11.11 Reliability Predictions

Successful hydraulic system designs require that component and system reliabilities be known. This means that a reliability program must be established to assess the reliability of system components or the designer must have access to dependable reliability values for all standardized components. The only way to measure system reliability is to test completed products or components, if there is no precise physical model available, under conditions that simulate application life, until failure occurs. Data is critical in establishing reliability information. The more data available, the greater confidence that can be expressed in the estimated or predicted reliability level.

The reliability of a component will grow or increase throughout its development and production life cycle. The reliability of a new technology component starts at near zero and may reach 50% or higher if the component is an extension of a current product or is based on well developed technology. In reality, the reliability of a component grows quite rapidly during the early prototype stages of development, then levels off at or near the established goal during early production. Also, product updates may often raise reliability above the set goal if reliability considerations are a part of the update. Hence, the actual reliability level of a component, as well as the confidence in the estimated level, grows with the test program and as the resulting corrective actions take place.

Effective reliability programs require the ability to assess reliability at key decision points along the growth curve. Such data available for making projections increase as the test program progresses. During the feasibility stage, little statistically sound data may be available. Hence, reliability projections must be made on such information as theoretical life and stress calculations, proven component data from similar component applications, potential problem analysis, and various fragmented data. It may even be necessary to establish accelerated test programs to obtain answers more quickly. This action is particularly necessary for long life products and extended longevity type failure modes.

Reasonably accurate predictions of reliability can be made when the failures are due to chance and wear-out. In fact, when the failure rate is constant, reliability prediction is made much easier mathematically since it is possible to use exponential curves to assist in the analysis—see Eqs. (11-13), (11-14), (11-15), and (11-16). According to these equations, a “chance-failure” nomograph as illustrated in Fig. 11-22 was developed which provides the numerical relationship between reliability, mean time to failure, and operating time for the exponential distribution model during a constant failure rate period. The chance-failure allows one to find the reliability of an item at a given operating time with a known MTBF. Conversely, it also provides a short cut to select an item with an appropriate MTBF to satisfy the required reliability at a specific operating time. The procedure to use the *Chance Failure nomograph* is as follows:

1. Determine the life units, LU, (e.g., hours, cycles, etc.) and the associated plotting range.

2. Label the operating time axis with numbers in ascending order from 10^n (at bottom) to 10^{n+3} (at top). Note the exponent, n, should be so chosen that the life data of interest would be in the range from 10^n to 10^{n+3}.
3. Label the MTBF axis with numbers in descending order from 10^{n+3} (at bottom) to 10^n (at top). The exponent, n, must be identical to the one used in labeling the operating time.
4. Label the Failure Rate axis in ascending order from 10^{-n} (at bottom) to $10^{-(n+3)}$ (at top).
5. Connect the specific operating time point and the MTFB point.
6. Read values of the reliability, R(t), and the probability of failures, F(t), at the intersection point.

