PERFORMANCE TEST CONCEPTS

Performance Test Theory

Performance tests are accelerated use simulations that can help to determine how well a piece of furniture may be expected to perform in service. In a general sense, therefore, the term *performance test* may be defined as any test that aims at predicting the adequacy of a product for its intended use. As indicators of performance, these tests are powerful analytical tools that can be used to greatly reduce the hazards and uncertainties associated with the specification and buying of furniture.

The performance testing concept assumes that furniture can be described and its performance measured in terms of user requirements without regard for its physical characteristics, design, or method of manufacture. Implicit in this statement is the notion that furniture possesses certain inherent identifiable, measurable characteristics that are reliable indicators of its ability to satisfy user expectations. A further supposition underlying the performance test concept is that consumer expectations for products can also be defined and established. This is, in fact, the basis for the entire performance test concept. Formulation of meaningful performance tests, therefore, demands that those characteristics of the furniture that serve as reliable indicators of its performance and that reflect the performance expectations of the users be identified and defined. Methods and tests can then be developed to measure the extent to which they are present.

It is essential that the definition of performance in a test method evolve naturally from an appreciation of what the consumers expect from a product and how they evaluate it. Tests based on unimportant characteristics or nonessential features, for example, are at best useless—if indeed not deceptive and misleading—because they deal with characteristics purported to relate to user expectations but may actually be concerned with incidental factors.

Basis for Test Method

Once developed, individual tests are incorporated into test methods or standards that serve as tools of research and development or as instruments of commerce and trade. These test methods and the basic concepts that underlie them tend naturally to reflect the vested interests and objectives of those responsible for their development. Numerous test methods have been developed and promoted, and each tends to reflect the special interests of its sponsoring group. The most important differences, however, deal with the generality of range or application of the test method and with the procedures for measuring and defining performance.

Range of Application

At issue with respect to the range of application of the test method is whether a single test method can or should be applied to an entire category of furniture, such as chairs, or whether individual tests and methods should be required for the different items within that cate-
gory. There are advantages and disadvantages to both systems. Standards confined to a narrow range of application are more easily definable, the results less subject to misinterpretation and, therefore, presumably more comprehensible.

The principal advantage of a standard having a broad range of application arises from its apparent simplicity of use—only one standard is needed to cover a multitude of products within a given category. A serious disadvantage is that it may not treat individual differences with sufficient depth.

Methods of Defining Performance

Procedures for defining performance differ primarily with respect to whether single or multiple acceptance level test methods should be used. Differences here largely relate to how and by whom the results of the tests are to be used. They also concern the matter of the desire for quality beyond minimum standards.

Single point acceptance level tests are generally preferred when the intent is to establish a base level of performance and safety for a product group as a whole. Such tests enable industries and associations to establish performance and safety standards without accentuating differences in quality among the products of their members.

Establishment of optimum acceptance levels, in this method, is critical. If acceptance levels are set too low in order to accommodate the maximum number of members in the sponsoring organization, the tests have little value and may be misleading to consumers. On the other hand, if acceptance levels are set too high, they become restrictive and are likely to be regarded by governing bodies as restraints to trade. Standards that can be met by only a few manufacturers in a field should be carefully scrutinized to ensure that their negative impact on competition is significantly outweighed by the benefits derived. Furthermore, the adoption of unreasonable, rigid standards may impede product improvement and innovation. To avoid this problem, single point acceptance levels must necessarily be minimum performance levels. In the end, acceptance levels are ordinarily established by compromise; i.e., the requirements are set higher than some members, and lower than others, would prefer. As a result, many members who belong to such organizations may use acceptance levels in their own programs that exceed those prescribed in the test method.

Multi-point acceptance level tests, often termed graded performance tests, are preferred when distinguishing between differences in performance of similar competing products is desirable. Whereas a single point acceptance level test seeks to establish that all of a number of competing products satisfy certain basic safety and performance requirements, a multi-point acceptance level test seeks to establish that some products within that group may be expected to perform better than others even though all satisfy the same basic requirements. Multi-point acceptance level tests, accordingly, tend to be favored by those concerned with specifying and buying furniture. The results of such tests enable
users to compare the cost/performance ratio of each of the products offered and thereby to make informed purchasing decisions. This information is of particular value with life-cycle costing because the higher cost of a specific product may be justified if its performance sufficiently exceeds that of lower-priced/lower quality competing products.

Obviously, range of application and methods of defining performance are different, yet interrelated, concepts. If, for example, a test is narrowly defined and restricted to a specific end use, a single acceptance level is in keeping with the test because a test method is presumably developed to meet essentially every situation. On the other hand, if test methods with broad scopes of application and definitions are used (for example, one standard for all chairs), several acceptance levels must be established to reflect the different intensities of use to which the chairs will be subjected. In other cases, safety is of overriding concern, so that minimum performance levels must be set that will satisfy safety requirements.

Practical Considerations

There is much to be said for simplicity in both the test method and the reporting of the results. If a test method is to be widely accepted and used—particularly by the manufacturers themselves, which is most desirable—the tests must be relatively simple to carry out, necessitate only a reasonable amount of time for their completion, and require relatively simple, inexpensive, reliable, easily maintained equipment. Test methods based on the use of complex, expensive equipment that requires highly trained technicians to operate and maintain will have little chance of achieving widespread acceptance and use.

