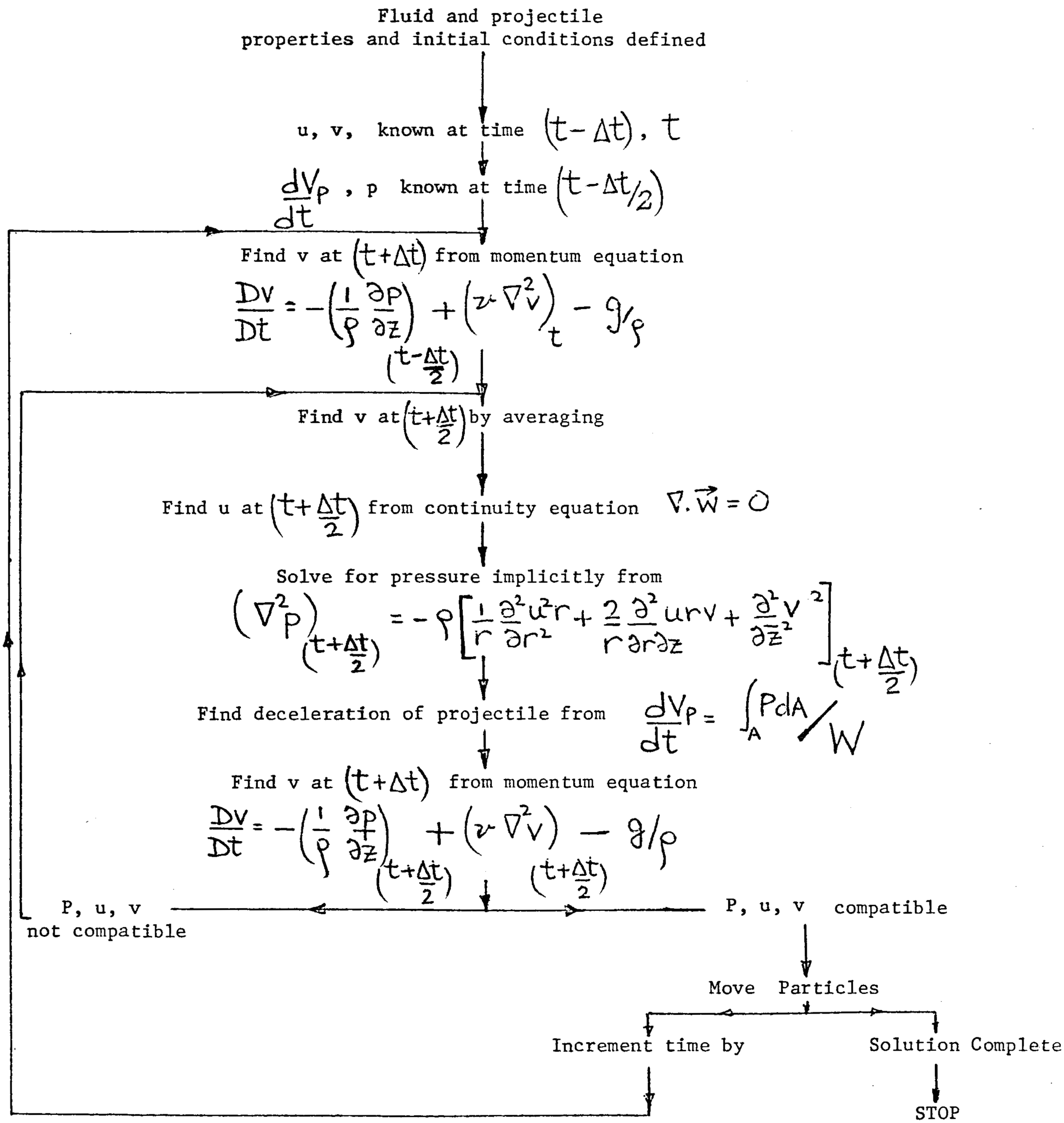

Figure 2. Brief Outline of Computational Procedure