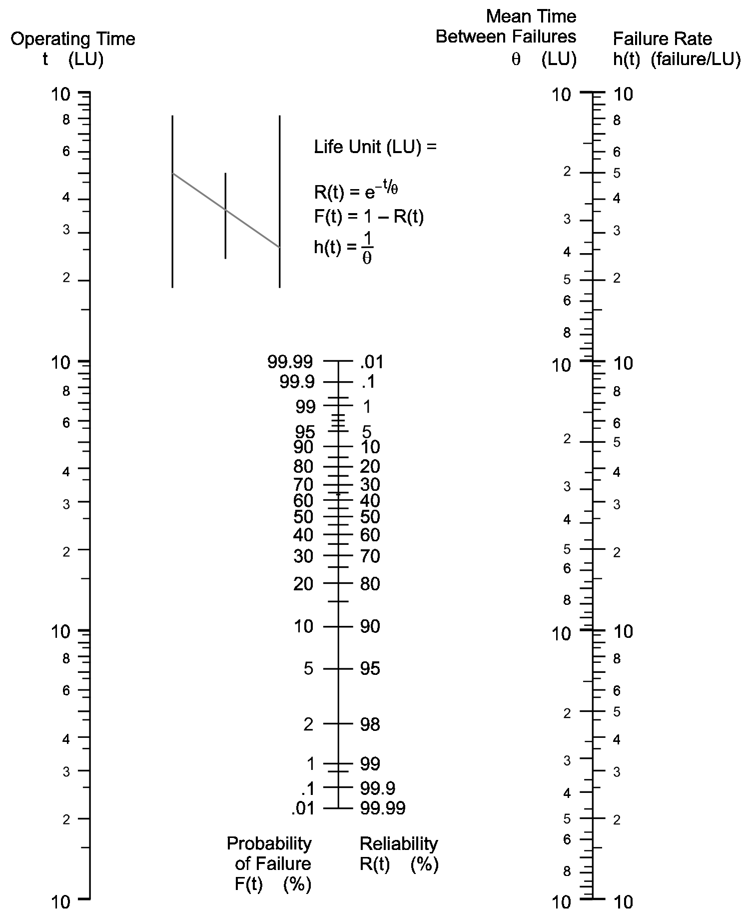

Figure 11-22. MTBF Nomograph.

Example 11-5

A cylinder is designed to have a reliability of 70% or higher for an operating period of 350,000 cycles during its useful life. Determine the minimum MTBF of the cylinder required.

Solution

The MTBF can easily be obtained from the chance failure nomograph assuming the failure rate is constant during the useful life. Since the operating time of concern is 350,000 cycles, it is appropriate to label the operating time from 10^4 to 10^7 as shown in Fig. 11-23. In this figure, the point of 350,000 cycles is located around at the center of the operating time axis. Connect this point with the 70% point at the reliability axis to obtain the corresponding MTBF that is about one million (10^6) cycles.

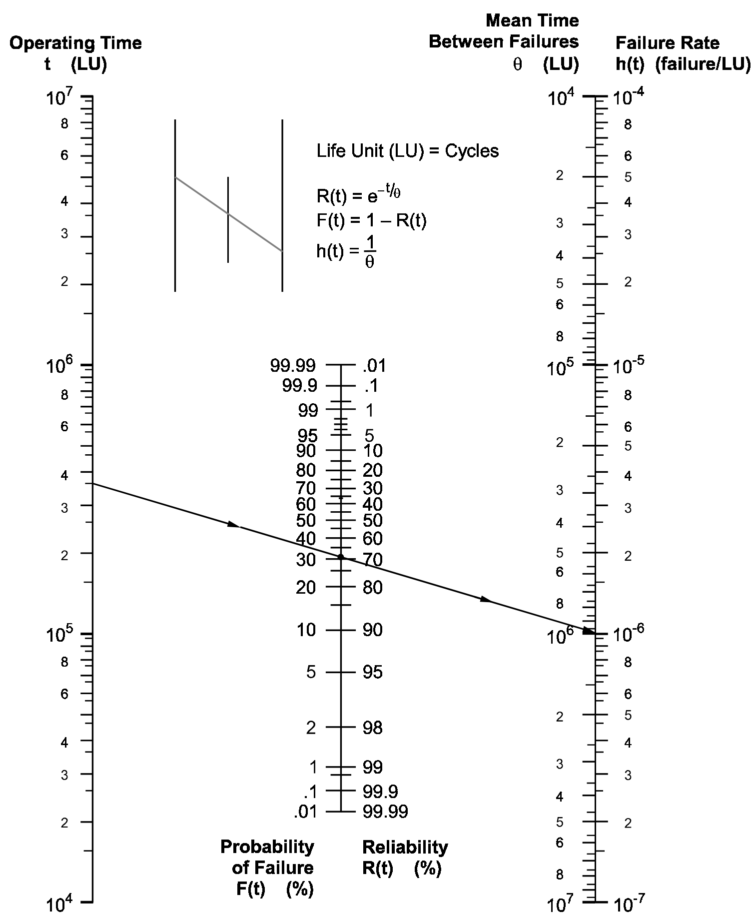

Figure 11-23. MTBF Nomograph for Example 11-5.