In developing performance tests for furniture, it must be recognized that they are expensive. In the long run, the costs of testing will be passed on to the consumer. It is important, therefore, that these added costs be consistent with the value of the information obtained and with the price of the product itself. A testing program for a commodity such as furniture should employ tests which are relatively simple in nature and do not take undue time to complete. The equipment needed to carry out the tests should be relatively simple in construction, reliable in operation, and inexpensive to build and maintain. The equipment utilized in the LTR test method satisfies all of these criteria.

Finally, test results must be presented to consumers in a form that will enable them to make meaningful purchasing decisions. To be useful, information dealing with truly important performance characteristics should be concisely presented. Nonessential characteristics should not be presented with the same apparent weight as that given important characteristics.

Furthermore, graded performance tests tend to be most useful to non-technical buyers when acceptance levels are formulated in intuitively understandable terms which have meanings to which users can relate their needs.
DEVELOPMENT AND DESCRIPTION OF SPECIFIC PERFORMANCE TESTS

In developing the tests needed to evaluate the performance characteristics of chairs, consideration must be paid to the types of loads that can be used in these tests and the number of times that they are applied. Numerous types of loads can be used in evaluating furniture performance, but perhaps the two most common are static and simple fatigue loads. These are used, respectively, in (a) single cycle tests, which may be referred to as static load tests, and (b) multi-cycle tests, which may be referred to as fatigue tests. Static load tests are ordinarily used either to determine the ultimate strength of furniture or to qualify it in a pass/fail type of test. Fatigue tests are carried out to determine the resistance of the furniture to repeated applications of low level loads such as might occur in service. They may be conducted at a constant load level until the furniture fails or for some prescribed number of load cycles. The latter type of testing is ordinarily done on a pass/fail basis.

Static loads do not appear well-suited for evaluating the performance characteristics of chairs because most chair failures appear related to repeated use rather than to overloading. Simple fatigue load models also do not appear well suited for evaluating the performance characteristics of chairs. Typically, such tests are carried out at a given load level for an indefinite number of cycles until the furniture fails; i.e., they determine the structural resistance of a chair to repeated applications of a single load. Alternatively, such tests may be continued for only a designated number of cycles, and if the chair successfully completes these cycles, it is presumed to qualify for a given end use. Rarely, however, is a chair subjected to the same repeated action at one load level in service. Furthermore, during the course of fatigue tests carried out at a constant load level, it is often apparent that the chair would fail if the load were increased even a slight amount, yet the chair may continue to carry the load for thousands of additional cycles at the constant load level. Consequently, the results of the test may vary over such a wide cyclic range that it is difficult to interpret the results; in addition, the values may tend to give an optimistic prediction of service life since chance overloads are not allowed to occur.

Development of more realistic load models for furniture subjected to repetitive dynamic loading requires a realistic reappraisal of typical service histories and the courses and modes of failure. A representative scenario is as follows: (a) during the course of its service life, furniture is subjected to repeated normal load applications along with occasional chance abusive loadings; (b) while the furniture is relatively new and retains a high degree of its initial design strength, it is able to resist these loads; (c) as its strength decreases with time, however, a point is reached when a chance overload exceeds its residual strength, and it fails.

This sequence of events corresponds to what may be defined as a "first crossing" concept of failure, which is based largely on a theory of cumulative damage. In essence, it is postulated that each time a chair is subjected to a load, it is slightly damaged by this action and thereby slightly weakened. When it is new, the chair retains a high degree of its
initial strength, and it is able to resist both normal and "abusive" or abnormal loadings. With time and use, the strength (or resistance) of the parts and joints diminishes, and eventually a point is reached when an applied load, often a chance overload, is greater than the residual resistance of the construction. At this point, a first crossing occurs, i.e., the load applied to the chair exceeds its strength and failure occurs.

It would be difficult to simulate the first-crossing concept exactly in chair testing both because appropriate load models have not been developed and also because introducing loads of random magnitude at random time intervals into the loading sequence would be difficult. A reasonable alternative to this procedure is to increase the load level by a fixed increment each time a specified number of load cycles have been completed, and then to repeat this sequence until failure occurs.

To elaborate, in this multi-cycle load method, a load is applied to the chair at a given cyclic rate for a specified number of cycles. Following this step, the load level is increased by a specified increment and the test continued. After the specified number of cycles has been completed at the new load level, the process is repeated until a particular load level is reached or until the chair fails. This testing procedure obviously involves an interaction between load cycles and load levels. A major advantage of the procedure is that it permits chairs to be evaluated on a graded basis. In addition, the emphasis of a test can readily be accommodated to either the static strength or the fatigue strength of a chair in accordance with the types of failure observed in service. Furthermore, the sensitivity of the test can be readily adjusted by changing the load increments. This process helps point up performance differences of any magnitude between chairs.

Because of this advantage, the increasing load fatigue type test appears best suited for use in chair performance tests. Once a cyclic stepped load model is selected as a basis for the test process, the primary factors to determine are the cyclic rate of loading, initial load level for each test, and load increments. These values are given in the following sections and in the description of the individual tests.

The performance test method previously reported in the September-October 1982 issue of LTR may be described as a graded test method, or a multi-point acceptance level test method. These tests attempt to show that some products within a group may perform better than others even though all may satisfy certain basic strength and performance requirements. They tend to be favored by those charged with specifying furniture, therefore, since they enable buyers to compare the cost/ performance ratio for the products offered and make informed purchasing decisions. Results of the tests are particularly important for life-cycle costing since the higher cost of a chair may be justified if its performance sufficiently exceeds that of lower-priced/lower quality competing products.
SPECIFIC TEST PROCEDURES

The present set of tests differs little in concept from those previously presented. The back-to-front-load test on backrests has been eliminated because it was found that the front-to-back-load test on backrests provides essentially the same information.

