4 ELASTIC INTEGRAL MECHANICAL ATTACHMENTS OR INTERLOCKS

4.1 HOW ELASTIC INTERLOCKS WORK

An increasingly popular method of mechanical joining is "snap-fit fastening." While there are, indeed, fasteners that operate with what has come to be known as a "snap-fit" (see Section 4.2), most of the time when people speak of snap-fit fastening, the term is actually a misnomer because fasteners (i.e., supplemental devices specifically designed for joining parts together, without any other function) are not usually involved. Rather, elastic integral mechanical attachment features or elastic interlocks are.

As described in Chapter 2, Section 2.3, *elastic integral mechanical attachments* or *elastic interlocks* function by having a geometric feature on one part in a mating pair be designed so that it can and does elastically deflect when it comes into contact with a relatively more rigid geometric feature on the mating part. Once deflection of the elastic feature occurs and the insertion of the mating part, which is normally the one being moved, into the base part, which is normally the one that remains fixed or stationary, reaches a certain point, the designs of the deflecting and rigid features are such that some portion of the elastic feature clears some portion of the rigid feature and is able to recover at least partially, if not completely. When this recovery takes place, there is usually a distinctive "snap" that can be both heard and felt. This interesting and unique characteristic of these interlocks enables built-in quality assurance that successful part-to-part engagement *and* locking has occurred. In the recovered position, the detailed geometry of the engaging features act to lock the two parts

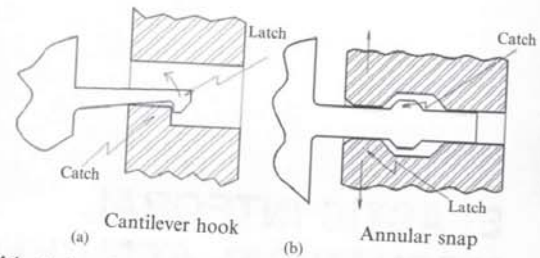

FIGURE 4.1 A schematic illustration of the role of a "catch-latch" pair of details for the operation of elastic snap-fit locking features, the hook as the latch and a ledge as the catch in a cantilever hook snap-fit feature pair (a) and the rigid ring as the catch and the flexible annulus as the latch in an annular snap feature pair (b).

together. Thus, the two features operate as a "catch" and a "latch,"[1] with one deflecting and the other remaining at least relatively rigid. In "catch-latch" pairs involved in *all* elastic interlocks, there is usually no particular difference as to which part does what. The concept of elastic snap-fits always involving a catch-latch pair was described and classified by Genc et al (1998a).

Figure 4.1 schematically illustrates how typical elastic integral snap-fit features operate as "catch-latch" pairs.

As will be seen in Section 4.2 on the sub-classification of elastic interlocks, there are actually many types. All rely on the elastic deflection of at least one part or part feature in a mating pair, but some primarily function to accomplish joining and secondarily, if at all, as parts with another primary function (carrying or transferring loads or forces, allowing motion, causing actuation, etc.). As such, the latter operate more like mechanical fasteners than like integral mechanical attachments. Pure fasteners that themselves operate by relying on elastic deflection and recovery, including the associated audible and tactile "snap," will be included in the sub-classification scheme but will not be described or discussed further. Suffice to say that there are such fasteners that can accurately be referred to as "snap-fit fasteners" (Messler, 1993). Most are clevis-like rivets or pins that are inserted into pre-prepared holes by squeezing some elastically deformable feature until the fastener is fully in place, and then releasing the squeezing force to allow the fastener to elastically recover, at least partially, and lock the assembly.

[1] The terms "catch" and "latch" are best exemplified by the features that allow a door to click into place in a jamb. A feature that can somehow deflect is caused to deflect by a relatively rigid feature on the mating part. For a door, the protruding feature is called the "latch" and the recessed feature is called the "catch." In general, either the catch or the latch can be elastic or rigid, so long as one behaves elastically and the other rigidly. Also, the catch or latch can, in the example of a door, be located on the door, as long as the mating feature is located on the jamb. For most doors, the latch deflects (as it is backed by a spring), and the catch (usually a cutout in a metal plate) is rigid.

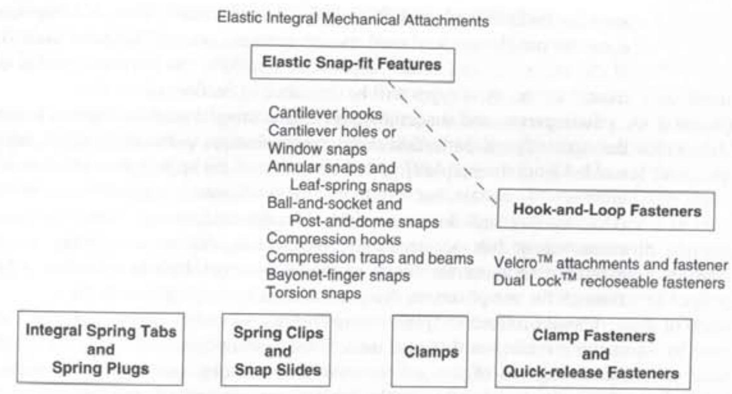

FIGURE 4.2 Taxonomy for elastic integral mechanical attachment methods.

4.2 SUB-CLASSIFICATION OF ELASTIC INTERLOCKS

Using the elastic deflection and at least partial recovery of parts or integral features of parts to accomplish assembly and locking is an old, diverse, and widespread method of mechanical joining, in general, and of integral mechanical attachment, in particular. Including approaches that actually employ true, fairly conventional fasteners,[2] Figure 4.2 gives a proposed taxonomy that attempts to reflect technical, if not familial, relationships. In fact, other than the close similarity between typical elastic snap-fit features and hook-and-loop fasteners, there is very little familial relationship. The sole similarity is the dependence of design features which operate to allow and enable attachment and locking via elastic deflection and at least some recovery; possibly with some remaining, residual stress.

The largest sub-class, by far, is also the newest application of elastic interlocks, namely so-called "plastic snap-fit features" or, simply, "plastic snap-fits." Contrary to the use of the term "plastic" in reference to integral mechanical attachments elsewhere in this book (e.g., Chapter 5), the term "plastic" here refers to the fact that these elastic integral features are used extensively (though no longer exclusively!) in parts made from plastics. Examples of the use of plastic

[2] True, conventional fasteners that operate using elastic deflection and at least partial recovery include: certain clevis-like (bifurcated) or two-piece tubular rivets, various clevis and spring pins, many eyelet/grommet pairs, virtually all retaining rings and clips, and some washers (e.g., spring-washers, Belleville washers, and curved and conical washers). Examples exist made of metal and made of more rigid polymers (Messler, 1993, 2004; Parmley, 1989).

snap-fits abound from parts of automobiles and aircraft to parts of computers and computer peripherals (keyboard, mouse, speakers, printers, scanners, etc.) to parts of children's toys and adults' appliances, furniture, and lawn and garden equipment. The variety of types will be described in Section 4.3.

So important and successful have elastic integral snap-fit features become in the assembly of parts fabricated from plastics, particularly parts injection molded from thermoplastics, that extension of the approach to other materials, most notably metals, but also to various reinforced composites, was inevitable (Goldsworthy and Johnson, 1994; Messler and Genc, 1998). Performance enhancement has occurred with plastic snap-fits by employing combined assembly motions for more secure part-to-part locking (Section 4.5) and through the use of certain designed-in enhancements (Section 4.6).

Closely related to "plastic snap-fits" are so-called *"hook-and-loop"* attachments.[3] While mostly found made from thermoplastic polymers, the possibility of analogs in higher-performance thermosetting polymers, polymer-matrix composites, and even metals has not gone unnoticed, unexplored, or unexploited (Messler and Genc, 1998). The actual features responsible for allowing joining are really just miniature versions of many of the types of features found in larger-scale plastic snap-fits. Hook-and-loop attachments are described in Section 4.7.

The remaining sub-classes of elastic integral mechanical attachments or elastic interlocks span a wide spectrum of sizes, geometric forms, materials of construction, applications, and degree of integration within a part or parts of the actual feature(s) responsible for allowing interlocking, as opposed to operating more as fasteners. In fact, the various sub-classes are sometimes difficult to relate to one another, but all share the common trait that they accomplish joining through the elastic deflection and at least partial recovery of one part or feature of a part with another. The various sub-classes, from most to least integral to a part, are:

- Integral spring tabs
- Spring plugs
- Snap slides and snap clips
- Clamp fasteners
- Clamps
- Quick-release fasteners

There are almost certainly other devices (e.g., toggles and certain types of latches) that could be included under the classification of elastic interlocks, but what is covered in this chapter thoroughly covers the operating concepts, if not the full diversity of specific embodiments.

[3] Hook-and-loop attachments are sometimes called "hook-and-loop fasteners" because their sole function, as parts, is to allow joining. Nothing else!

