scope of this series, but time varying voltage analogues of acceleration are fairly easy to generate on the computer.

The drag on a body moving through air or a fluid conforms to an exponential law, and is proportional to velocity when there is little or no turbulence. Viscous friction should not be confused with the friction resulting from solid surfaces in contact, as the latter is independent of velocity except at very low speeds. A general solution to an equation which describes the motion of an object through a viscous medium—where composite velocities are involved—is often unwieldy and can demand extensive calculations.

However, an exponential decay can be set-up on the computer to simulate true viscous friction, in terms of a coefficient value $\mu$ which remains constant for all velocities. Nevertheless, as $\mu$ will be dependent on such factors as the surface area, shape, and relative smoothness of an object, it can only be determined by practical experiment, or by comparison between the computer solution and the timed motion of an actual object.

Looking at the symbolised diagram of Fig 7.5, OA1 is employed to integrate a known voltage against time, so that $t$ can be conveniently and accurately displayed as a meter reading. OA2 integrates $a$ to give an output $v$, and at the same time handles the initial velocity $iv$. The exponential decay $e^{-(\mu/m)t}$ is introduced by CP1. Resulting velocity $v$ is then integrated by OA3 and initial distance $is$ is included to give distance or height $s$ at any time $t$.

**Routine**. Set-up the problem according to the simplified patching circuit of Fig. 7.5 but omit for the time being all $C_f$ capacitors. The integrator switch is linked to the three operational amplifiers by connecting IS/SK1 to OA1/SK9, IS/SK2 to OA1/SK10, IS/SK3 to OA1/SK4, IS/SK4 to OA2/SK9, IS/SK5 to OA2/SK10, IS/SK6 to OA2/SK4, IS/SK7 to OA3/SK9, IS/SK8 to OA3/SK10, and IS/SK9 to OA3/SK4.

Allow the computer to warm up before zero-setting the amplifiers, also make sure that S6 is off. Using the readout meter on its 10V range, zero-set amplifier outputs (OA1/SK13, S3/I5/SK2, and OA3/SK13) by means of VR1 on each amplifier panel, from the back of the UNIT "A" box.

Next insert the $C_f$ computing capacitors into amplifier feedback loop sockets (SK11 and SK12) and set the integrator switching controls to give reset and compute times of approximately 0·1 second. Put S8 in the "hold" position. With the readout meter on its 1V range, applied to the output of OA1, press S7 and adjust VR15 for a zero voltage reading. Repeat for OA2 output and VR16, and OA3 output and VR17, in that order. The amplifiers should now be balanced for near zero input offset voltage.

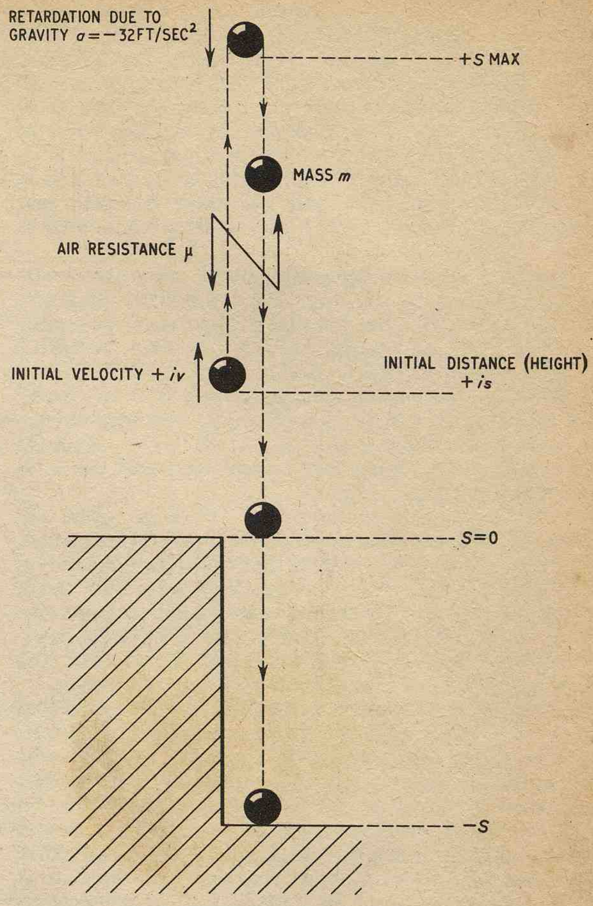
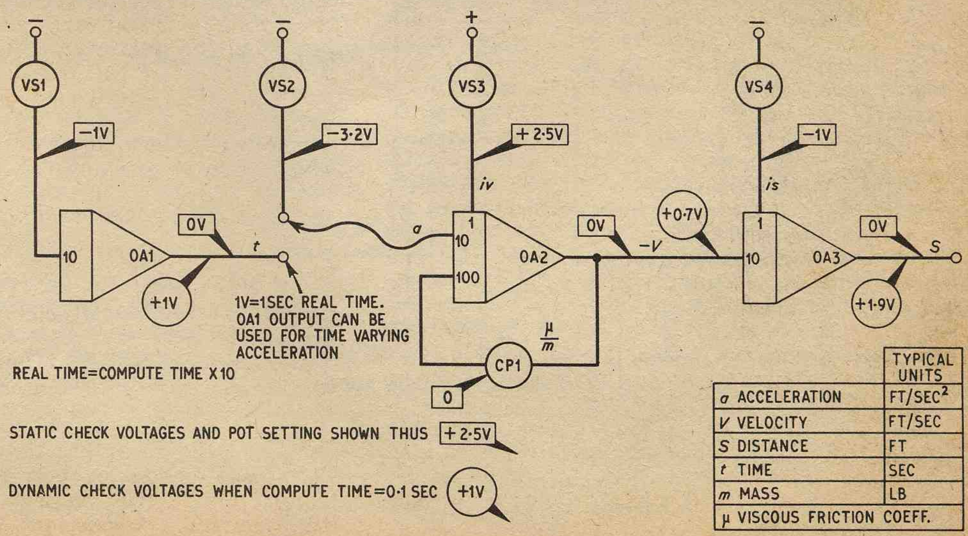



*Fig. 7.4. An experiment in dynamics with a ball*




| | TYPICAL UNITS |
|---|---|
| a ACCELERATION | FT/SEC$^2$ |
| v VELOCITY | FT/SEC |
| s DISTANCE | FT |
| t TIME | SEC |
| m MASS | LB |
| μ VISCOUS FRICTION COEFF. | |

*Fig. 7.5. Symbolised diagram of the ball problem illustrated in Fig. 7.4.*