These procedures are described in detail in the subsequent discussion of the test method. Beginning loads and load increments have also been changed slightly for some of the tests. In particular, the tests have been shortened by starting the tests at higher load levels when it was apparent that the starting loads were too low.

1A. CYCLIC VERTICAL LOAD TEST ON CHAIR SEATS

Purpose

Purpose of the test is to evaluate the resistance of the chair and seat system to vertical loads applied to the seat such as occur when someone sits down in a chair.

Procedure

The chair is mounted on a smooth steel plate for testing as shown in Figure la. Loads are applied to the surface of the seat by means of a vertical load frame and a pneumatic dual-wheel load head which can also be seen in the figure. This type of head allows the load to be equally distributed over the seat and is particularly useful in the testing of chairs with solid wood seats.

A vertical load is applied to the chair seat at a rate of 20 cycles per minute. The test is begun at the 100-pound load level; loads are increased in increments of 50 pounds after 25,000 cycles have been completed at each preceding load level. Testing is continued until the chair suffers disabling damage.

Discussion

This is a particularly important test for chairs having splayed or "wall saver" legs because it evaluates the ability of the chair to resist the forces that tend to spread the legs apart. It is also important for stool or plank type seating such as captain's and Windsor chairs because the legs ordinarily collapse if the stretcher to leg connection fails. It is of equal importance for chairs with splayed tubular steel legs, particularly when they are not braced with stretchers.
Fig. 1a. Vertical Load test on seat

The test also evaluates the resistance of the front rail to vertical loads placed upon it when a user sits down. An evaluation of the strength of the front rail and its connections is particularly important in the case of chairs in which a solid seat or a seat frame rests directly on the front rail so that a large portion of the seat load is transferred directly to the front rail and its joints.

The test may also be used to evaluate the resistance of the seat and the seat foundation system as a whole to vertical loads placed upon it. In this respect, it is particularly valuable in evaluating seats (usually slip seats) that fit between the seat rails (rather than rest on top of them) and are supported by the corner blocks alone. A similar test, as described in lb, was adopted for use with tubular steel cantilever chairs commonly referred to as "Marcel Breuer" chairs.
1B. CYCLIC VERTICAL LOAD TEST ON TUBULAR STEEL CANTILEVER CHAIRS: YIELD TEST

Purpose

Purpose of the test is to evaluate the resistance of the tubular steel framework to cumulative yielding under repetitive cyclic loading.

Procedure

A vertical load is applied to the seat of the chair at a point 10 inches behind the front edge of the front posts at a rate of 20 cycles per minute. The test is begun at the 375-pound load level. Loads are increased in increments of 25 pounds after 25,000 cycles have been completed at each preceding load level. Testing is continued until the chair frame suffers disabling damage.

The chair is mounted for testing as shown in Figure 1b. Loads are applied to the surface of the seat by means of a vertical load frame and a pneumatic dual-wheel load head. Since it is the chair frame that is being tested, should the seat panel fail during the tests, it may be necessary to remove the seat and seat frame and replace it with a solid board or piece of plywood so the testing can proceed.

![Diagram of chair showing front post and vertical load test](image)

Fig. 1b. Vertical load test on tubular steel cantilever chairs

2. CYCLIC FRONT-TO-BACK-LOAD TEST ON CHAIR SEATS

Purpose

Purpose of the test is to determine the resistance of the chair to repeated back tilting. The test also discloses how well the joints in the side frames were constructed—that is, whether tight tolerances were maintained in manufacturing the joints, whether adequate glue was used, and
whether quality control was exercised from one joint to the next in construction of the chair.

Procedure

A horizontal load is applied to the chair seat in a front-to-back direction at a rate of 20 cycles per minute. The test is begun at the 100-pound load level; loads are increased in increments of 25 pounds after 25,000 cycles have been completed at each preceding load level and in increments of 50 pounds after the chair has passed the 250 pound load level. Tests are continued until the chair suffers disabling damage.

The chair is mounted for testing as shown in Figure 2. Reaction brackets are placed behind each of the back legs to prevent the chair from sliding backward. A strap is then passed over the seat from front-to-back and attached to a small clevis connected to the rod end of an air cylinder which is used to apply loads to the chair. The other end of the belt is dropped over the front edge of the seat, allowed to hang vertically, and attached to a crossbar located directly below the front edge of the seat. The strap prevents the chair from over turning when front-to-back loads are applied to the seat. It is important that the strap be attached directly beneath the front edge of the seat so that it does not provide any resistance to front-to-back movement of the chair. Because of this, it is advantageous if the strap can be attached to a point on the testing machine frame located several feet below the chair.

The air cylinder is attached to the main testing machine frame and should be supported in the horizontal position. Ordinarily, a cylinder with a bore of 2-1/2 inches and a stroke of 10 to 18 inches can be used to carry out the test.

Discussion

This test consists of pushing from front to back on the seat of a chair. This action produces internal resisting forces in the side frames of the chair which closely simulate those caused by the action of someone tilting backward. A strap passes over the seat and is pulled backward by the air cylinder (or some other similar loading mechanism) located behind the chair, which tends to tip the chair over backward. As the chair begins to tilt slightly, however, its motion is resisted by that portion of the strap that hangs vertically from the front edge of the seat and is anchored below—in effect, the vertical portion of the strap always provides the exact force needed to keep the chair from overturning.