4.3 ELASTIC INTEGRAL SNAP-FITS USED IN ASSEMBLY OF PLASTIC PARTS

With the appearance of products of all types made from plastics after World War II, new methods for joining plastic parts became necessary. As is usually the case, initial approaches simply extended what was being used with metal,[4] the material of choice prior to World War II, namely, mechanical fastening. Self-tapping screws (later modified for plastics from the types used with sheet-metal), machine screws and bolts with internally-threaded parts or with nuts, and, occasionally, rivets (later modified specifically for use with plastics, including some types of "pop rivets"). The problem with all of these mechanical fastening methods is that they create severe point or concentrated loading and highly localized stresses. Such concentration of stress easily leads to stress relaxation in polymers, even at relatively low temperatures, because of their inherent viscoelastic[5] strain behavior. As a result of stress relaxation (or "cold flow"), tightened screws or bolts and nuts become loose as the underlying material strains and relaxes with time. As a result of this same viscoelastic strain behavior, fasteners that operate by carrying shear by bearing against the side of the fastener hole, rivets, screws, and bolts, as well as keys, pins, and other fasteners, elongate the hole and lose their effectiveness of joining. Because of the softness of most polymers compared to most metals, the threads produced by self-tapping screws tear out in time or under heavy loading. The only answer to these problems has been to customize fasteners for use with plastics. Head and nut bearing faces are made larger to spread loading, load-spreading washers are used, threaded inserts are used with screws (to preclude tear-out), and fastener holes are lined with sleeves to reduce the bearing stress somewhat.

As a further and generally more appropriate response to these problems, the use of load-spreading adhesive bonding emerged and proliferated. To a lesser extent, thermal bonding (actually a welding process for thermoplastics) emerged. But, joints produced by both adhesive bonding and thermal bonding proved difficult to inspect for defects and even more difficult, if at all possible, to repair.

Finally, it occurred to designers that by designing into parts geometric features that explicitly enabled and allowed interlocking between mating parts, several problems could be overcome at once. First, the need for supplemental

[4] A similar thing happened with the appearance of reinforced plastics and other composites, when rivets were used to assemble parts made from composite materials in the aerospace industry, based more on experiential knowledge and facility than on purely technical rationale.

[5] "Viscoelastic strain behavior" means that, after responding elastically, and perhaps also plastically, to a load immediately upon its application, a material continues to strain with time, albeit at a decreasing rate. Likewise, upon unloading, the material immediately recovers the elastic component of strain and then continues to recover some additional strain with time.

fasteners was virtually eliminated, precluding problems both of logistics in production manufacturing and with the often labor-intensive preparation of suitable fastener holes. Second, by taking advantage of the inherent property of polymers to deflect easily under the application of a force and to recover (at least partially), catch-latch mechanisms for attachment could be created. Integral snap-fits were born! Of course, what appeared as an unexpected by-product—and bonus—was an embedded system for quality assurance (i.e., listening for and/or sensing the force response associated with the snap's recovery). Beyond these advantages are: partial or complete elimination of fixtures and/or tools for assembling parts, since snap-fit joints tend to self-align, self-key, and, thus, self-fixture; elimination of fastener fallout, with the attendant dangers posed to young children who often put such small objects in their mouths and choke; and security against unwanted disassembly without specific knowledge of where integral attachment features are located within the interior of a closed assembly and, perhaps, the requirement for specialized tools.

There are almost as many different designs of snap-fits as there are designers. That's both the good news and the bad news. It's good news because it suggests there should be a design suitable for the assembly of almost any type of parts for any type of situation, including: prevention of unwanted movement in selected directions, ease of insertion of one part into another during assembly, strength of retention against unintentional disengagement, and so on. It's bad news because without some standardization of designs, new designers, unfamiliar with snap-fits from previous experience, may be too intimidated to try them in a design. The really good news is that there have been a relatively small and manageable variety of snap-fit feature types for which there is now fairly significant information on application, at least as guides.[6] The following major types (as sub-classes) of snap-fits will be described[7]:

- Cantilever hooks
- Cantilevered holes or window snaps
- Annular and leaf-spring snaps
- Ball-and-socket or post-and-dome snaps
- Compression hooks and L-shaped and U-shaped hooks
- Compression traps and beams
- Bayonet-and-finger snaps
- Torsion snaps

[6] In fact, in a paper by Genc et al (1997), an attempt was made to enumerate the number of possible designs based on some key factors relating to the fundamental geometry of the parts being assembled.
[7] The particular contribution of descriptions from Dr. Dean Q. Lewis, former graduate student leader of the Integral Fastening Program at Rensselaer Polytechnic Institute, Troy, NY, after 1999, is gratefully acknowledged (Lewis, 2005).

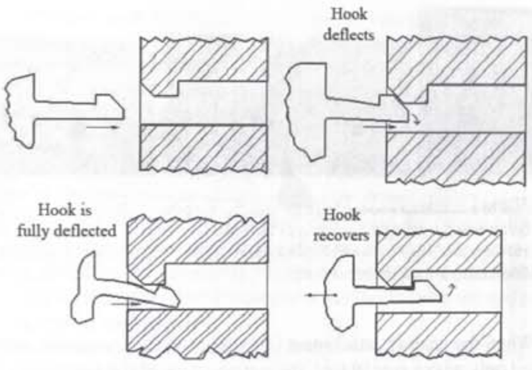

FIGURE 4.3 A schematic illustrating the key steps in the process of assembling cantilever hook snap-fits.

4.3.1 Cantilever Hooks

The most familiar of snap-fit features is surely the basic *cantilever hook*. The latch in this snap-fit locking pair[8] is composed of an elastic beam with a trapezoid-shaped head located at its free end referred to as the "hook." The body of the cantilever hook, that is, the beam portion, is integral to the part at its root. The hook-shaped latch of the cantilever hook snap-fit is paired with a catch that can be a raised ledge protruding from the wall of a mating part, a hole in the wall of a mating part, or even the edge of the mating part itself. The elastic beam portion of the latch feature may be tapered so that the cross-section at the base is larger than just beneath the head or hook, further facilitating beam deflection. The cross-section itself may be rectangular, trapezoidal, or curvilinear (e.g., a circular arc).

Cantilever hook features should be designed (as with all snap-fit pairs) so that the distance between the latch and catch will result in the latch being fully engaged with and locked to the catch when the parts are fully mated. As the active features on a mating part and a base part are brought into closer proximity so that contact first occurs between them, the catch feature will contact the hook along its angled face and, thereby, cause the beam to deflect back as the insertion motion continues. Once the head has passed the recessed edge of the catch, the elastic stress in the deflected cantilevered beam will cause it to "snap" into place.

Figure 4.3 shows the key steps in the process of assembling cantilever hook snap-fits.

[8] Recall from Chapter 3, Section 3.8, Bonenberger (2000) recognized that snap-fits fall into two broad categories: locating features (or locators) and locking features. The former are almost always rigid integral features and serve to help guide and fix the position of a mating part on a base part. The latter are always elastic integral features and serve to actually hold parts together once they are fully and properly engaged one with the other.

FIGURE 4.4 The use of a cantilever hook snap-fit for securing the cover of the battery compartment for a TV hand-held remote control unit by sliding the cover until the hook (left) engages the unit's housing (middle), is deflected, and then recovers and locks the cover in place (right). (Photographs taken by Sam Chiappone for the author, Robert W. Messler, Jr.; used with permission.)

When the snap-fit attachment is designed to be permanent and to be disengaged only with a special tool, the mating edges of the cantilever's head and the catch should be nearly perpendicular to the elastic beam. In this case, if access is allowed during design by placement of a molded-in hole in a plastic part, the snap can be disengaged by physically causing the elastic beam to deflect back so that the latch and the catch disengage. If a sloped edge (without a re-entrant angle) is used for either the cantilever hook's head or the mating catch's edge, a sufficient force in the separating direction will cause the two to disengage.

The insertion and retention forces for the cantilever hook snap are dependent upon the physical dimensions of the elastic beam (i.e., length, width and depth, cross-sectional shape, and taper) as well as on the angles and height of the head or hook. The material properties of the feature (e.g., flexural modulus, yield strength, fracture strength) are, obviously, also important, but are fixed by the material used to make the parts.

Figure 4.4 shows the use of a cantilever hook snap-fit on the sliding cover for the battery compartment of a hand-held TV remote control unit.

Cantilever hooks offer easy push assembly, reasonably secure locking for preventing motion in controlled directions by proper feature placement and orientation, and flexibility to resist shock loads (e.g., from dropping).

