A key point in safety factor selection is *balance*. All parts of a machine or system should have *consistent* safety factors. Components that might possibly cause human injury or entail major costs should have the greatest safety factors; components that are comparable in these respects should generally have about the same safety factor, and so on. In fact, balance is perhaps the key to proper safety factor selection—balance based on good engineering judgment, which is in turn based on all available information and experience. (Now, marvel again at the balance achieved by the deacon in his design of the amazing "One-Hoss Shay"!)

6.12.2 Recommended Values for a Safety Factor

Having read through this much philosophy of safety factor selection, the reader is entitled to have, at least as a guide, some suggestions for "ball park" values of safety factor that have been found useful. For this purpose, the following recommendations of Joseph Vidosic [8] are suggested. These safety factors are based on yield strength.

1. SF = 1.25 to 1.5 for exceptionally reliable materials used under controllable conditions and subjected to loads and stresses that can be determined with certainty—used almost invariably where low weight is a particularly important consideration.
2. SF = 1.5 to 2 for well-known materials, under reasonably constant environmental conditions, subjected to loads and stresses that can be determined readily.
3. SF = 2 to 2.5 for average materials operated in ordinary environments and subjected to loads and stresses that can be determined.
4. SF = 2.5 to 3 for less tried materials or for brittle materials under average conditions of environment, load, and stress.
5. SF = 3 to 4 for untried materials used under average conditions of environment, load, and stress.
6. SF = 3 to 4 should also be used with better known materials that are to be used in uncertain environments or subjected to uncertain stresses.
7. Repeated loads: The factors established in items 1 to 6 are acceptable but must be applied to the *endurance limit* rather than to the yield strength of the material.
8. Impact forces: The factors given in items 3 to 6 are acceptable, but an *impact factor* should be included.
9. Brittle materials: Where the ultimate strength is used as the theoretical maximum, the factors presented in items 1 to 6 should be approximately doubled.
10. Where higher factors might appear desirable, a more thorough analysis of the problem should be undertaken before deciding on their use.

6.13 Reliability

A concept closely related to safety factor is *reliability*. If 100 "identical" parts are put into service and two fail, then the parts proved to be 98 percent reliable (which might or might not be good enough). Although the reliability concept finds considerably more application with parts subjected to wear and fatigue loading, we introduce it which there is no previous experience to serve as a guide? The greater the uncertainty, the more conservative the engineer must be in selecting an appropriate design overload or safety factor.

2. *Degree of uncertainty about material strength.* Ideally, the engineer would have available extensive data pertaining to the strength of the material *as fabricated* into the actual (or very similar) parts, and tested at temperatures and in environments similar to those actually encountered. But this is seldom the case. More often, the available material strength data pertain to samples smaller than the actual part, which have not experienced any cold working in part fabrication, and which have been tested at room temperature in ordinary air. Moreover, there is bound to be some variation in strength from one test specimen to another. Sometimes the engineer must work with material test data for which such information as specimen size and degree of data scatter (and the relationship between the reported single value and the total range of scatter) are unknown. Furthermore, the material properties may sometimes change significantly over the service life of the part. The greater the uncertainty about all these factors, the larger the safety factor that must be used.
3. *Uncertainties in relating applied loads to material strength via stress analysis.* At this point the reader is already familiar with a number of possible uncertainties, such as (a) validity of the assumptions involved in the standard equations for calculating nominal stresses, (b) accuracy in determining the effective stress concentration factors, (c) accuracy in estimating residual stresses, if any, introduced in fabricating the part, and (d) suitability of any failure theories and other relationships used to estimate "significant strength" from available laboratory strength test data.
4. *Consequences of failure—human safety and economics.* If the consequences of failure are catastrophic, relatively large safety factors must, of course, be used. In addition, if the failure of some relatively inexpensive part could cause extensive shutdown of a major assembly line, simple economics dictates increasing the cost of this part severalfold (if necessary) in order to virtually eliminate the possibility of its failure.

   An important item is the *nature* of a failure. If failure is caused by ductile yielding, the consequences are likely to be less severe than if caused by brittle fracture. Accordingly, safety factors recommended in handbooks are invariably larger for brittle materials.
5. *Cost of providing a large safety factor.* This cost involves a monetary consideration and may also involve important consumption of resources. In some cases, a safety factor larger than needed may have serious consequences. A dramatic example is a hypothetical aircraft with excessive safety factors making it too heavy to fly! With respect to the design of an automobile, it would be possible to increase safety factors on structural components to the point that a "maniac" driver could hardly cause a failure even when trying. But to do so would penalize "sane" drivers by requiring them to pay for stronger components than they can use. More likely, of course, it would motivate them to buy competitor's cars! Consider this situation. Should an automotive engineer increase the cost per car by $10 in order to avoid 100 failures in a production run of a million cars, where the failures would not involve safety, but would entail a $100 repair? That is, should $10,000,000 be spent to save $10,000 plus some customer inconvenience?

is due to nonlinearity of the load–stress curve. It is clear which interpretation is most conducive to the engineer's peace of mind.

Another example in support of the design overload concept concerns the general case of fatigue loading (treated in Chapter 8), which consists of a combination of mean (or static) and alternating loads. The kind of overload most likely to occur may involve increasing either or both of these load components. The design overload concept permits the safety factor to be computed with respect to whatever kind of overload is of interest.

A word of caution: It follows from the preceding comments that there are instances in which the term "safety factor" is ambiguous. It is therefore necessary to be sure that it is clearly defined in all cases for which there could be ambiguity.

6.12 Safety Factors—Selection of a Numerical Value

After going as far as is practical in determining the significant strength of the actual fabricated part and the details of the loading to which it will be subjected, there always remains some margin of uncertainty that must be covered by a safety factor. The part *must* be designed to withstand a "design overload" somewhat larger than the normally expected load.

In the last analysis, selection of the safety factor comes down to engineering judgment based on experience. Sometimes these selections are formalized into design codes covering specific situations—for example, the ASME Pressure Vessel Codes, the various building codes, and stipulated safety factor values in legal contracts covering the design and development of special machines. Safety factors are often embodied into computer programs or software for the design of specific components. Then the responsibility for making the engineering judgment falls upon the engineer responsible for the code or computer software. But only partly so because the engineer *using* the code or software must be satisfied that this detail of the code or software is indeed appropriate for the particular application.

6.12.1 Factors in the Selection of a Safety Factor

The selection of an appropriate value of safety factor is based primarily on the following five factors.

1. *Degree of uncertainty about loading.* In some situations loads can be determined with virtual certainty. The centrifugal forces in the rotor of an alternating-current motor cannot exceed those calculated for synchronous speed. The loads acting on an engine valve spring are definitely established by the "valve open" and "valve closed" positions (however, in a later chapter we will mention "spring surge," which could introduce a degree of uncertainty). But what loads should be used for the design of automotive suspension components, whose loads can vary tremendously depending on the severity of use and abuse? And what about a comparable situation in a completely new kind of machine for