Forty years ago, flexible polyurethane foam (FPF) made its way onto the upholstered furniture scene in a big way. More cost-effective than its predecessor, latex foam rubber, FPF offered furniture manufacturers a high-quality cushioning material with unprecedented performance properties. Over the past four decades, the FPF industry has streamlined its production techniques to contain costs and improve its quality to provide manufacturers with the most durable and versatile cushioning available on the market.

Today, FPF is the cushioning material of choice in almost all upholstered furniture. Over 2.1 billion pounds of FPF are produced and used every year in the U.S.

Thanks to the foresight of furniture and FPF manufacturers, FPF specifications for upholstered furniture were developed in the 1980s. By opening this new exchange with FPF manufacturers, furniture manufacturers gained a much greater understanding of the versatility of FPF, and FPF manufacturers gained a greater understanding of what was required by furniture manufacturers. This dialogue helped form bonds that will continue to enhance furniture production into the 21st century.

With the mutual increased knowledge about FPF's properties comes the potential for unlimited design/use opportunities. But, that knowledge alone is not enough. Just as FPF is an integral part of the upholstered furniture package, its application must also be an integral part of the design and construction process.

In this Millennium Report on Engineered Comfort, we take a close look at the design/construction criteria that is necessary for superior, high-performance furniture. We review FPF properties and how they affect comfort and quality. We give you information that sometimes is used in furniture design/construction today, but perhaps not used often enough. We hope that the use of this quantitative, numerical data in the furniture manufacturing process will increase in the future. We believe that the orderly use of engineering information will change the landscape of upholstered furniture. We call it Engineered Comfort.

FPF = Flexible Polyurethane Foam

What is Engineered Comfort?

As furniture designers and manufacturers, you know that comfort is an important requirement for success in the marketplace. Each furniture component has performance objectives, and when it comes to cushioning, that means comfort, support and durability. Engineered comfort places quantitative numbers on comfort by matching the capabilities of the furniture components with specifications on use. Successful comfort engineers understand the human body and apply that knowledge to the design of various furniture components.

The intended use of an upholstered piece sets the design and engineering criteria that is specific for that application. For example, a dining room chair is designed for a short term sitting and therefore, has limited cradling and thin FPF cushioning. An office chair that may be called to service for hours at a time usually has a harder, thicker FPF that allows the user to sit comfortably in an erect position. That cushioning, however, will not be the same as that used in a sofa or easy chair whose purpose is altogether different. Engineered comfort takes into consideration all of the features and components and determines the appropriate response for each design.

Art or Science?

Let there be no doubt: furniture design is an art. The ability to create a vision and put it on paper is a skill that only a privileged few enjoy. But engineered comfort, as part of the furniture-making process, is very much a science. It is a carefully choreographed process that examines the details, formulates a strategy and applies them in a calculated, precise manner.

Engineered comfort moves furniture designers and engineers away from the more traditional, empirical method of specifying, and toward a more theoretical system based on scientific data obtained by standardized performance characteristics. In most cases, the marriage of art and science produces a higher-quality product.

Partners in Design

The key to engineered comfort is to obtain and utilize performance data early in the design process. This requires establishing a partnership between FPF and furniture manufacturers at the design and engineering stages. Selecting the right FPF for the intended end-use, desired comfort and maximum durability is no easy task. In the case of cushioning, the right FPF for the correct fit should be determined at the planning stage so that specifications can be incorporated into the design/construction. Doing so can save time and money, and will go a long way toward manufacturing a superior product.

The Bottom Line in Furniture Design

When talking about comfort, we have to talk about capillary pressure, or pressure on the skin surface. The harder the seating surface, the more capillary pressure, thus blood flow is restricted. Pressure on the capillaries causes physical discomfort which shortens the length of time consumers can sit comfortably. In upholstered furniture, the seating comfort system is a combination of many items including fabric, cushion construction, FPF, decking materials, springs, frame construction and system geometry. All of these items provide the synergism that leads to comfort.

Design Criteria

The subject of comfort is subjective; however, understanding the design capabilities of FPF can play a significant role in the styling and comfort of the final product. Here are some basic considerations in seating design for upholstered furniture:

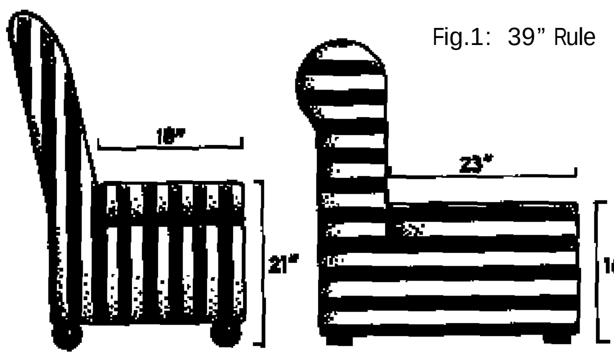


Fig.1: 39" Rule

Seat height and seat depth. Seat height will vary depending on the function of the furniture piece. In general, the dimensions of the seat height and seat depth should add up to approximately 39 inches (Fig.1). If there is a significant variation of the 39" rule, the body of the person sitting will not be positioned to enjoy the benefits of ideal construction materials.

