process filters out rapid, noisy fluctuations but only slightly modifies long-term trends. The attentuation of fluctuations is more severe as the smoothing or delay time increases (Figure F-1).

The two information delay structures, or macros, provided in DYNAMO are SMOOTH (also called DLINF1) and DLINF3. They are represented symbolically by a rectangle (Figure F-2). X is the input to the delay; it may be a level, a rate, or an auxiliary. AX is the output of the delay, representing the averaged, smoothed, or delayed value of X, with the same dimensional units as X. AT is the averaging time, which may be a constant or a variable. The DYNAMO equations for these information delays are:

```
A     AX.K = SMOOTH(X.K,AT)
A     AX.K = DLINF3(X.K,AT)
```

SMOOTH is a first-order delay containing one internal level. DLINF3 is a third-order delay containing three internal levels. For details of the internal equations generated by DYNAMO to give the output variable, see Forrester (1961, 1968).

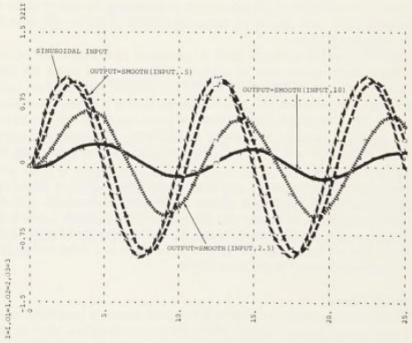

Figure F-1 Response of a first-order information delay to a sinusoidal input

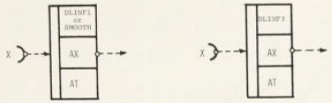

Figure F-2 DYNAMO flow diagram representation of first- and third-order information delays

The time response of first- and third-order delays to a given input signal is qualitatively different, although there is no difference between the time response of information or material delays of the same order with the same constant delay time. Their responses to pulse, step, and ramp inputs are shown in Figure F-3. Note that a first-order delay gives a finite response in the next DT after the change in input, whereas a third-order delay does not respond immediately but ultimately adjusts more rapidly to the same input change. A third-order delay is a series of three first-order delays. Higher-order delays can be created similarly by using first- and third-order delays in series.

It can be seen from Figure F-3 that the outputs of the delay functions have almost fully adjusted to the changed inputs after a time of about 3AT. Thus, loosely speaking, 3AT is the delay between a change in the input and the completed response to that change. AT is the average response time of the output to the change in the input.

Material Delays

Material delays change the time shape of material flows. The input to a material delay is always a material flow rate, such as the persistent pollution generation rate PPGR. The output is also a rate. Two material delay macros available in DYNAMO are DELAY1 and DELAY3. The former is a first-order delay; the latter is a third-order delay. The DYNAMO flow diagram representations of these delay functions are shown in Figure F-4. The input rates in both diagrams are X. The output rates are the delayed values of X, XD. The adjustment time in both cases is AT, which may be a constant or a variable.