4.3.2 Cantilevered Holes or Window Snaps

A similar feature to the cantilever hook type of snap-fit is the *cantilevered hole feature,* also known as a *window snap feature*. The major difference from the cantilever hook is that the elastic beam member of the locking pair contains a hole or window instead of a protruding head or hook. Most designs will have a rectangular cross-section for the elastic beam portion, but a curvilinear cross-section could also be employed. The mating catch for this type of latch must be a feature that will cause the elastic beam to deflect back during assembly, and then once the hole clears and aligns with a similar-shaped protrusion on the

more rigid catch, the beam will recover and the parts will be locked or latched. Both the assembly and the disassembly processes for the cantilevered hole-type snap are similar to the cantilever hook-type snap. The insertion and retention forces for this type of snap are, as they are for the cantilever hook, dependent upon the physical dimensions of the beam (e.g., length, width and depth, moment of inertia), as well as by the angles and height of the catch.

The cantilevered-hole snap-fit also operates with a simple push and is capable of resisting unwanted movements by proper placement (i.e., location and orientation) of the latch-catch pairs. Otherwise, the choice between this and the cantilever-hook snap-fit is largely based on convenience in the molding of parts and, possibly, clearance issues in the assembly (see Section 4.6).

Figure 4.5 schematically compares the cantilever hook and cantilevered hole snap-fits as mating pairs.

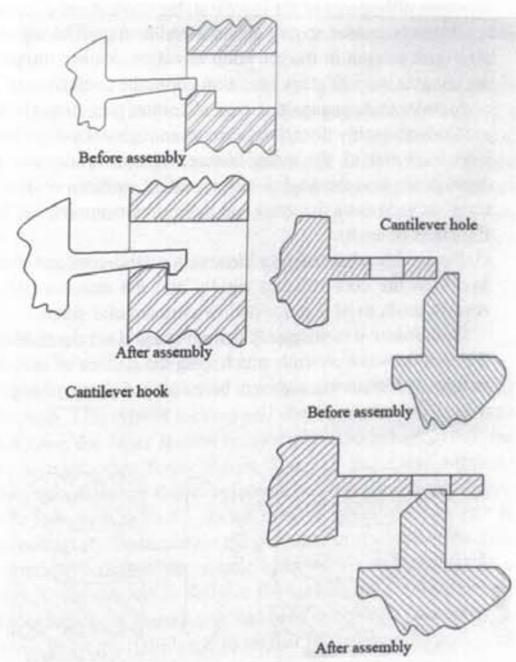

FIGURE 4.5 A schematic illustration comparing the cantilever hook and cantilevered hole snap-fits, shown before and after assembly in each case.

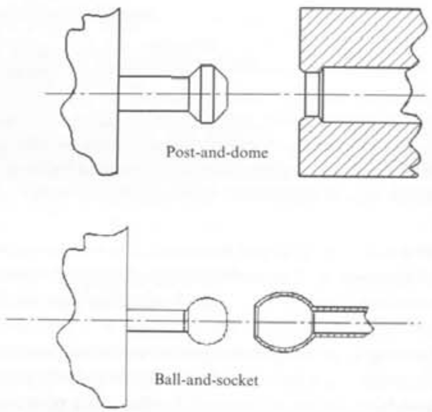

FIGURE 4.8 Schematic illustrations of a couple of common post-and-dome snaps, the lower one of which is a ball-and-socket snap.

Once mated, this type of feature pair will restrict displacement motion but allow rotational motion around the centerline of the post and some limited rotation about the two axes orthogonal to this axis. Disengagement for this type of feature pair can only occur when enough force is applied in the disassembly direction to cause the socket to expand enough to release the ball end of the post. The diameter of the ball and of the socket, as well as the wall thickness of the socket, will determine the insertion and retention forces. Retention force can be enhanced by designing the socket to have re-entrant angles and no sloping surface to aid extraction of the ball.

Figure 4.8 schematically illustrates a couple of common post-and-dome snaps, one of which is commonly, and understandably, referred to as a "ball-and-socket" snap. Hip and shoulder joints in humans, and many other animals, employ a ball-and-socket configuration.

4.3.5 Compression Hook and L-shaped and U-shaped Hooks

A traditional cantilever hook feature will experience tensile forces while under retention. By modifying the design of the cantilever hook slightly, it can be made to experience compressive forces and provide a strong snap in a small feature. The compression hook snap engages in a similar way to the cantilever hook in that the elastic beam portion deflects away as the angled face of the head passes over and passed the catch. But, since the beam is under compression to keep the parts mated, either it will need to be physically moved away from the catch or enough force will need to be applied to buckle the beam in order to cause disengagement.

This type of snap is commonly used for small electrical connections, including telephone jacks. The cross-section of the beam portion of the latch feature may be tapered. The cross-sectional shape, as well as the physical dimensions of the beam and the engaging head, are factors that determine the insertion and retention forces.

Figure 4.9a schematically illustrates a compression hook.

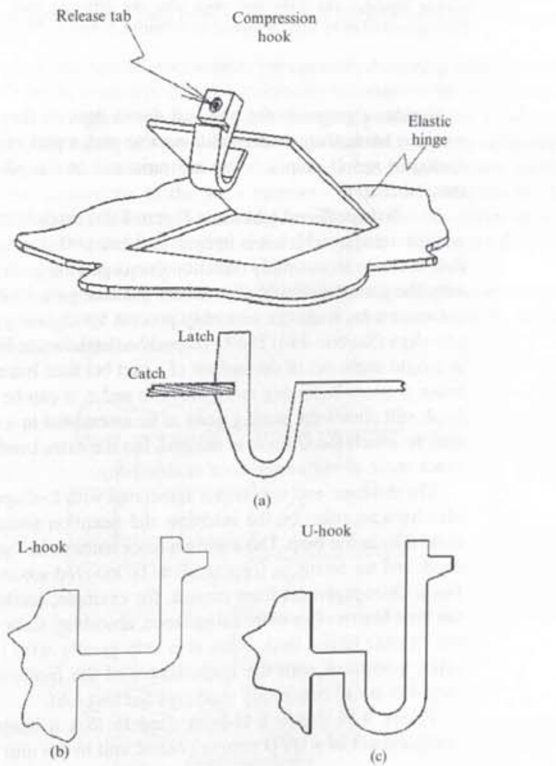

FIGURE 4.9 Schematic illustrations of the operation of a compression hook (a), and an L-shaped hook (b) and a U-shaped hook (c).

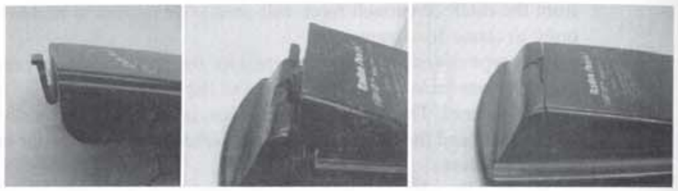

FIGURE 4.10 The use of a U-hook snap-fit for securing the cover of the battery compartment of a DVD hand-held remote control unit by engaging rigid hinges at the left end of the cover (in the photo) and tilting it downward until the U-hook (right) engages the edge of the opening in the unit's housing (middle) and locks into place after the deflected hook recovers elastically (right). (Photographs taken by Sam Chiappone for the author, Robert W. Messler, Jr.; used with permission.)

Besides changes to the physical dimensions of the snap feature in a compression hook, their base conditions also play a part in their performance. The *L-shaped* and *U-shaped hooks* are variations of the compression hook type of integral snap-fit.

The *L-shaped hook* (shown in Figure 4.9b) extends at a right angle out of the wall of a part to which it is integral and has a 90-degree bend in the beam portion to create an assembly direction that is parallel to the wall's surface.[9] In this way, the mating part will slide across the base part during assembly, which can sometimes facilitate the assembly process by allowing features to be mated to pre-align (Section 4.6). The *U-shaped hook* (shown in Figure 4.9c) also extends at a right angle out of the surface of a part but then has a 180-degree bend in its beam portion. Referring to Figure 4.9b and c, it can be seen that the U-shaped hook still allows the mating parts to be assembled in a direction parallel to the wall to which the U-hook is integral, but the extra bends give this snap feature much more elastic compliance or flexibility.

The different end conditions associated with L-shaped and U-shaped hooks also have an effect on the insertion and retention forces as they provide more flexibility in the snap. The insertion force tends to be "softened" more than lessened, and the retention force tends to be lowered somewhat; however, unintentional disengagement from impact, for example, tends to be reduced because the bent beams offer more compliance, absorbing some of the shock impulse in the flexible beam. Both types also help greatly with tolerance issues that are often associated with the manufacture of the molded plastic parts in which snap-fits are so commonly used (see Section 4.6).

Figure 4.10 shows a U-hook used to lock a hinged cover to the battery compartment of a DVD remote control unit to the unit's housing.

[9] In most instances, assembly motions are perpendicular to the placement of the base of an integral snap-fit feature.