Total Vertical Motion (TVM). Also known as ride, total vertical motion is a function of how deeply a person sits on and in the piece of furniture. It is a delicate balance between too much and too little cushioning and depends on fabric selection, seat cushion thickness, decking materials, deck cover, deck construction, spring type and spring installation construction. If a cushion has inadequate support, or too much ride, the user's buttocks will sit too deep, forcing a slouch position. The buttocks move toward the front rail, the knees are bent and the shoulders and back are curved, causing discomfort because the load is not equally distributed in the chair (Fig.2, p.4).

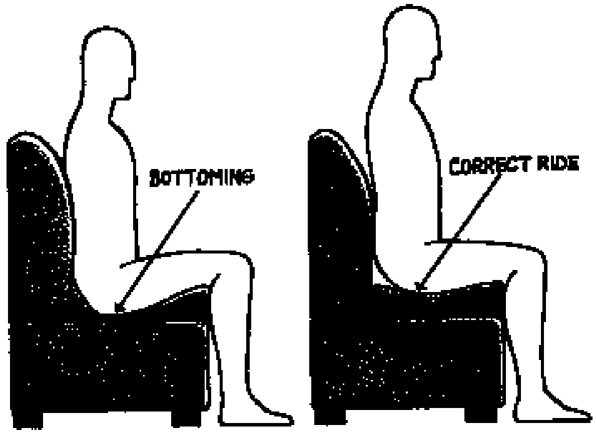
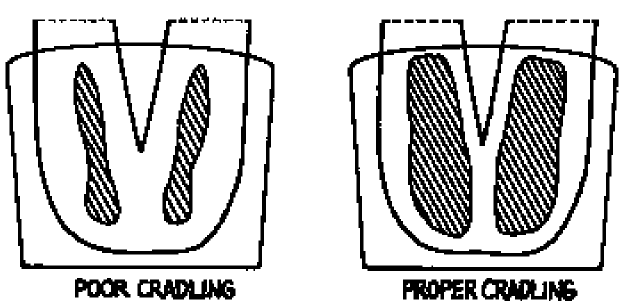


Fig. 2: Total Vertical Motion (TVM)

Cradling. Cradling is the property of an upholstered seat system and back system in which the body weight is distributed uniformly over the sitting and leaning area of a cushion or back. The uniform distribution of body weight results in low pressure between the interface of the seating system and the parts of the body, which are in contact with the seating system. Low "interfacial pressure" between the body and the seating system minimizes the restriction of blood flow in the contact areas (Fig.3).

The amount of cradling varies with the end-use and design of the upholstered piece. For example, cradling is minimal in typical dining room chairs — usually because of typically thin cushions and restriction of ride. Dining room chairs are usually used for short-term sitting. On the other hand, fully upholstered chairs, love seats, sofas, recliners and other long-term sitting seats can be designed with good ride, which usually results in good cradling. Ride is the basic promoter of cradling, but excessive ride can lead to "bottoming out" of a sitting system. In long-term sitting, bottoming out can produce as much discomfort as sitting on a flat, immovable board. The comfort of an upholstered piece is a direct function of the entire seating system, e.g., cover fabric, cushion wrap, FPF type, deck fabric, decking materials, springs, spring mounting system, frame design and integration of basic design with the overall construction of the upholstered piece.

Fig. 3: Cradling

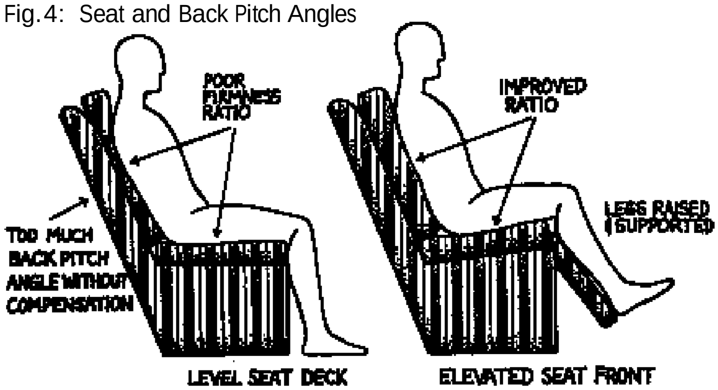


Given the variety of factors, one can easily see why it is imperative for FPF manufacturers to be involved early in the design and engineering of upholstered furniture.