Similar tests are ordinarily carried out with weights on the seats to prevent the chair from over-turning. Use of a strap instead of weights, however, simplifies this test, prevents much of the danger associated with falling weights should the chair fail, and eliminates the dynamic loading of the frame that results when a chair seat is loaded with weights. The strap has an added advantage; it loads the front seat rail of a chair so that this member is also evaluated. Because the method of loading produces vertical forces on the back legs, it also evaluates the ability of the chair to resist floor forces that tend to spread the legs.
apart, particularly important in the case of chairs that have splayed back legs. Finally, use of the strap allows applications of higher front-to-back loads than would be possible if weights were used. Hence, tests can ordinarily be carried to failure in order to determine the ultimate strength of the construction.

Fig. 2. Front-to-back-load on seat
3. CYCLIC BACK-TO-FRONT-LOAD TEST ON CHAIR SEATS

Purpose

Purpose of the test is to evaluate the resistance of the side frames to back-to-front forces that occur when someone leaning backward in a chair suddenly drops forward. Side rail to front and back post joints along with stretcher to front and back post joints are normally heavily stressed during this test.

Procedure

A horizontal load is applied to the chair seat in a back-to-front direction at a rate of 20 cycles per minute. The test is begun at the 100-pound load level; loads are increased in increments of 25 pounds after 25,000 cycles have been completed at each preceding load level and in increments of 50 pounds after the chair has passed the 225-pound load level. Tests are continued until the chair suffers disabling damage.

Fig. 3. Back-to-front-load test on seat
The chair is mounted for testing as shown in Figure 3. Reaction brackets are clamped to the rails to prevent the chair from sliding forward. A strap is then passed over the chair seat and attached to the rod end of an air cylinder by means of a small clevis. The other end of the belt is dropped over the back edge of the seat, allowed to hang vertically, and attached to a crossbar located directly below the back edge of the seat. The strap prevents the chair from overturning when back-to-front loads are applied to the seat. It is important that the strap be attached directly beneath the back edge of the seat so that it does not provide any resistance to back-to-front movement of the chair. Because of this, it is advantageous if the strap can be attached to a point on the testing machine frame located several feet below the chair.

The air cylinder is attached to the main testing machine frame and should be supported in the horizontal position. Ordinarily, a cylinder with a bore of 2-1/2 inches and a stroke of 10 to 18 inches can be used to carry out the test.

Discussion

Just as a chair is loaded in a front-to-back direction, so it can also be loaded in a back-to-front direction. This action occurs when someone leaning backward allows the chair to drop forward onto the front legs. It can also happen when a user slides forward in the seat or even deliberately tilts forward on the front legs.

In some tests, such as the rock tilt test, the resistance of the front legs to this type of action is evaluated by rocking a loaded chair forward on its front legs. In other tests, a static load is applied to the legs to evaluate their strength. The shortcomings of the first test have previously been discussed. The static load test has merit, but it is not well-suited for evaluating the performance of the front leg system with respect to repeated use. This test eliminates those problems. The action of the loading device pulling forward on the strap that passes over the seat causes the chair to tip forward, a movement that is resisted by the section of the strap hanging vertically from the rear edge of the seat. Hence, the chair is loaded horizontally in a back-to-front direction and is simultaneously loaded on its back edge in a vertical direction with just enough force to prevent the chair from tipping over. In practice, it is found that the chair does in fact tip just enough to lift the rear legs about half an inch off the base on which they are sitting. This action ensures that all of the back-to-front load is carried by the front legs, which is the state desired.

Because the method of loading produces vertical forces on the front legs, it also evaluates the ability of the chair to resist floor forces that tend to spread the legs apart, a particularly important feature in the case of chairs that have splayed front legs.
4. CYCLIC SIDETHRUST LOAD TEST ON CHAIR SEATS

Purpose

Purpose of the test is to evaluate the resistance of the chair frame to racking forces that occur when someone pulls sideways on an occupied chair or when someone tilts sideways on a chair.

Procedure

A horizontal sidethrust load is applied to the chair seat in a sideways direction at a rate of 20 cycles per minute. The test is begun at the 50-pound load level; loads are increased in increments of 25 pounds after 25,000 cycles have been completed at each preceding load level and in increments of 50 pounds after the chair has passed the 250-pound load level. Tests are continued until the chair suffers disabling damage.

The chair is mounted for testing as shown in Figure 4. Reaction brackets are clamped to the rails to prevent the chair from sliding. A strap is then passed across the chair seat and attached to the rod end of an air cylinder by means of a small clevis. The other end of the belt is dropped over the side of the seat, allowed to hang vertically, and attached to a crossbar located directly below the edge of the seat. This strap provides the reactive force required to keep the chair from overturning; it must be located in such a position that it does not provide resistance to the sidethrust force applied to the chair. The crossbar must, therefore, be adjusted to the proper position to allow the strap to achieve this condition. In addition, it is advantageous if the strap can be attached to a point on the testing machine frame located several feet below the chair.

The air cylinder is attached to the main testing machine frame and should be supported in the horizontal position. Ordinarily, a cylinder with a bore of 2-1/2 inches and a stroke of 10 to 18 inches can be used to carry out the test.