The MTBF can also be calculated by rearranging Eqs. (11-15) and (11-17) as follows:

$$\text{MTBF} = -\left[\frac{t}{\ell n(R(t))}\right] = -\left[\frac{350000}{\ell n(0.7)}\right] = 981286 \text{ cycles}$$

Predicting the wear-out failure is more complicated, both mathematically and graphically, than the chance-failure. The wear-out failure nomograph as shown in Fig. 11-24 is derived from Eqs. (11-20), (11-21), (11-22), (11-23), and (11-24) assuming the failure density is normally distributed. It is worthwhile to reemphasize that the MTBF for the chance failure and the mean wear-out life are two entirely different reliability variables in mathematical terms and in concept as discussed earlier. The procedure to use the *Wear-out Failure nomograph* is as follows:

1. Determine the life units, LU, (e.g., hours, cycles, etc.) and the associated plotting range.
2. Label the operating time axis with numbers in ascending order from left to right in 10 units, and assign an appropriate magnitude representing the data to plot. For example, if the operating time of interest is 8300 hours, a good choice of the magnitude for the operating time axis would be from 4 to 14 with each division of 1000 hours. This will set the 8300 hour point around the center of the axis. In addition, the magnitude of each division, [e.g., 1000 hours used here applied to μ, σ, z, and h(t)] is shown in the nomograph. In other words, for a LU = 1000 hours implies that a σ of 1.2 means the standard deviation is 1200 hours. Likewise, h(t) = 1.75 indicates the failure rate is 1.75 failures per 1000 hours.
3. Label the mean wear-out time axis with numbers in descending order using the same magnitude and scale used for the operating time.
4. Connect the specific operating time point and the mean wear-out point to locate pivot point A.
5. Connect pivot point A and the specific standard derivation σ to locate point B at the standardized variable z axis.
6. Draw a vertical line downward from B to read the reliability value obtained at the R(t) axis.
7. Extend the vertical line to intersect the specific σ from its family curve at point C, and further to touch the failure density axis, f(t), at point D.
8. Read the value at point D for the wear-out failure density, f(t).

