Things are held together in many ways. A group sat down several years ago, and came up with over two hundred ways that attachments could be made. Among the leaders in the number of currently used attachments are the concepts and designs of plastic snap fits. A quick look around your office or home will show multiple plastic devices held together with snap fit attachments - the battery cover on your Smartphone, the TV remote, the children's toys, and much of your car trim.

Modern design concepts have dictated that metallic fasteners should not be visible cosmetically, (an idea that I as a bolt & nut guy find hard to swallow. I like to know how to take things apart). When coupled with the fact that much modern manufacture is made of plastic, it was inevitable that plastic snap-together joints would surface.

Like them or not, they are here to stay and every designer should be acquainted with the major types and designs and their functioning. The subject matter of snap fits is extremely large and educational courses several hours long on design are available. The best we can do here is to review the most used ones with some data on function, etc. If enough interest is passed on to the editors more articles can be written.

The two most common designs of snap fit fasteners are the cantilever hook and the cylindrical fit. The cantilever (hook) beam type has a lip on one end of the flexible arm which interlocks with a ramp, lip or slot on the other side of the joint. The cylindrical snap type design utilizes a raised projection on a cylinder which interlocks (snaps) into a groove or undercut in a round hole. (Look at your plastic pill bottle- the lid snaps into the neck!).

Plastics, for all their advantages, present a liturgy of concerns. Plastics are soft, they cold flow under time, temperatures and stress. To join them by welding they must be made of compatible materials.

On the other hand, snap fits allow plastic to plastic, to metal, to glass, even plastic to wood joints to be made. Snap fits are stronger than press fits as retention in a press fit (which is held together by friction only) is about equal for both the installation and removal forces. Snap fits can be designed to have pull out forces hundreds of times greater than the installation force. While press fits (and threaded joints too) are under stress continually; snap fits, once installed, are not under load. No worries about stress relaxation and creep-over-time failures, snap fit strength will not decrease with time.

When compared with threaded fastener joints, snap fits offer additional advantages: vibration resistant (they are low potential energy joints) as opposed to threaded joints which may loosen with vibration; fewer parts in the joint, resulting in lower costs, inventory, and handling; and greater ease of assembly, often with just hand effort. The obvious disadvantage is that they are plastic and consequently have little of the strength of a metallic attachment. Design rule one, snap fits are basically cosmetic and should be used only on attachments that will have little disassembly forces acting upon them.

While the mathematics and technical side of snap fit design can be disturbingly complex, let’s go through a simple example for illustration purposes. Our exemplar starts with our determining what type of snap design we need (we choose a beam) and how often it will be engaged and disengaged. Some types of snap fits can be very strong but will not come apart without damage, others will open and close easily (easily but loosely!!). Consideration of the limits of the material (plastic) that the beam and mating parts are made of is important. Definition of the stress and strain of the beam (during the installation) is a property of the material which will define the holding strength of the joint as well as the forces encountered during the assembly as well.

After the beam is deflected (installed) it should return to its original position to obtain minimum residual loading and maximum holding strength. The cantilever beam feature is especially desired for assembly as it “snaps” into place audibly. The flexural ability of the beam base and the cross-sectional area of the beam (discussed in greater detail below) bears a great deal of importance to the ability of the joint to function. Higher ratios of beam length to thickness at the base allow for greater deflection during installation and allow for full return. The smaller the L/T ratio the greater the strain the beam can withstand without permanent set, limited by the
yield point of the plastic. Stress on the beam can be reduced by tapering, thinning, or lengthening the beam as well as changes to cross-sectional area. Caution in designing a beam that needs too much force to engage and/or deflects so much that the snap feature breaks or deforms or is too weak should be exercised. There are many design variations for beams and many variations to cross sectional areas. We have selected just a few typical examples for our discussion. Type 1 is a straight section, 2 is a tapered beam and 3 is a triangular shape part. As mentioned before, the world of snap fit design is well documented with mathematics and calculations for the various properties of the design elements. Choosing a single item for illustration, deflection, we can examine the extent of development of engineering design of some of the properties of a typical beam design. A few of the calculations of deflection force for various beam designs and cross sectional areas as shown on the right.