Discussion

The sidethrust load test on seats is designed to evaluate the resistance of a chair to those types of forces caused by a user's tilting sideways in a chair or by another person's attempts to pull a chair sideways. The test is carried out in much the same manner as the front-to-back-load test on seats except that in this case the chair is turned sideways. As the loading mechanism pulls sideways on the chair, the strap (acting vertically on the edge of the seat) prevents the chair from overturning, eliminates the need for weights, and in general provides the same test advantages as in the front-to-back load test.
5. CYCLIC FRONT-TO-BACK-LOAD TEST ON CHAIR BACKRESTS

Purpose

The purpose of this test is to evaluate the strength and durability of the back construction and especially the backrest itself and the backpost connections. Of additional interest are the strengths of the backposts at their point of intersection with the side rail and in areas of significant cross grain where strength would be expected to be significantly reduced.
Procedure

A cyclic front-to-back horizontal load is applied to the backrest at a rate of 20 cycles per minute. The test is begun at the 200-pound load level; loads are increased in increments of 100 pounds after 25,000 cycles have been completed at each preceding load level. Tests are continued until a disabling failure occurs, usually complete failure of the backrest or top rail to backpost joints, fracture of the backrest itself, or fracture of the backpost.

The chair is mounted for testing as shown in Figure 5. A horizontal member of the testing machine frame passes directly behind the backposts at the height of the side rails; i.e., the member is located directly behind the side rail to backpost joints. Reaction brackets are then clamped to the testing machine base rails directly in front of the back legs (or, front legs for sled base chairs). The horizontal support member together with the reaction brackets prevent the chair from tipping over backward when the front-to-back loads are applied to the backrest. A variation in the test procedure is required for chairs not having a continuous back post. In such constructions as Windsor chairs, where the hoop back and spindles frame into the solid wood seat, the horizontal member must be located behind the rear edge of the seat rather than the backposts.

A short strap is looped around the backrest and attached to a small clevis connected to the rod end of an air cylinder located behind the chair. This air cylinder, which is placed in a horizontal position, is used to apply loads to the backrest in a front-to-back direction. The height of the air cylinder is adjusted so that its longitudinal axis is coincident with the geometric center of the top rail or backrest.

If the geometric center of the backrest is less than 12 inches above the seat, or if the shape of the backrest prevents it from being loaded as described above, an alternative procedure is used, namely, a hole is drilled through what is perceived to be the center of the effective or usable geometric area of the backrest (but not less than 12 inches above the seat) and an eye-bolt is attached to a load head placed on the front surface of the backrest. The clevis connected to the rod end of the air cylinder is then attached to the eye-bolt.

Discussion

Chair backs must be able to resist the forces imposed upon them each time a user leans backward in a chair and when someone deliberately pulls a chair backward—either to move it or, perhaps prankishly, to attempt to overturn the user.

Loosening of the backrest to backpost connections may also be implicated in the failure of the backrest or backrest system. The test, therefore, must evaluate the durability of a backrest as well as its static strength.
The strengths of the backposts themselves are also of considerable interest, and a strong case can be made for requiring a test which evaluates their strength and durability independently of the backrests. The ability of the backposts to resist the impact forces which arise when a chair tips over backward and strikes the floor is significant as is the weakening effect of severe cross grain in the case of curved backposts which are bandsawn from straight stock rather than steam bent.

Although the information obtained from tests of backposts would be useful, it does not appear that it is essential. Both backrest and backpost tests were carried out on the chairs included in this report. An examination of the test results obtained indicate that the loads used and the acceptance levels established for the backrest tests are sufficiently high to also qualify the backposts. Hence, a separate test for backposts alone has not been included.
6. CYCLIC SIDETHRUST LOAD TEST ON ARMS

Purpose

The purpose of this test is to evaluate the resistance of arms to sidethrust forces such as occur when someone pulls sideways on an arm or when a user pushes outward on the arms while rising or sitting down.

Procedure

In this test, a cyclic sidethrust load is applied to an arm of the chair at a rate of 20 cycles per minute. The test is begun at the 100-pound load level, and loads are increased in increments of 25 pounds after each 25,000 cycles until disabling damage occurs or until a desired acceptance level has been reached.

Fig 6. Sidethrust load test on arms
The chair is mounted for testing as shown in Figure 6. Loads are applied to the arm by means of an air cylinder. A short strap is used to attach the cylinder rod to the arm. Loads are applied to what is judged the most usable forward point of the arm rest area. The opposite arm is anchored with a short strap to a member on the main testing machine frame. This strap should be positioned exactly as the one on the other arm. In effect, both arms of the chair are evaluated through this test arrangement, and it should be noted that the weaker of the two arms will fail. If desired, the distance between the arms may be measured while the arm is loaded to obtain a sidethrust force versus a deflection curve for the chair. Measurements taken when the arms are unloaded determine the permanent set.

Discussion

A major problem in determining arm strength is how to anchor the chair so that an arm can be loaded without unintentionally reinforcing it or some other interactive part of the chair frame. The simplest test that can be proposed is to load both arms of the chair simultaneously, which prevents unintentional reinforcing of the arms. Two problems arise here, however. First, the weaker of the two arms always fails first; this gives a low biased estimate of the strength of the arms. Second, the chair as a whole is often so severely damaged by this procedure that it cannot be used for any further tests. Given the straightforward simplicity of this method of test, however, it appears worthwhile to adopt the symmetrical arm loading arrangement.
DETERMINATION OF ACCEPTANCE LEVELS

Acceptance levels for performance tests should accomplish two objectives:

1. They should establish a minimum acceptable level of strength and durability for library chairs.
2. They should provide a means of differentiating levels of strength and durability among similar chairs.

Ultimately, acceptance levels for the performance of chairs must rest upon analyses of historical performance data obtained for a variety of chairs subjected to a wide range of service conditions. Lacking such comprehensive data, acceptance levels must presently be set on the basis of (1) analyses of available historical performance data, and (2) analyses of current manufacturing construction practices. Therefore, determination of meaningful acceptance levels is closely linked to how widely the test method is used in chair selection—that is, the more chairs that are tested and placed in service, the more service history performance data become available which can be used in setting ever more precise acceptance levels.