4.3.6 Compressive Traps and Beams

The concept of a plug (such as a split clevis) that is inserted into a hole and then expands by recovering elastically on the opposite side so that it cannot be removed is the idea behind a *compressive beam snap*. Many variations of this snap exist, but the general form consists of a rigid post with flexible members protruding from it to act as the latch features in a locking pair. When the post is inserted through a hole (which serves as the catch feature in the locking pair), these flexible members are forced to elastically deflect back toward the post, allowing the post plug to pass through the hole. Once fully engaged, the deflected members recover to their original, pre-deflected positions. Together, they then prevent the post plug from passing back through or being withdrawn from the hole.

To disengage this type of snap without permanently damaging either it or the mating part's catch, some type of tool is necessary to compress the relaxed latch members close enough to the post to allow the plug portion to be withdrawn from the hole. Since there are many different ways that the latches in such snaps can be implemented, the insertion and retention forces are dependent on the design details, dimensions of the latch members, and the orientations of the latch members. Compressive trap-type snap-fits all share the sometimes advantageous characteristic that they tend to resist disengagement the more they are forced to disengage improperly.

Figure 4.11 schematically illustrates a couple of designs for a compressive trap and one design for what is known as a *compressive beam snap-fit*, which operates virtually the same way.

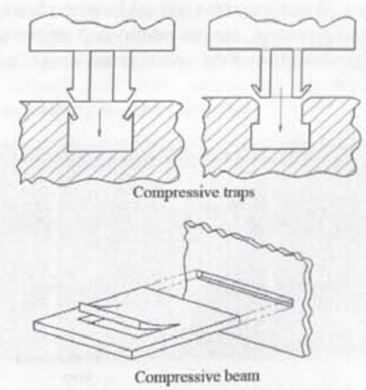

FIGURE 4.11 Schematic illustrations of two different compressive traps (top) and a compressive beam (bottom) snap-fit locking pair.

4.3.7 Bayonet-and-Finger Snaps

Occasionally, features from different types of snap-fits can be combined to create a different type of snap with different beneficial attributes. The *bayonet-and-finger snap* is an example of this, being a cross between a cantilever hook and a compressive trap integral attachment feature.

In a bayonet-and-finger snap, two "fingers" or trap features project out of one of the parts to be mated, and a cantilever hook or "bayonet" feature projects from the other part so that it must pass between the two fingers (Figure 4.12). The fingers must be designed so that the space between their tips is approximately the width of the beam portion of the bayonet below the head. As the two features of a locking pair are brought together, the fingers deflect back to allow the head of the bayonet to pass between them, after which they elastically recover and act as supports to keep the features and parts attached.

The finger that engages the head of the bayonet can move slightly with the head, keeping the engagement intact, and would need to either buckle or be physically moved by a tool in order to release the bayonet. The finger behind the head of the bayonet applies pressure on the bayonet to help prevent it from cantilevering away from the engagement finger.

A high (10–20 times) ratio of retention force to insertion force can be obtained with this type of locking pair. In order to disengage this type of snap, a tool capable of separating the fingers enough to allow the bayonet's head to be released would be needed. Additional strength can be obtained by designing the bayonet to have a head that protrudes in both directions, rather than in only one direction, so that both fingers will be engaged simultaneously. The physical dimensions of the bayonet (e.g., length, width, and depth of the beam portion, as well as dimensions and angles of the head) and the physical dimensions of the fingers (e.g., length, width, and depth) and the angle at which they protrude, all influence the insertion and retention forces for this snap.

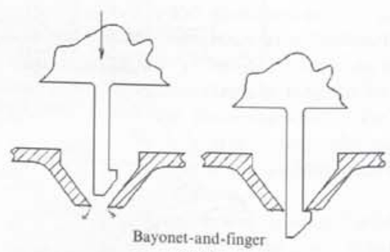

FIGURE 4.12 A schematic illustration of a bayonet-and-finger snap, shown before and after assembly.

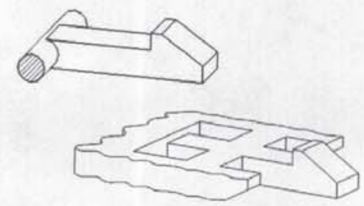

FIGURE 4.13 Schematic illustrations of two different designs for torsional snaps.

The snaps discussed above are the most commonly used examples, but this list is not exhaustive. Many other types of integral attachment snap-fit features have been designed and applied with success. Specific needs can be addressed with unique designs that may find only limited use. All, however, are based on elastic beams.

One more example is noteworthy, that is, torsional snaps.

4.3.8 Torsional Snaps

If it is desired that the typical pushing and pulling forces and motions that parts undergo not cause the snap-fit to disengage, a *torsional snap* can be used. Here, the latch feature in the mating part pair is engaged and disengaged with a twisting motion of its elastic beam, instead of a cantilever motion. The catch feature can be designed to impose a twist to the latch during assembly, but a tool would be needed to cause the torsional motion on the latch to cause it to disengage. A familiar example of torsional snaps is found in some plastic medicine bottles. A couple of designs for torsional snaps are shown schematically in Figure 4.13.

Figures 4.14 through 4.19 show applications of various elastic integral snap-fit features in plastic parts and assemblies.

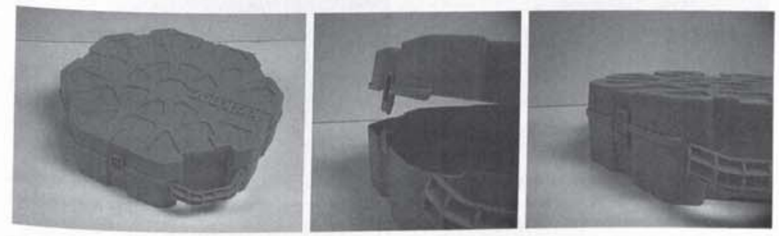

FIGURE 4.14 The use of a cantilevered hole type snap-fit to serve as the easy to operate, but still effective latch for the lid of a child's tool kit. The toolkit is shown having the cover-securing latch snapped together. (Photograph courtesy of KNex Industries, Inc., Hatfield, PA; used with permission.)

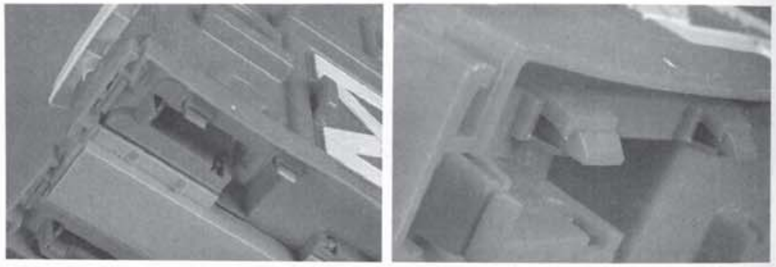

FIGURE 4.15 Multiple bayonet-and-finger-snaps (overview at left and close-up at right) are used in the assembly of the barn to the base of the Little People Farm™ shown in Figure 2.9. (Photograph courtesy of Fisher-Price; used with permission.)

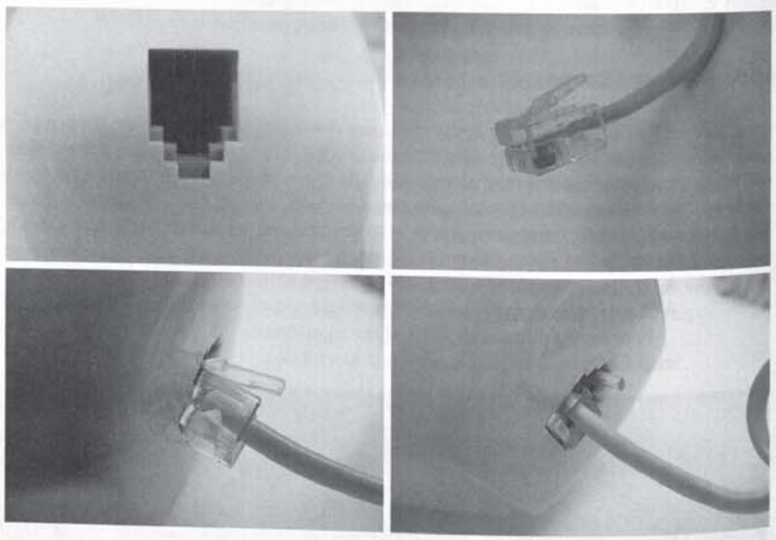

FIGURE 4.16 Photographs showing the use of a compression trap snap-fit at the end of the coiled wire that connects to a telephone receiver and wall jack. The receptacle in the end of the telephone (upper left) is shaped to accept the compression trap connector fitting on the end of the coiled wire (upper right) in only one orientation. As the compression trap connector enters the receptacle (lower left), the spring on the snap-fit is deflected to allow engagement. Once the connector is fully inserted, the deflected spring recovers elastically and locks the connector into the receptacle (lower right). (Photographs taken by Sam Chiappone for the author, Robert W. Messler, Jr.; used with permission.)