A FEW POSSIBLE BEAM DESIGNS

A FEW CROSS SECTIONAL AREAS

(As usual we must define terms)

\[ \varepsilon = \text{strain in the outer fiber at the root} \]
\[ E = \text{percentage/100} \]
\[ h = \text{thickness at root} \]
\[ a = \text{width at top of trapezoid} \]
\[ b = \text{width at root} \]
\[ l = \text{length of arm} \]
\[ c = \text{distance between outer fiber and neutral fiber (center of gravity)} \]
\[ Z = \text{section modulus } Z = \frac{l}{c} \text{ where } l = \text{axial moment of inertia.} \]
\[ E_c = \text{secant modulus} \]
\[ P = \text{permissible deflection force} \]

For rectangular cross sections (A): \[ P = \frac{Z}{bh^2} \cdot \frac{E_c \varepsilon}{6} \]

For trapezoidal cross sections (B): \[ P = \frac{Z}{12} \cdot \frac{a^2 + 4ab + b^2}{2a + b} \cdot \frac{E_c \varepsilon}{6} \]

And for irregular cross sections (no exact shape): \[ P = Z \cdot \frac{E_c \varepsilon}{6} \]

While these are approximations and exact formulas are somewhat more complex, it can be seen that cantilever beam snap fits, despite their advantages, will present some head scratching problems in design calculations. But when done correctly (and probably with the help of a plastics engineer), cantilever beam snap fits are viable methods of strong, long life attachments for holding plastics together. As mentioned above, beam snap fits also lend themselves to dissimilar material attachments.

The rectangular cross section straight beam is thought to be stronger because of its thickness. However, studies show that the tapered beam outperforms the straight in longevity. The deflection stresses tend to be concentrated at the base of the beam, where it attaches to the sidewall. Repeated opening and closing can cause cracks to develop at that point. Tapering the beam, especially in multi-use snaps, redistributes the stress concentrations from the base fillet to along the beam length and can reduce the stress level by 25% or more. Other tips to reduce strain in rectangular cross sections are to: reduce the thickness, make the beam longer, and reduce the deflection distance. These will change the assembly “feel” of the snap and the amount of force to engaged and loosen the snap.

An often-raised argument against beam snap fits is that they might pop out. Well-designed beam snaps cannot be easily removed. The smaller the lead angle is the easier it is to install. Conversely, the smaller the return angle in the hook is the easier it is to remove. When the return angle is 90 degrees the snap is self-locking. Angles greater than 90 degrees are barbs.

The second most important calculation of a beam snap fit is determining the retention force. As can be seen as the coefficient of friction times the tangent of the retention angle approaches 1, the retention force approaches \( \infty \) (infinity). As the force approaches this end point, the removal force of the part is actually determined by the force to shear off the catch, not the hook force.
A simple removal force calculation is:

\[ Fr = \frac{Fhf}{1 - \mu - \tan \theta} \]

Where \( Fr \) = removal force
\( Fhf \) = hook force
\( \mu \) = coefficient of friction
\( \theta \) = retention angle

A quick table to determine the critical angle vs. \( \mu \)

<table>
<thead>
<tr>
<th>Critical Angle</th>
<th>Coefficient of Friction (( \mu ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
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<td>80</td>
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<td>70</td>
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While this article can run into several pages or more of mathematical determinations of deflection forces, hook and catch design calculations, stress, strain, and thickness ratios and so on, let’s just quickly review the pros and cons of cantilever beam snap fit designs before looking at cylindrical snaps.

When is a beam snap fit NOT the best solution:

-When there are excessive tolerances between the mating parts (making for poor fits, looseness or tight [breakable] fits).
-When the joint requires adjustment beyond installation.
-When squeak and rattle prevention requires high retention loads.
-When a high retention load is necessary to hold a heavy part.
-When the exact composition (and hence, the properties) of the parts are unknown.
-When there is not enough space available to prevent bending loads on the hook after installation.
-When used in detrimental environmental conditions (temperature, chemical, and corrosive conditions).
-When high strength joining (as obtainable from steel fastening) is required. Snap fits are plastic. High strength structural joining is the provenance of steel.