Historical performance data for chairs which have suffered significant numbers of service failures are of particular value since they allow a lower performance plane to be established which it is known must be exceeded if the chairs are to survive in service even in less demanding environments.

Historical performance data for chairs which have not suffered significant numbers of field failure are also valuable since these data provide an indication of a satisfactory (though not a minimum) level of strength which can also often be related to severity of usage.

Finally, analyses of current manufacturing construction practices can provide invaluable information concerning acceptance levels. Manufacturers who have produced chairs for the library market for a significant number of years have learned from experience how to build chairs which will hold up in service under essentially any specified use conditions. Data obtained from testing these chairs provide valid estimates of acceptance levels.

Low Acceptance Level Criteria

Low acceptance levels for chairs must be set at strength/durability values which will ensure that a chair will survive in service under reasonable conditions of use. What constitutes reasonable conditions
of use is, of course, not precisely defined and to a large extent is based on intuition. Chairs used in dormitory rooms in a university, for example, would be expected to receive harsher treatment than those used in university libraries. Therefore, a chair which is quite suitable for use in the library under reasonable conditions might be totally unsuited for dormitory use. Neither condition of use is quantitatively defined, yet the potential differences in conditions of use in a supervised versus an unsupervised environment are intuitively well understood.

Determination of low acceptance levels must necessarily be based largely on historical performance data. Some of the most useful information is obtained from chairs that have failed in the field. If chairs of the same type can be obtained and tested, their strength can be determined. As a result of such testing, a database of values is obtained, all of which are known to be less than what is required for a chair to survive in service. Very useful data are obtained from manufacturers who routinely test their chairs and know that they can expect a high percentage of returns if the chairs have less than a specified strength value. Usually, this takes the form of a high percentage, perhaps 30 percent, of returns the first year of service.

Medium and High Acceptance Levels

Determination of medium and high acceptance levels must reflect the cumulative experience of the chair manufacturers themselves and also provide a meaningful, although largely intuitive, relationship of strength and durability to fitness for specific service conditions. If it is assumed that manufacturers through trial and error have developed designs which will survive under given service conditions (and that they have eliminated those designs which have failed in service), then required levels of strength can be set on the basis of the strength values obtained for the chairs when they are subjected to the prescribed performance tests.

To a certain extent, high acceptance levels can also be obtained from historical data obtained for chairs which have survived heavy usage for extended periods of time without experiencing significant failures. Historical data exist, for example, for one library chair which has been used in a university library for 11 years. To date, none of the chairs have failed. The strength values for this chair presumably should fall into the high category; whether they are higher than is necessary is, of course, not known.

Discussion of Potential Acceptance Levels by Test

Cyclic Vertical Load Test on Seats

Test results indicate that solid wood, plywood, and slip seats are generally able to withstand vertical loads of 1000 pounds. This statement applies to leg base, sled base, and even to Windsor style chairs. Other types of chairs, such as Marcel Breuer type tubular steel chairs, and chairs with upholstered seats cannot withstand such high loads. Furthermore, it would be unreasonable to compare the vertical strength of an
upholstered seat with one constructed of solid wood. For these reasons, it appears reasonable to establish load levels for both upholstered and solid wood seats. In the case of upholstered seats, it appears reasonable to use the acceptance levels similar to those established for upholstered furniture by the General Services Administration of the federal government (Upholstered Furniture Test method, FNAE-80-214), namely, 300, 375, and 450 pounds for low, medium, and high, respectively. In the case of solid wood seats, acceptance levels of 600, 800, and 1000 pounds are used for low, medium, and high, respectively. Significantly high acceptance load levels are specified for solid wood seats in order to provide a means of testing unbraced solid wood seats such as those used in captain's chairs and Windsor chairs. In addition, these loadings are needed in order to evaluate cantilever style tubular steel chairs such as the Marcel Breuer type chair. This type of cantilever chair should be included in the solid seat category regardless of seat construction.

Cyclic Front-to-back Load Test on Seats

Manufacturers' historical performance data indicate that large number of returns must be expected with chairs which are not able to exceed testing at the 175-pound load level. Other industrial historical experience with this test indicates that the minimum strength value for this test should be at least 225 pounds. On the other hand, problems have been reported in a hotel setting with an armless sled base chair which meets the 250-pound load level.

Long-term historical performance data also indicate that there have been no failures for two styles of chairs with front-to-back strengths of 425 and 500 pounds, respectively. Significantly, the chair with the 425-pound front-to-back strength has been used for 11 years in a university setting.

It is also useful to look at the strength results obtained for chairs produced by several suppliers including those known to supply libraries. The results for front-to-back tests on seats carried out on 64 chairs are given in Figures 7a and 7b. These results apply to library chairs, but a few values (primarily those below 200 pounds) have been included for dinette chairs in order to provide some perspective on the strength of library chairs compared to domestic chairs. A smooth regression curve has been drawn through the data in order to help visualize results.

Results obtained for 55 of these chairs (primarily library chairs) with strengths equal to or greater than 200 pounds are given in Figure 7b. A smooth regression curve has been drawn through the data in order to help visualize results.

The near linear relationships obtained between successful load levels and the percentage of chairs which reach these load levels indicate that chairs are regularly produced with strengths at essentially all load levels between 200 and 600 pounds. It is interesting to note the high
Fig. 7a.