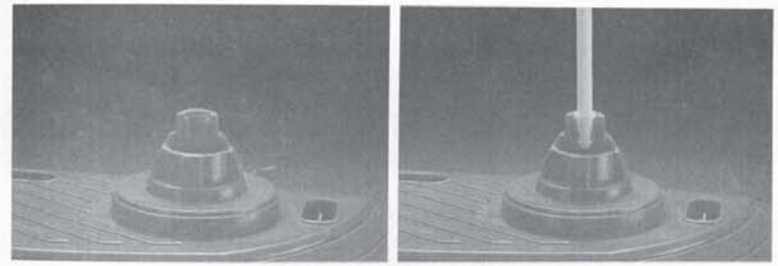

FIGURE 4.17 Photograph showing the use of an annular snap-fit in a child's toy. The cut-away annulus (left) is elastically deflected by the relatively more rigid post to allow engagement and locking (right). (Photograph courtesy of Fisher-Price, East Aurora, NY; used with permission.)

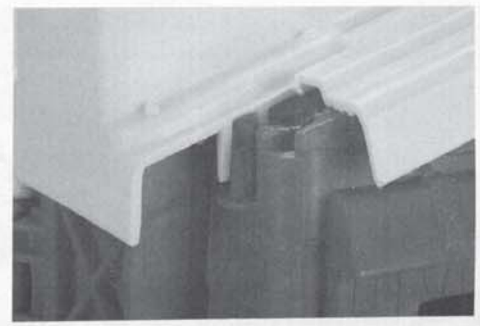

FIGURE 4.18 Another type of annular snap uses molded-in serrations to create a pine tree–like shape that aids in interlocking in an annulus simply from compression forces from elastic spring-back and from friction. (Photograph courtesy of Fisher-Price, East Aurora, NY; used with permission.)

4.4 DESIGN ANALYSIS FOR SNAP-FITS

By now it should have become apparent that integral snap-fits are a very simple, economical, and rapid way of joining two different components to produce an assembly. The common characteristics of all integral elastic snap-fit locking features are as follows:

- All types have in common a protruding portion on one component that engages a depression or undercut in the mating component, one acting as a latch and the other as a catch.

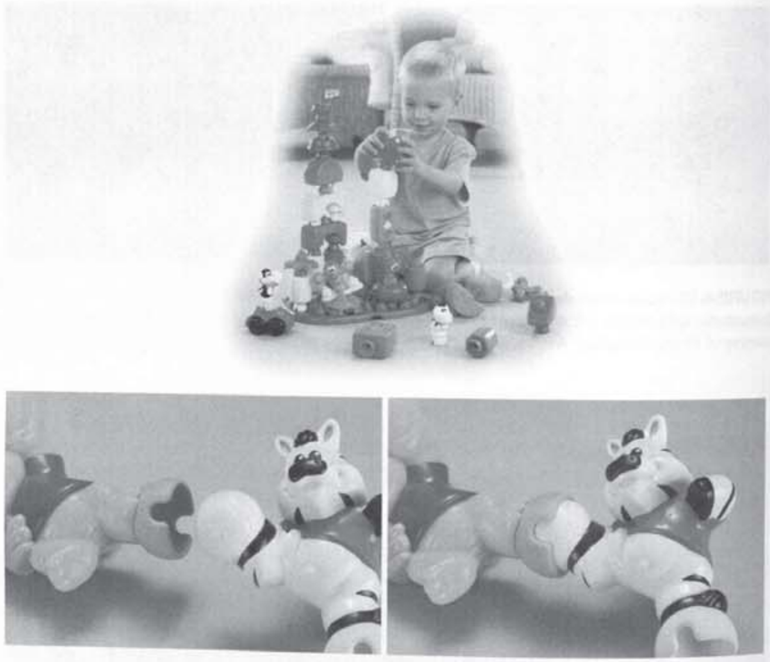

FIGURE 4.19 Ball-and-socket snap-fit joints allow children to easily assemble and disassemble parts of toys intended for this educational and entertainment purpose (top). Details of one such joint can be seen in the lower left and lower right images. (Photographs courtesy of Fisher-Price, East Aurora, NY; used with permission.)

- The catch-latch pair of integral locking features operates during assembly by either one deflecting elastically and the other remaining relatively rigid.
- After the joining operation, the integral locking joint features should return to a stress-free state.
- The resulting joint may or may not be separable, depending on the detailed shape of the undercut and the protruding feature.
- The force required to cause assembly (i.e., the insertion force) is typically low and is always 2–20 times lower than the retention force holding the assembly together.
- The force required to separate the components varies greatly depending on the design of the mating features—for a particular material of construction.
- Since they operate elastically, design analysis is based on elastic beam theory (Pilkey, 2002).

In the previous section (4.3), it was apparent that there are a wide range of design possibilities for snap-fit joints. Calculation principles have been derived (analytically, numerically, or empirically from experimental data, depending on the feature complexity) for many types including: cantilever hooks (Luscher, 1996); post-and-dome (Nichols and Luscher, 2000); compression hook (Lewis et al, 1997); bayonet-and-finger (Lewis et al, 1997); and annular snaps (Bayer Polymers Division, 1998).

Because polymers[10] normally exhibit high levels of flexibility, they are particularly well suited materials for elastic snap-fit assembly. Not surprisingly, a number of major polymer manufacturers have prepared excellent design manuals or guides for plastic snap-fit joints (Allied Signal Plastics; BASF; Bayer Polymers Division; DSM Engineering Polymers; Dupont Polymers; GE Plastics; Hoechst Celanese/Ticona). These have tended to focus on three major categories of snap-fits, and calculation principles have been rather well developed for these three, including:

1. *Cantilever snap joints,* for which the load is mainly flexural
2. *Torsion snap joints,* in which shear stresses carry the load
3. *Annular snap joints,* which are rotationally symmetrical and involve multiaxial stresses

Table 4.1, taken from the fine design guide by Bayer's Polymer Division (formerly Miles-Mobay) (Pittsburgh, PA), gives equations for calculating permissible deflection[11] y and deflection force P for cantilever snap features with various beam cross-sections. Figure 4.20 gives the geometric factors K (upper portion of the figure) and Z (lower portion of the figure) required for ring segments in Table 4.1.

The most comprehensive discussion of design using integral elastic snap-fit features appears in the seven-part series by Messler et al, (1997–1998).

4.5 COMBINING ASSEMBLY MOTIONS FOR SNAP-FIT ASSEMBLY SECURITY

Anyone who has been around long enough knows that if something can go wrong, it will go wrong.[12] To those involved with joining, this appears as if something can be disassembled intentionally, it can disassemble accidentally. We have all experienced this, but let me give one personal example specific to elastic integral snap-fits.

[10] While commonly known as "plastics" in the vernacular, materials scientists and engineers tend to refer to these materials as polymers.

[11] "Permissible deflection" derives from the permissible strain for the polymer used in the snap feature, which relates to a yield point for the material, and on the shape of the beam.

[12] This is popularly known as "Murphy's Law" and has a corollary that states, "And, when something does go wrong, it will do so at the worst possible time." While not a law of physics, it surely seems to be a perverse fact of life.

TABLE 4.1 Equations for dimensioning cantilevers (From Snap-fit Joints for Plastics—A Design Guide, 1996, Bayer Polymer Division, Bayer Corporation, Pittsburgh, PA [formerly Miles-Mobay Corporation]; used with permission.)

Type of design ▼ / Shape of cross section ►	A Rectangle	B Trapezoid	C Ring segment	D Irregular cross section
(Permissible) deflection 1: Cross section constant over the length	$y = 0.67 \cdot \frac{\epsilon \cdot l^2}{h}$	$y = \frac{a+b_{(1)}}{2a+b} \cdot \frac{\epsilon \cdot l^2}{h}$	$y = K_{(2)} \frac{\epsilon \cdot l^2}{r_2}$	$y = \frac{1}{3} \cdot \frac{\epsilon \cdot l^2}{c_{(3)}}$
(Permissible) deflection 2: All dimensions in direction y, e. g., h or Δr, decrease to one-half	$y = 1.09 \cdot \frac{\epsilon \cdot l^2}{h}$	$y = 1.64 \frac{a+b_{(1)}}{2a+b} \cdot \frac{\epsilon \cdot l^2}{h}$	$y = 1.64 \cdot K_{(2)} \frac{\epsilon \cdot l^2}{r_2}$	$y = 0.55 \cdot \frac{\epsilon \cdot l^2}{c_{(3)}}$
(Permissible) deflection 3: All dimensions in direction z, e. g., b and a, decrease to one-quarter	$y = 0.86 \cdot \frac{\epsilon \cdot l^2}{h}$	$y = 1.28 \frac{a+b_{(1)}}{2a+b} \cdot \frac{\epsilon \cdot l^2}{h}$	$y = 1.28 \cdot K_{(2)} \frac{\epsilon \cdot l^2}{r_2}$	$y = 0.43 \cdot \frac{\epsilon \cdot l^2}{c_{(3)}}$
Deflection force 1, 2, 3	$P = \overbrace{\frac{bh^2}{6}}^{Z} \cdot \frac{E_s \epsilon}{l}$	$P = \overbrace{\frac{h^2}{12} \cdot \frac{a^2+4ab_{(1)}+b^2}{2a+b}}^{Z} \cdot \frac{E_s \epsilon}{l}$	$P = Z_{(4)} \cdot \frac{E_s \epsilon}{l}$	$P = Z_{(4)} \cdot \frac{E_s \epsilon}{l}$

Subscript numbers in parenthesis designate the note to refer to.