9. Turn right from point C to read the failure rate, h(t), at point E.

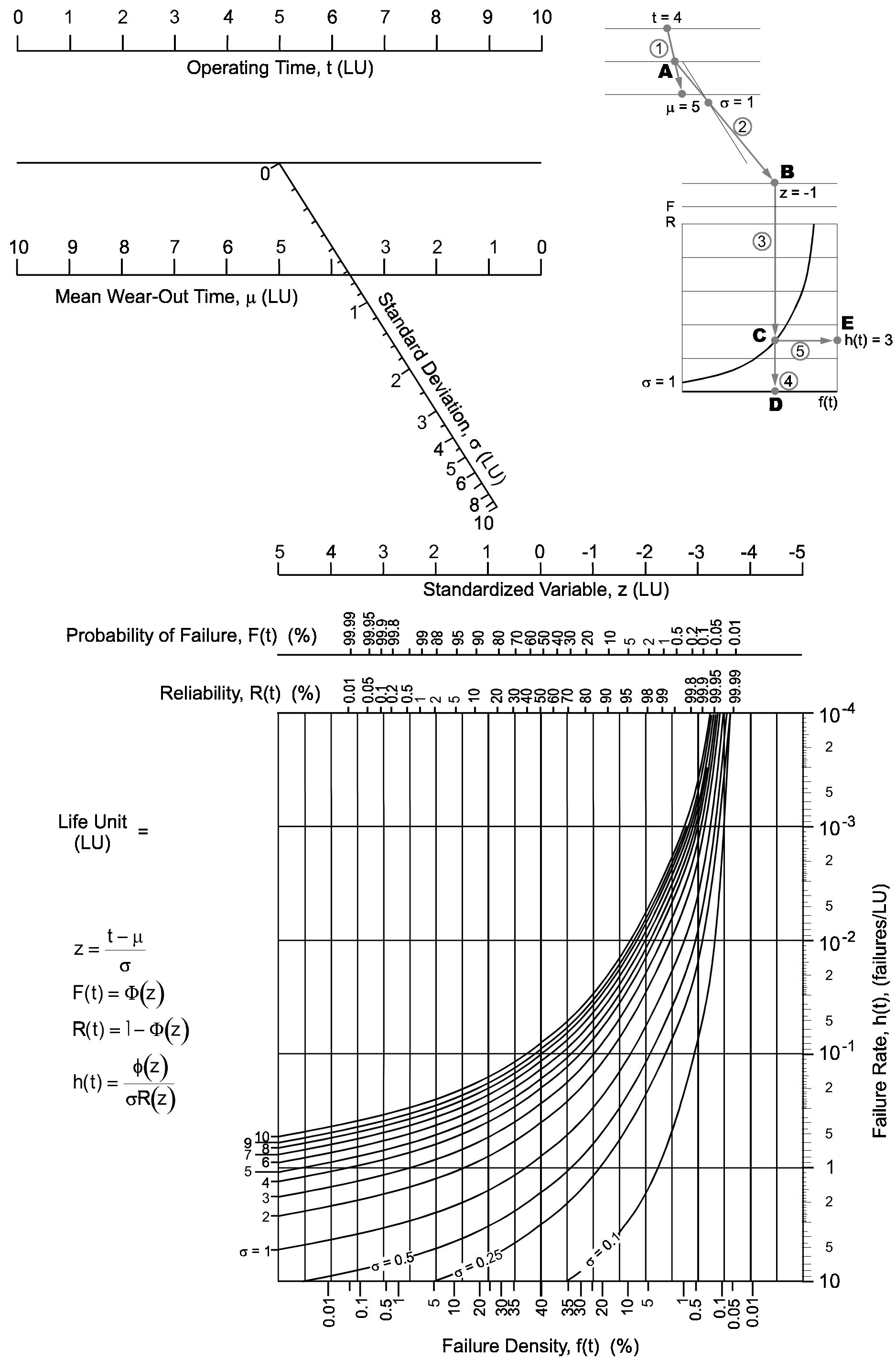

Figure 11-24. Wear-out Failure Nomograph.

Example 11-6

Assuming the wear-out failure of a given pump is normally distributed with a mean value of 5000 hours and a standard deviation of 1000 hours, estimate the reliability and failure rate of the pump at the end of an operating of

a. 4000 hours

b. 6000 hours

Solution

Let's use the wear-out failure nomograph. First, label the operating axis from 0 to 10 with each division of 1000 hours, i.e., LU = 1000 hours. Next, label each of μ, σ, z, and h(t) axes with the consistent magnitude in LU as the operating axis as shown in Fig. 11-25. Follow the procedure to obtain the wear-out parameters as presented earlier. The corresponding plots (solid line for 4000 hours, dash line for 6000 hours) are illustrated in Fig. 11-25. In this figure, at 4000 hours operating time, the reliability is about 85% and the failure rate is around 0.29 failures per 1000 hours or 0.00029 failures per hour. Similarly, at 6000 hours operating time, the reliability is about 15% and the failure rate is 1.6 failures per 1000 hours.

Both the reliability and failure rate can also be calculated using Eqs. (11-19), (11-23), and (11-24) while using the values of $\phi(z)$ and $\Phi(z)$ which are obtained from the standardized table for normal distribution (see Appendix) as follows:

At 4000 hours,

$$z = \frac{t - \mu}{\sigma} = \frac{4000 - 5000}{1000} = -1$$

$$R(t) = 1 - \Phi(z) = 1 - (1 - 0.8413) = 84.13\%$$

$$h(t) = \frac{\phi(z)}{\sigma R(t)} = \frac{0.2420}{(1000)(0.8413)} = 0.000288 \text{ failures / hours}$$

Similarly, the values at 6000 hours are R(t) = 15.87 % and h(t) = 0.001525 failures per hour, respectively. Notice the significant difference in the reliability at one σ less than μ and at one σ more than μ. This is a typical wear-out failure characteristic.