Fig. 7b.
percentages of chairs with high levels of strength. Twenty percent of the chairs, for example, achieved the 600-pound load level. More noteworthy, perhaps, fully 50 percent achieved the 400-pound load level. The high percentage of chairs produced with this level of strength tends to support the conclusion that this is not a chance result. To the extent that these results reflect the experience of manufacturers, they indicate that acceptance levels for this performance trait should be set at higher load levels than otherwise thought necessary.

Given the information presented above, it seems prudent to set the low acceptance limit at 250 pounds, at least until more historical performance data are accumulated which will allow it to be set with more precision. Experience with the one library chair with 11 years' history of use indicates that the high acceptance level might reasonably be set at 425 pounds. The large percentage of chairs produced with strengths above this value, however, indicate that it should be set higher. A value of 450 pounds is proposed, accordingly, for the present. Since chairs are produced with all levels of strengths between these values, it is proposed that the medium acceptance level be set midway between the lower and upper values, namely, at 350 pounds. For those chairs with strengths of 200 pounds and greater, at these acceptance levels, 91 percent had strengths greater than 250 pounds, 55 percent had strengths greater than 350 pounds, and 44 percent had strengths greater than 450 pounds.

These values are proposed as reasonable estimates which can be adjusted as historical performance data accumulate which will allow acceptance levels to be set with greater precision and certainty. It is not expected that future values will differ greatly, however. It should also be noted that the information presented is immediately useful in determining cost versus performance ratios for chairs.

Cyclic Back-to-Front Load Test on Seats

Historical performance data for back-to-front-load tests on seats are limited. Long-term historical data available for one chair with a back-to-front strength of 400 pounds, however, indicate that there have been no failures.

Considerable laboratory test data do exist for this trait, however. Back-to-front test data are given for 38 chairs in Figures 8a and 8b. The curve in Figure 8b relates only to those 36 chairs which attained a load level of at least 200 pounds, whereas the curve in Figure 8a relates to the results for all 38 chairs. Smooth regression curves have been drawn through both sets of data to aid in interpretation of results.

Intuitively, back-to-front strength would be expected to be less than front-to-back strength. For all practical purposes, however, there was essentially no difference in the test results. One reason for this occurrence is that most of the chairs tested either had a sled base or a side stretcher. Thus, the high strength values observed are likely related by design to the strength values observed in the front-to-back load tests rather than to a conscious effort to obtain high back-to-front strength.
Determination of Acceptance Levels

Fig. 8a.

Fig. 8b.
In general, chairs in service would not be expected to be subjected to back-to-front loads which are as high as front-to-back loads. It appears, therefore, that acceptance levels for back-to-front strength should be similar to front-to-back acceptance levels but somewhat lower. It is proposed here, accordingly, that the low acceptance value be set at 25 pounds less than the front-to-back value, i.e., the low acceptance value should be set at 225 pounds. Similarly, a value of 425 pounds is proposed for the high acceptance level. Again, since chairs are produced with all levels of strengths between these values, it is proposed that the medium acceptance level be set midway between the lower and upper values, namely, at 325 pounds. For those chairs with strengths of 200 pounds and greater, at these acceptance levels, 95 percent had strengths greater than 225 pounds, 77 percent had strengths greater than 325 pounds, and 63 percent had strengths greater than 425 pounds.

Cyclic Sidethrust Load Test on Seats

Historical performance data for sidethrust load tests on seats are limited; however, considerable laboratory test data quantifying manufacturers' experience exist for this trait. Sidethrust test data are given for 50 chairs in Figure 9a. Test data for those 41 chairs with strengths equal to or greater than 200 pounds are given in Figure 9b. Regression curves have been drawn through both sets of data to aid in interpretation of results.

Intuitively, side load strength would be expected to be less than front-to-back strength, particularly for those chairs which lack a front stretcher or which have only center stretchers. To some extent, however, the strength of the back frame system including the back rail, back stretcher, and top rail compensates for the weakness of the front frame system. As can be seen in Figure 9a, however, a much lower percentage of chairs achieved high levels of strength.

Historical performance data exist for one library chair which has been used since 1982 in a university library. Side load strength of this chair was 350 pounds. No failures have been reported for the chair. Other performance data for commercial chairs used in a public transportation setting indicated that a side strength of 150 pounds was too low for such service. On the other hand, one chair which has given excellent library service had a side strength of only 225 pounds.

In general, chairs in service would not be expected to be subjected to side loads which are as high as front-to-back loads. It appears, therefore, that acceptance levels for side strength should be similar to front-to-back acceptance levels but somewhat lower. It is proposed here, accordingly, that the low acceptance value be set at 50 pounds less than the front-to-back value, i.e., the low acceptance value should be set at 200 pounds. Similarly, a value of 300 pounds is proposed for the high acceptance level. This value is based both upon the performance of the one library chair and also upon the test results obtained. Over the range of 200 to 300 pounds, chairs are produced with all levels of intermediate strengths. It is proposed, therefore, that the medium
Fig. 9a.

Fig. 9b.
acceptance level be set midway between the lower and upper values, namely, at 250 pounds. For those chairs with strengths of 200 pounds and greater, at these acceptance levels, 100 percent had strengths greater than 200 pounds, 75 percent had strengths greater than 250 pounds, and 40 percent had strengths greater than 300 pounds.

Cyclic Front-to-Back Load Test on Backrests

Backrest test data are given for 41 chairs in Figure 10a. Test data for those 39 chairs with strengths equal to or greater than 300 pounds are given in Figure 10b. Regression curves have been drawn through both sets of data to aid in interpretation of results.