Symbols

y = (permissible) deflection (= undercut)

ε = (permissible) strain in the outer fiber at the root; in formulae: ε as absolute value = percentage/100 (see Table 2)

l = length of arm

h = thickness at root

b = width at root

c = distance between outer fiber and neutral fiber (center of gravity)

Z = section modulus $Z = \frac{I}{C}$, where I = axial moment of inertia

E_s = secant modulus (see Figure 16)

P = (permissible) deflection force

K = geometric factor (see Figure 10)

Notes

(1) These formulae apply when the tensile stress is in the small surface area b. If it occurs in the larger surface area a, however, a and b must be interchanged.

(2) If the tensile stress occurs in the convex surface, use K_2 in Figure 10; if it occurs in the concave surface, use K_1 accordingly.

(3) c is the distance between the outer fiber and the center of gravity (neutral axis) in the surface subject to tensile stress.

(4) The section modulus should be determined for the surface subject to tensile stress. Section moduli for cross-section shape type C are given in Figure 11. Section moduli for other basic geometrical shapes are to be found in mechanical engineering manuals.

Permissible stresses are usually more affected by temperatures than the associated strains. One preferably determines the strain associated with the permissible stress at room temperature. As a first approximation, the computation may be based on this value regardless of the temperature. Although the equations in Table 1 may appear unfamiliar, they are simple manipulations of the conventional engineering equations to put the analysis in terms of permissible strain levels.

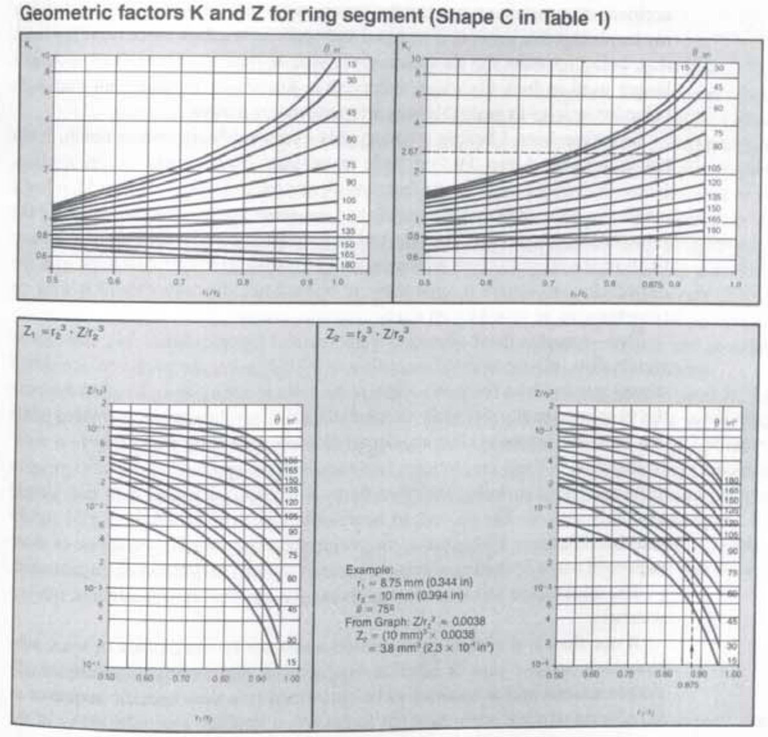

FIGURE 4.20 Plots for determining geometric factors K (top) and Z (bottom) required the design of cantilever hooks consisting of ring segments. (From *Snap-fit Joints for Plastics—A Design Guide*, 1998, Bayer Polymer Division, Bayer Corporation, Pittsburgh, PA [formerly Miles-Mobay Corporation]; used with permission.)

Years ago, I had a wristwatch that had a stainless steel linked wristband that latched with a thin sheet-metal hinged piece with two small tabs or prongs at its free end. These were angled inward, toward the wearer's wrist, and were designed to contact a round pin on the catch portion of the band. They did so by deflecting elastically a small amount until they cleared the pin, at which point there was a distinct and characteristic snap that ensured that the clasp was fully engaged and locked in place.

One day during a lecture on joining, ironically, I clapped my hands together fairly vigorously to make a point about impact loading on joints, and when I did, the clasp of my watchband sprang open and the watch slid up my hand, nearly flying off! What had happened, which I immediately turned from an accident of a fortuitous and timely lesson, was that the impact from clapping my hands together generated an equal and opposite reaction force (ala Newton!) that, being opposite the direction of the simple push motion (albeit around a hinge) used to lock the clasp, unlocked it. I went on to point out that such behavior in snap-fit assembly was an ever-present danger.

Sometime later, I bought a new, highly-esteemed Swiss-made watch. It too had a wristband that latched with an integral elastic snap-fit on a clasp. However, besides being made from stainless steel and 18k yellow gold, it had a small clip-like cover that hinged around the same pin used as the catch for the pronged, latching clasp. The clip had to be rotated out of the way of the clasp to allow the clasp to close with a snap and then had to be rotated back over the closed clasp to secure it against being opened accidentally should it snag on something or be jarred by an overly vigorous owner.

Two—actually three—lessons were learned by me from this fine Swiss watch: first, elastic integral snap-fit assembled joints are prone to accidental disengagement by a force of sufficient magnitude acting in a direction opposite the simple assembly direction. Second, elastic integral snap-fit assembled joints can be made secure against accidental disengagement by designing in a security feature.[13] There are, in turn, two fundamental approaches for designing-in security. The first, to be described here, is to combine more than one simple assembly motion. The second, to be described in Section 4.6, is to add certain additional features that enhance the performance of the snap-fit in one or more of several ways, including enhanced security against accidental disengagement.

The third lesson was that "You get what you pay for" in watchbands, not just watches.

If one thinks of a child-proof plastic container for medicines or toxic substances, most have caps or lids that require a specific combination of relatively simple actions and/or motions to be performed in a very specific sequence or simultaneously and with the right forces. As a familiar example, many of the caps on over-the-counter pain remedies (such as aspirin) require that they be pushed down (against a resisting spring-action) and turned once they come up against a fixed stop. This is all accomplished by proper design placement and sizing of various protruding and recessed features in the cap and or bottle's mouth. Another example appears in the covers to battery compartments on hand-held telephones, calculators, cameras, and toys. To remove the cover requires a slight downward push and a simultaneous slide in the proper direction. What both of these combinations do is drastically reduce the probability that such coordinated (i.e., simultaneous or sequential) actions could occur accidentally, say, by dropping the assembly.

So, by combining two or more simple assembly motions into a precise sequence or to be performed simultaneously, accidental disengagement is quickly reduced to a near-zero probability.

[13] Women and men know the principle of security locks from their common use on the clasps of fine jewelry.

4.6 SNAP-FIT FEATURE ENHANCEMENTS

It has been said that "Good designs work and great designs give pleasure." The difference is often more attention to detail than anything else. The designer thinks about not only what the design must do, and makes sure it will do it, but also about how to produce the actual device or structure to ensure it will be correct and how to ensure that the user uses it to its fullest potential. In the design of plastic parts that will be assembled using integral snap-fit features, these worthy goals are often ensured through the use of *enhancements*. While they may not be essential to the design of a snap-fit assembly, enhancements complete the snap-fit system by adding robustness and user-friendliness to the part and to the assembly portion of the manufacturing process and to product use. According to Bonenberger (2000), *enhancements* in snap-fit design are the third component required to form a mechanical attachment between parts beyond the proper selection and arrangement of locators and locks, which have already been discussed elsewhere.

Enhancements can and probably ought to be used at several stages in the evolution and production of a snap-fit assembly, including: (1) for supporting the actual assembly of mating and base parts; (2) for achieving optimum, beyond proper, snap-fit performance; (3) for supporting the physical activation and use of snap-fits; and (4) for supporting the manufacturing of detail parts of a snap-fit assembly. Each of these, and more, is covered thoroughly by Bonenberger (2000) in his fine book *The First Snap-fit Handbook: Creating Attachments for Plastic Parts*, as well as other references on plastic part design (Tres, 2000). What will be given here is a short overview.