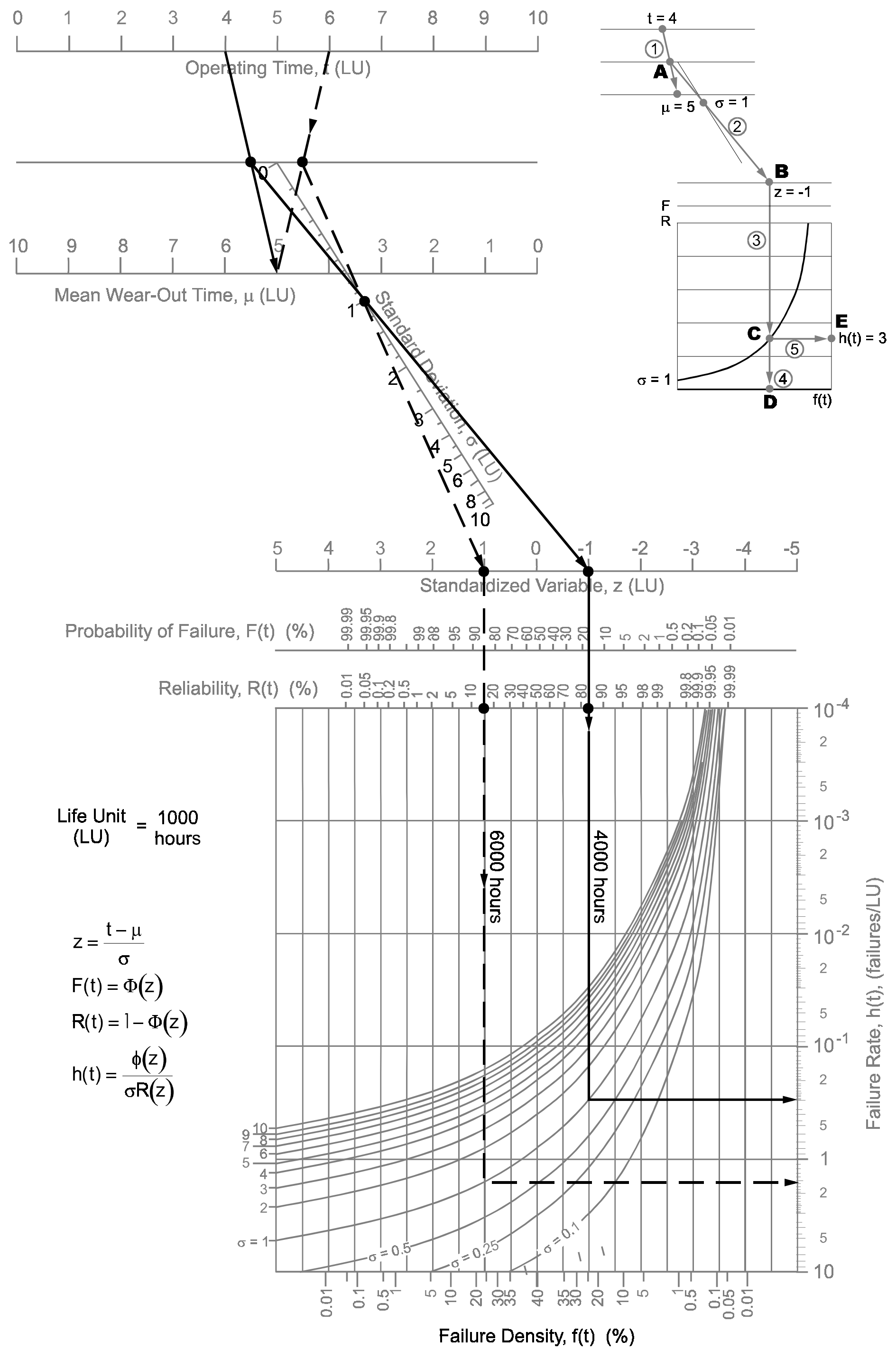

Figure 11-25. Wear-out Failure Nomograph of Example 11-6.