Seat and Back Pitch Angles. We all remember how long our grandparents could sit in an unpadded, wooden rocking chair. The reason that a rocking chair is so comfortable for a long period of time is because the rocking motion of the chair produces an instant, or even constant, change of the forces on the parts of the body in contact with the chair. Even if blood flow is restricted, it is so for only a short period of time due to the constantly changing distribution of the body weight from the process of rocking.

Rocking also changes the pitch angle of the seat and back of the chair relative to the floor, which are important factors when designing comfortable upholstered furniture. If the seat of an upholstered piece has no pitch, is perfectly parallel to the floor and the back is at an absolute right angle to the seat, the piece's comfort is totally dependent on the seat construction. In this instance, it is doubtful that the piece will be comfortable for long-term sitting because the seat is bearing most of the weight of the individual sitting and denying a good load distribution of the body.

Fig.4: Seat and Back Pitch Angles



This is where engineering is important in the development of a comfortable seating system. On virtually every different style/design, the seat pitch and relative back pitch must be determined so that the back plays a significant role in bearing some of the weight of the body. One way to accomplish this is to design the seat frame with some front-to-back pitch. For example, the front of the seat frame may be higher than the back of the seat frame. The pitch angle of the seat will then force the body to lean on the back and, if the back has a moderate pitch and proper padding under the fabric, it will begin to carry some of the person's sitting weight. Obviously, there are many different possibilities for seat and back pitch, and the materials selected for the seat and back systems are very important to the overall comfort of the piece (Fig.4).

Effect of Fabric Selection. In most instances, fabric selection is controlled by the consumer. When designing and constructing an upholstered piece, it is very important to remember that fabric selection can positively or negatively change the sitting characteristics of upholstery. For example, if an upholstered piece is shown in the retail store in a lightweight cotton print, but the consumer purchases it in a heavier, stiffer fabric, the sit of the piece is going to be firmer than the sit on the sample. The opposite scenario is also true. The differences in sitting characteristics can be great, so it is imperative to select the proper materials in the early stages of design development. Proper seat and back pitch, FPF/padding selection and the engineering of the remainder of the seating system can minimize the effects of fabrics. One must remember that the fabric effect can only be minimized, never totally eliminated.

Ratio of Firmness. The ratio of firmness is the relationship of seat firmness to back firmness. The firmness of the seat construction must be matched to the firmness of the back construction or the comfort of the system will be negatively affected.

FPF Properties that Affect Design Criteria

Density. Density affects the FPF's ability to provide support, comfort and durability. It is a measurement of mass per unit of volume and is expressed in pounds per cubic foot (PCF). It is a primary measurement used to gauge FPF durability. Generally, as FPF density increases, durability also increases. Some of the factors related to durability are loss of firmness (flex fatigue), breakdown in the sitting area of the cushion (dishing) and fabric bagging caused by loss of FPF dimensions (compression set and fatigue loss, including loss of cushion height and IFD).

Indentation Force Deflection (IFD). Indentation force deflection is a measure of FPF firmness that is independent of density. IFD is determined by measuring the pounds of force required to indent a 4-inch thick FPF sample 25% of its thickness, or one-inch. For upholstery, 25% IFD can range from five pounds to 50 pounds. Firmness affects the ride of a cushion.

Support Factor (Compression Modulus).
Support factor is the ratio of 65% IFD divided by 25% IFD. Technically referred to as "compression modulus," the ratio typically ranges between 1.9 and 3.0. Conventional FPFs cover the range between 1.9 and 2.1. Filled FPFs (depending on filler type and loading) are generally 2.2 to 2.6. FPFs based on high resilience technology cover the range from 2.4 to 3.0 (high density is required for the upper range). The higher the number, the greater the FPF's ability to provide support.

Fig.5, 6, 7: Support Factor

Measured Thickness	IFD25	IFD65	Support Factor
4”	18	50	2.8
4”	21	50	2.4
4”	24	50	2.1
4”	27	50	1.8

Fig. 5 Higher support factors allow you to soften the surface and maintain deep down support.

Measured Thickness	IFD25	IFD65	Support Factor
4”	26	50	1.9
4”	26	52	2.0
4”	26	55	2.1
4”	26	57	2.2

Fig. 6 Support factor is critical to deep down firmness

Measured Thickness	IFD25	IFD65	Support Factor
4”	28	50	1.9
5”	31	50	1.9
6”	35	50	1.9
7”	39	50	1.9

Fig. 7 Surface firmness changes with measured cushion thickness even when support factor is constant.
Note: It is an industry practice to calculate and measure support factor & IFD readings based on a 4” thick sample.