4.6.1 Enhancements to Assembly

It is possible, and worthwhile, to employ certain features and attributes[14] that specifically support the assembly of a product using snap-fits. Doing so improves both the consistency and the efficiency of the assembly process. Possible enhancements for assembly are of three types: (1) physical features that provide guidance for locating the mating part to the base part to reduce the actual process of assembly to only the final simple motion needed to achieve engagement and locking; (2) the attribute of clearance that assures that once a mating part is brought to a base part nothing will interfere with its engagement and locking; and (3) the attribute of feedback to verify to the assembly operator or device (e.g., robot) that assembly and locking have occurred properly. Guidance, clearance, and feedback are three enhancements to assembly worth considering a little more.

Guidance is achieved using separate and distinct physical guides or using the added detail of a pilot or pilots on snap-fit feature locating and/or locking

[14] "Attributes" are to designs and processes what desirable properties are to materials.

features. *Guides* are added physical details or features that help the assembly process by simplifying the coarse or gross movements needed to bring mating parts to base parts to even begin their assembly. Most often, guides stabilize the mating part to the base part. Examples of common guides are integral pins or posts that extend from the mating and base parts to help align the parts for proper nesting and the locking features for proper attachment, or, alternatively, guiding extensions on the locking features themselves. Bevels, tapers, reduced sections at free ends are all examples of guiding extensions. *Pilots* are another form of details added to locking features that help them align with one another upon initial contact. Pilots are usually reduced sections on posts or pins but can take other forms.

Clearance needs to be dealt with by the designer at the point that locating and locking features are being placed on parts, and even earlier as the parts are being designed to perform their needed function(s). Walls, stiffeners, support posts, and all other features required for structural integrity and for assembly must be considered when two or more parts are to be joined. Details of one part cannot, obviously, physically interfere with details of another part if they are to mate properly. Likewise, actual locator and lock features must be selected (by type), located, and sized to preclude interference during assembly.

Feedback to verify proper assembly uses a combination of visual, audible, and tactile signals, including the distinctive "snap" that gives snap-fits their name. Beyond actually adding visual guides or cues, and audible and tactile "snaps," the designer can and should be sensitive to the "feel" during assembly. Feel, whether to be sensed by a human operator or an automated device (through sensors), is somewhat more esoteric. It involves controlling the force-deflection signature for the snap-fits. A familiar example of feel in assembly is how one senses whether a nut is being placed onto a bolt correctly, or not. If the nut is slightly off-angle, the external and internal threads engage incorrectly in what is known as "cross-threading." This can be felt by the lack of smoothness and eventual sticking of the nut and bolt.

4.6.2 Enhancements for Performance

The performance of snap-fit features in integral attachment to have them not only work properly but also work optimally can be enhanced through the use of physical guards and/or retainers and/or through part and/or feature compliance. *Guards* are physical details designed and fabricated into mating and base parts that protect sensitive locking features from damage. *Retainers* are physical details that provide lock and locking strength and lock performance. *Compliance* is a design attribute that allows the integral attachment features to accommodate dimensional variations in parts so that parts will still assemble without binding or with too much looseness or sloppiness. The designer can develop such compliance through some combination of local yielding in

details, elasticity in details, or, if absolutely necessary, by using isolating materials such as soft (e.g., felt or rubber) fillers, O-rings, cushions, pads, and so on.

Another valuable enhancement for the performance of snap-fit assemblies is the use of *back-up locks*. These extra devices provide a locking alternative in the event the intended lock features cannot provide adequate locking, or fail in service. Most often, back-up locks involve provisions for threaded fasteners (to be installed later, if required), use of special push-in fasteners, or metal spring clips. Many designers frown on the use of such back-up locks because they seem to suggest lack of confidence in the snap-fits. However, for critical assemblies, better to be safe than sorry!

Figure 4.21 schematically illustrates some of the enhancements discussed earlier.

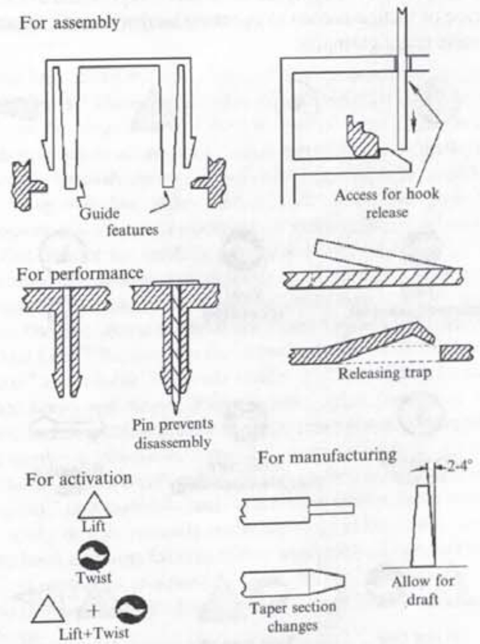

FIGURE 4.21 Schematic illustrations of various enhancements used in snap-fit assembly, for example, for guiding assembly or facilitating disassembly, for enhancing performance, for informing the user how to activate the snap, or for facilitating manufacturing by molding of plastic.

4.6.3 Enhancements for Activating and Using Snap-Fits

One of the advantages of integral snap-fits in the assembly of parts made from plastics is the clean look they provide from outside the assembly. Freedom from obvious fasteners can be purely aesthetic but can also be necessary for proper functionality. Two examples are clearance between nesting assemblies and aerodynamic smoothness. However, when integral snap-fits are used, one of the problems encountered with them is that they cannot be seen—and thus located—from outside the assembly. If they cannot be seen, it is very difficult to disassemble the assembly, which might be the intent, that is, to make the assembly tamper proof! Another problem is, even if they can be located, they cannot be disengaged. This is where some combination of mechanical and informational features can help support attachment usage and, particularly, disassembly for some essential purpose (e.g., repair or ultimate disposal).

On many snap-fit–assembled devices, molded-in, embossed, or adhesive-labeled written or symbolic information is provided to identify the presence and type of motion needed to operate a hidden snap-fit feature. Figure 4.22 shows some major examples.

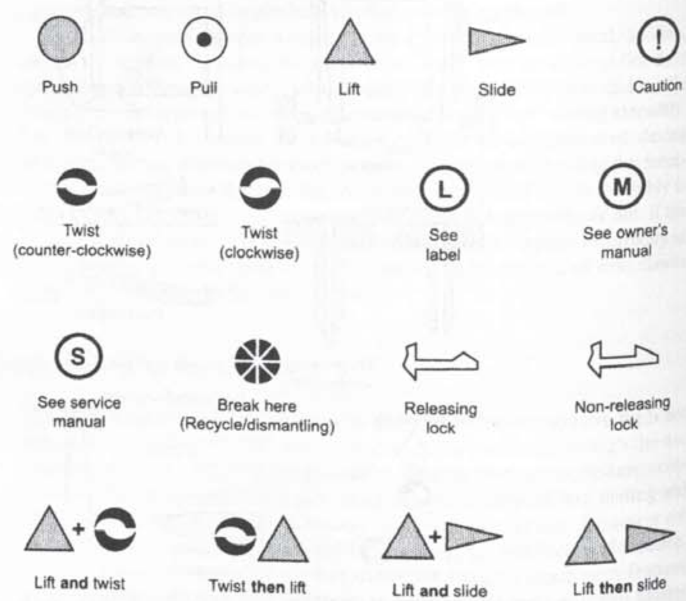

FIGURE 4.22 Symbols used to identify snap-fits and enhance their use. (Used with permission of the publisher from P.R. Bonenberger's fine detailed reference *The First Snap-fit Handbook: Creating Attachments for Plastic Parts*, Hanser Gardner Publications, Inc., Cincinnati, OH, 2000.)

Mechanical assists can also be used to make easier the release of locked features. Typical *assists* include: finger tabs; lock release tabs; recesses for finger pulls; tool access holes; and manufacturer-provided lock-release push-pins.

4.6.4 Enhancements for Snap-Fit Manufacturing

There are a number of ways in which plastic parts that are to be assembled using integral snap-fits can be designed to facilitate the manufacture of what usually turn out to be more geometrically complicated detail parts. The specialized nature of the manufacturing processes used with plastics/polymers, most notably, injection molding, warrants that the interested reader refer to any of several excellent references on plastic parts design for manufacture (Tres, 2000; GE Plastics).