In determining the minimum backrest acceptance level, it should be noted that American National Standards Institute standard ANSI X5.1, which sets minimum performance levels for office furniture, requires a chair to resist a backrest load of 300 pounds for one minute. On the other hand, one library chair which has been used for 11 years in a university library had a backrest strength of 800 pounds.

Realistically, a user cannot be expected to exert a back force of more than 200 pounds. Hence, both values appear to be needlessly high. If a user tilts over backward in a chair, however, high impact forces are imposed when the backrest strikes the floor. Furthermore, this test is particularly effective in detecting weaknesses in the systems used to fasten the backrest to the backposts. Because of this, what otherwise appear to be rather high acceptance levels are justified.

An examination of Figure 10b indicates that all levels of backrest strengths are produced between 300 and 1000 pounds. For chairs with one-piece backposts, acceptance levels of 300, 500, and 700 pounds are proposed for low, medium, and high categories, respectively. For the 39 chairs with back strengths of at least 300 pounds, 100 percent had strengths greater than 300 pounds, 67 percent had strengths greater than 500 pounds, and 43 percent had strengths greater than 700 pounds.

At this time, there is insufficient information to define acceptance levels for chairs with discontinuous back legs and backposts such as Windsor and captain’s chairs. Failures have occurred after only a few cycles have been completed at the 200-pound load level with quality chairs of this style. Obviously, test results for a variety of such chairs are needed to clearly define acceptance levels.

Cyclic Sidethrust Load Test on Arms

Historical performance data on side load arm strength are limited, but a sufficient number of chairs have been tested to determine the levels of strength built into the chairs by the manufacturers. Results of these tests are given in Figure 11.

The side load arm strength of chairs will depend to a large extent on the nature of the chair construction itself. Thus, those chairs
Fig. 10a.

Fig. 10b.
in which the stump is attached to the side rail will often fail below 150 pounds; those chairs with a continuous front leg/stump but without a front stretcher will often fail below 250 pounds; and finally, those chairs with a continuous front leg/stump and a front stretcher will often fail at 325 to 350 pounds and above. These observations are based on the test results obtained for chairs with all three types of construction.

Limited historical performance data suggest that a chair must have a minimum arm side strength of 150 pounds to survive. At the other end of the spectrum, one chair which has undergone extensive use in a university library without the occurrence of any arm failure had an arm side load strength of 350 pounds. It is also useful to note that American National Standards Institute standard ANSI X5.1, Tests for General Office Chairs, requires that office chairs be able to resist a side load force of 150 pounds for one minute.

Given the above considerations, acceptance levels of 150, 225, and 300 pounds are proposed for low, medium, and high acceptance levels for side loads on arms. For these acceptance levels, 60 percent had strengths greater than 150 pounds, 35 percent had strengths greater than 225 pounds, and 25 percent had strengths greater than 300 pounds.
LTR PERFORMANCE CATEGORIES FOR LIBRARY CHAIRS

As was discussed in the previous section, determination of specific acceptance levels for chairs must be based largely on the accumulation of historical performance data in which the strength and durability of a chair, as determined by a standard set of tests, can be related to its field performance. Furthermore, it is very difficult to change or adjust acceptance levels once they have been set, since such actions are always subject to suspicion and the inherent desire to leave well enough alone. In addition, such changes usually require significant adjustments in product engineering and manufacturing processes in response to the accompanying changes in marketing strategies. It is important, therefore, that sufficient laboratory and historical field performance data be accumulated to permit the determination of functional relationships between laboratory tests and field performance before an attempt is made to definitively fix standard acceptance levels for library chairs. Because of these considerations, no attempt was made to rate the chairs included in the test program in strict adherence with the system of acceptance levels crafted in the previous section.

To aid in the accumulation of such data as well as to assist librarians and purchasing agents in selecting furniture which best meets their needs, however, it is useful to establish strength/durability performance categories for the chairs tested. These categories serve to bracket performance and thereby provide a means for quantifying subsequent historical experience. In addition, the use of performance categories greatly simplifies performance comparisons and cost versus performance analyses.

In setting up such categories, it appears worthwhile to establish one category below the performance levels regularly obtained from chairs intended for library reading rooms. In addition, it appears worthwhile to establish an upper category for strength/durability related to the upper limits of performance. Based on these criteria, for the test procedure described, the following five strength/durability levels result.

Table 1. Strength/durability categories expressed in pounds for the six performance tests for library chairs

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Strength/Durability Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Vertical load on seats</td>
<td></td>
</tr>
<tr>
<td>Solid wood</td>
<td>&lt;600</td>
</tr>
<tr>
<td>Upholstered</td>
<td>&lt;300</td>
</tr>
<tr>
<td>Front-to-back load on seats</td>
<td>&lt;250</td>
</tr>
<tr>
<td>Back-to-front load on seats</td>
<td>&lt;225</td>
</tr>
<tr>
<td>Sidethrust load on seats</td>
<td>&lt;200</td>
</tr>
<tr>
<td>Front-to-back load on backrests</td>
<td>&lt;300</td>
</tr>
<tr>
<td>Sidethrust load on arms</td>
<td>&lt;150</td>
</tr>
</tbody>
</table>
As previously stated, these categories provide a convenient framework for classifying and grouping the strength and durability of the many chairs offered to librarians. Based on the frequency of occurrence of load levels within the categories listed for chairs intended for use in library reading rooms, it appears reasonable to consider chairs in categories 2 through 4 for this purpose. Chairs in category 1 can be considered for less demanding service, whereas chairs in category 5 could be considered for the most demanding uses or in special situations.