For greatest comfort, the support factor should be selected to maximize cradling, allowing a seated person to sit into the cushion rather than on top of it. When cushions are thick, lower support factor FPFs may be used to improve cradling and to achieve more even distribution of body weight. For thinner cushions, where the ride is limited, higher support factor FPFs can be used to provide softer initial contact and resist bottoming out.

Lamination of conventional FPFs with different IFDs and/or densities can provide a high support factor and soft contact. In fact, when engineered properly, laminating two FPFs together can attain the desired feel and performance better than using alternative cushioning materials such as fiber. You can adjust the support factor by using FPFs of different density, thickness and IFD.

For best results when combining FPFs, the IFD must be close enough so that when a person sits on the cushion, the transition from the softer FPFs to the firmer FPFs is not apparent. As a general rule, the highest support factor values are achieved when 50% of the cushion thickness is of the firmer FPF and higher density, and 50% is of the softer FPF and lower density. This combination allows for more design features and greater durability. For reversible cushions, the laminate must be the same on the top and bottom.

It is possible to achieve even higher support factors if conventional, softer FPFs are combined with high resilience (HR) technology FPFs. This can be used in thin cushions to improve initial plushness of the cushion and prevent bottoming out.

Flex Fatigue. Flex fatigue is the loss of FPF firmness after flexing the FPF a predetermined number of cycles. It is an important measure of durability because it indicates a cushion’s long-term ability to provide the proper cradling and TVM. FPFs that have good flex fatigue values tend to retain their original firmness and support levels, which means that the cushion can retain more of its original characteristics.It is important to remember when designing upholstered furniture that even well-made, good-quality flexible polyurethane seat-cushion grade FPFs will lose some IFD with time in actual use. According to current Joint Industry FPF Standards and Guidelines, an acceptable level of flex fatigue is 25 to 30 percent loss. While this number may seem excessive, it is much less than that found in alternative materials where flex fatigue loss can be as high as 70 percent.

Resilience. Resilience is an indicator of the surface elasticity of FPF. It is measured by dropping a standard steel ball onto the FPF cushion from a given height and measuring what percentage the ball rebounds. FPFs with high resilience feel alive; FPFs with low resilience feel dead and mushy. Both have a role in upholstered furniture, depending on a product's end-use. For instance, low resilience FPFs would be used in back cushions or pillows, while FPFs with high resilience are typically found in seat cushions. High resilience FPF will have a ball-rebound of at least 55%.

Partners in the Next Millennium

As we enter the 21st century, the furniture industry, like so many others, has the benefit of increased and enhanced technology. Innovations continue to improve today's standards and set new heights for tomorrow's modernization and design.

The FPF industry has a proud history of adapting to change and moving forward with technological innovations. One example is in the early 1990s, when consumer and design trends led furniture designers away from firm cushioning toward alternative cushions that provided a softer feel. The FPF industry set its sights on developing a softer grade of FPF that provided more supple and comfortable properties without sacrificing support and durability. The net result was super-soft FPFs, which have an IFD within the five-to 10-pound range, a softness comparable to the feel of fiber. FPF/FPF cushions, time and time again, have outperformed fiber/FPF cushions in retention of original properties and appearance.

Since then, more consistent FPFs have appeared with the emergence of FPFs that yield less variation in IFD from top to bottom and side to side. High-resilience FPFs offer designers the ability to get the looks they want and the consistency to maintain that look over time.

An insatiable appetite for innovation and a keen desire to be responsive to their customers guarantees that FPF manufacturers will continue their quest for quality and versatility in FPF. But as design/styling trends change and technology in components evolves, it becomes increasingly imperative that strong partnerships with furniture manufacturers be forged earlier in the process. With better education and understanding, oversight errors will be reduced and end products will be inspired. Together, these partners will lead the way into a new millennium of comfort, support, value and durability.

FPF Resources.

Alliance for Flexible Polyurethane Foam (AFPF)
1300 Wilson Blvd.
8th Floor
Arlington, VA 22209
1-800-696-AFPF, Fax: 703-253-0658
http://www.afpf.com
attn: Neeva-Gayle Candelori

The Alliance for the
Polyurethanes Industry (API)
1300 Wilson Blvd.
8th Floor
Arlington, VA 22209
703-253-0656
Fax: 703-253-0658
http://www.polyurethane.org
attn: Fran W. Lichtenberg

Polyurethane Foam Association (PFA)
P.O. Box 1459
Wayne, NJ 07474-1459
973-633-9044
Fax: 973-628-8986
http://www.pfa.org
attn: Lou Peters

Available from PFA:

- *In Touch®* — a teaching bulletin with information about FPF
- *PFA Glossary*
- *FPF Performance* slide show

To receive a copy of the American Furniture Manufacturers Association's "Flexible Polyurethane Foam Voluntary Test Standards & Performance Guidelines," send $30.00 (per copy) to:

AFMA
P.O. Box HP-7
High Point, NC 27261

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