4.7 HOOK-AND-LOOP ATTACHMENTS

Anyone who has walked through a field in the autumn has undoubtedly encountered "thistle burrs." These are the dried seed-bearing pods of the thistle plant, which ensures the perpetuation of the species by having the pods attach themselves to the clothes of an unaware human or the fur of a passing animal. The burrs are small (typically the size of a gumdrop or jellybean), seed-filled hollow spheres bristling with fine spikes with small hooks at their ends. When these hooks encounter any material that consists of woven fibers or of curly hair or fur, they snag that fiber or fur, latching on to travel with the person or animal until they are brushed off, to deposit there seeds and re-generate a new plant.

From Nature's example of the thistle burr were born synthetic *hook-and-loop attachments*. The best known examples are Velcro™ made by Dupont (Wilmington, DE) and Dual Lock™ Recloseable Fasteners made by 3M (Minneapolis/St.Paul, MN). Velcro™ is available in a wide variety of forms (adhesive-backed tapes, double-sided hooks and loops), shapes (sheets, strips, circular or square pads, etc.), colors, and coarseness/fineness (which corresponds to strength of attachment). All employ a two-dimensional (2-D) array of hooked polymeric spikes, analogous to the thistle burrs' spikes. When pushed to intermesh with another piece of Velcro™ or a material (such as a woven fabric), these hooks interlock with other hooks or with naturally-occurring loops in the fabric. This interlocking between hook and loop features allows attachment of one part with bonded-on Velcro™ to another or to a suitable fabric. Velcro™ fasteners are well known for their use in wind-resistant closures on ski jackets and on some athletic shoes in lieu of laces.

Dual Lock™ Recloseable Fasteners by 3M differ somewhat in design, but not in the fundamental concept of interlocking between appropriately shaped elastically-deformable features. Designs exist that consist essentially of a close-packed, orderly 2-D array of posts with free ends that have been thermally

4.8.5 Clamps

Clamps are specially-designed devices to attach one part to another using an elastic squeezing force of some origin. Many require the use of fasteners, such as nuts and bolts or screws to pull split clamp-body elements together. Without going into much detail, because of the sheer variety of clamps, and for the fact that details abound in design handbooks for mechanical engineers (Avallone and Baumeister, 1996; Juvinall and Marshek, 1991; Shigley et al, 2004), there are the following specific types: (1) hose clamps (for joining hoses to nibbles or other fittings); (2) conduit clamps (for securing sheet-metal or plastic conduit or tubing together); and (3) wire and cable clamps (for splicing or otherwise connecting wires or cables to one another or to another part). Figure 4.29 shows some examples of clamps for hoses, conduits, and wires or cables.

4.8.6 Quick-Release Fasteners

There is a special group of fasteners, virtually always involving some type of rotating member that resembles (if it is not actually) a screw, that is intended to allow the quick engagement or intentional disengagement of parts of which

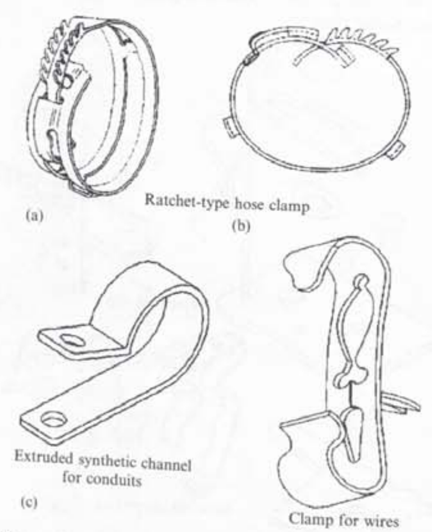

FIGURE 4.29 Schematic illustrations of examples of clamps for hoses (a), conduits (b), and wires or cables (c).

they are a part or with which they are used to hold those parts together. The key characteristic that differentiates *quick-release fasteners* from other fasteners is that they fully engage or disengage with a partial twist rather than requiring several turns. Because the highly specialized nature of these devices, and because they are really fasteners, even though they all operate using the principle of elastic interlocking, details will be left to the interested reader to find in standard handbooks on machine design (Avallone and Baumeister, 1996; Juvinall and Marshek, 1991; Shigley et al, 2004).

Figure 4.30 schematically illustrates some typical quick-release fasteners that operate by the elastic deflection and recovery of integral design features.

4.9 SUMMARY

Integral mechanical attachments can operate by deflecting elastically during assembly, with some degree of recovery to lock the assembled parts together. Such attachments are known as *elastic integral mechanical attachments* or *elas-*

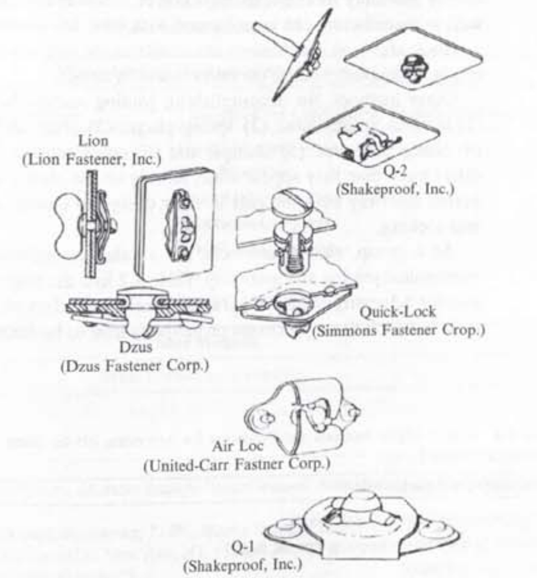

FIGURE 4.30 Schematic illustration of some typical quick-release fasteners, all of which rely on elastic deflection of a design features to operate.

tic interlocks. Because they are inherently highly elastic materials, polymers or plastics are ideally suited to assembly using elastic interlocks; however, metals are another possibility. Elastic integral mechanical attachments used to assemble parts made from plastics are commonly known as *snap-fit features* or simply *snap-fits*. The name derives from the characteristic telltale audible and tactile "snap" that occurs when a deflected feature in a pair of locking features recovers to complete the locking action.

Snap-fits come in a tremendous variety of types, each developed to satisfy a certain design need. The most common types are: (1) cantilever hooks; (2) cantilevered holes or window snaps; (3) annular and leaf-spring snaps; (4) ball-and-socket or post-and-dome snaps; (5) compression hooks and L- and U-shaped snaps; (6) compression traps and beams; (7) bayonet-and-finger snaps; and (8) torsion snaps.

The analysis of snap-fit features for a design has been reasonably well developed for the major types, treating them as elastic beams and using elastic beam theory to calculate permissible deflection and expected/required deflection force.

The security of snap-fits can be increased by employing a combination of simple assembly motions, in sequence or simultaneously, and performance as well as manufacture can be enhanced with what are known as "enhancements."

Hook-and-loop attachments are smaller-scale cousins of snap-fits, with their origin undoubtedly being the burrs found in nature.

Other methods for accomplishing joining using elastic attachments are: (1) integral spring tabs; (2) spring-plugs; (3) snap slides and spring clips; (4) clamp fasteners; (5) clamps; and (6) quick-release fasteners. While they differ more than they appear alike, all rely on the elastic deflection and at least partial recovery of some part in their design to enable and cause attachment and locking.

As a group, elastic interlocks are a valuable approach for accomplishing mechanical joining and assembly. Table 4.2 lists the major processes and methods for achieving elastic integral mechanical attachment, along with the materials in which these processes or methods tend to be found.

TABLE 4.2 List of Major Methods and Processes for Achieving Elastic Integral Mechanical Attachment (and Materials Where Used)

Integral Snap-Fit Attachments
Cantilever hooks (polymers; metal; wood)
Cantilevered holes/window snaps (polymers; metal)
Annular snaps (polymers)
Leaf-spring snaps (polymers; metal)
Ball-and-socket (polymers; metal; bone)

TABLE 4.2 *(Continued)*

	Hook-and-Loop Attachments
Post-and-dome (polymers; metal)	
Compression hooks (polymers)	
– straight	Velcro™ attachments/fasteners (polymers)
– L-shaped	Dual Lock™ recloseable fasteners (polymers)
– U-shaped	
Compression traps and beams (polymers)	
Bayonet-and-finger snaps (polymers; metal)	
Torsion snaps (polymers)	
Other Elastic Attachment Methods	
Integral spring tabs (metal)	
Spring plugs (metal)	
Snap slides (metal)	
Spring clips (metal)	
Clamps (metal)	
– hose clamps	
– conduit clamps	
– wire and cable clamps	
Quick-release fasteners	
Plastic Integral Mechanical Attachments	
Co-formed Features and Interlocks	**Conformed (or Conforming) Features and Interlocks**
Stakes/Staking	Crimps/crimping
Metal clinches/clinching	Hems/hemming
– Tog-L-Locs™	Formed tabs/sheet-metal forming
– Lance-N-Locs™	Indentation-type joints
Formed tabs/Sheet-metal forming	Beaded-assembly joints
	Folded joints
	Roll-and-press joints
Other Methods	
Metal stitches/metal stitching	

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