The advantages of cantilever beam snaps, to those previously mentioned, are:

- One piece construction. No extra parts, handling, assembly.
- One piece means lower cost.
- Plastic is cheaper than steel fasteners and requires less manufacturing steps.
- Easy assembly. Hand assembled in most cases.
- Positive assembly. Parts “click” into mating piece with audible “snap”.
- Can be assembled to any mating material; not limited to plastic components.
- The beam can be molded into the attaching part.
- Often the attachment is hidden from customer’s view, improving cosmetic appearance.

Cylindrical snap fits are encountered in many everyday items. One of the largest commercial usages is on plastic bottles. The illustration at the beginning of this article showed the standard snap on lid. The amount of force required for insertion and removal can be varied by the amount of interference between the two mating features. The snap in and removal forces can be varied by changing the amount of interference between the lid and “bottle” neck. A modification of this is designed for child-proof products. A ridge, bump or other raised feature is molded on the “bottle” neck. The lid must be deformed, by squeezing usually, to allow the lid lip to pass over the interference bumps. When released the lid cannot be removed without again squeezing and twisting the lid back over the bumps.

Other designs incorporate different alignment features. For one, by removing portions of the lid ring to match the areas where one or more “bumps” are located and indexing these areas with some feature (a pointer or arrow is commonly used) the user has to just align the index on the lid with a similar index on the mating part to remove the lid. A non-alignment makes the lid unremovable. The illustration shows that a joint can be either held together with either a cantilever beam design or a cylindrical feature. The cylindrical design shown is a high removal effort design useful for piping and low pressure...
applications. The cylindrical type is useful, as mentioned, for designs where the parts are tightly held together but are easily removed when necessary. Beam joints often require more than a sharp tug to separate. Remember, high retention also means high removal efforts too. (Getting that battery cover off has led to many frustrated words-ed). Another variation is to use several bumps (usually about three) and makes the operator compress the sides of the lid to allow passage over the bumps before allowing the lid to return to its “locked” and undeformed position. The plastic chosen for cylindrical designs must be capable of some distortion as the hoop stresses encountered during installation may exceed the yield point of some plastics, especially if the amount of bending is severe.

Some final comments about the choice of which plastic to use with these two types of snap fits. Soft plastics such as polyethylene, EVA and soft vinyls (those with elastic moduli of 0.41 x 10^9 N/m^2 [60 ksi] or less) are generally suitable for hollow cylinder type snap fits. The hollow cylinder snap design needs a stretchy material to allow it to expand over the mating member. Hoop stresses due to bending will influence the correct functioning of the joint. The mating member, however, must be made of a harder plastic to be rigid enough to resist the bending occurring during the installation deformation. Since these plastics lack good dimensional stability, they are not usable for cantilever or other distortion type snap designs. The strain on a hollow cylinder snap is about 10 times that of a tapered cantilever beam snap fit. This strain is, obviously, taken up by the softness of the plastic.

Hard plastics (moduli of 2.07 x 10^9 N/m^2 [300ksi] or more) like polystyrene, ABS, nylon, acetyl, rigid vinyls, polycarbonate, etc., are well suited for the precise manufacture of cantilever snaps and distortional functioning snaps because of their reliable shrinkage rates.

While this has been an extremely short discussion of plastic snap fits, the advantages and problems offered by plastic snap fit design technology needs a lengthier review by those designers with an interest in plastic, non-threaded fastening. To sum up what we have learned, hopefully, in this short article is that to design a proper snap fit requires the following steps; select the type of snap (we only chose the cantilever beam but a look at literature shows many other types), determine the spring rate (deflection), determine the amount of interference between the two members based upon the elastic limits of the plastic, and specify the lead angles to obtain the required snap in and removal forces. Related literature can be requested from most plastic manufacturers and on-line books and courses are another source.