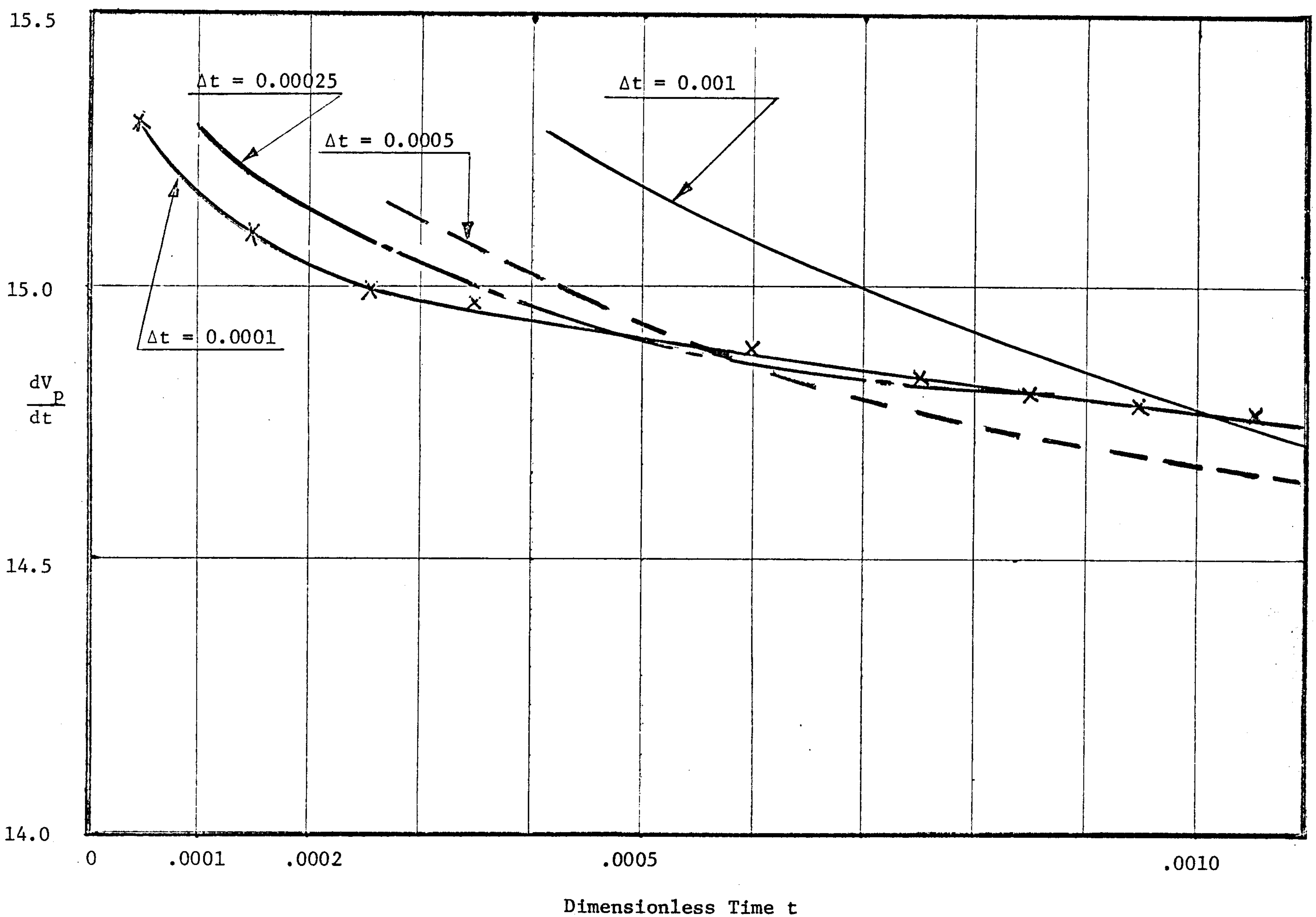

Figure 3. Deceleration of Projectile