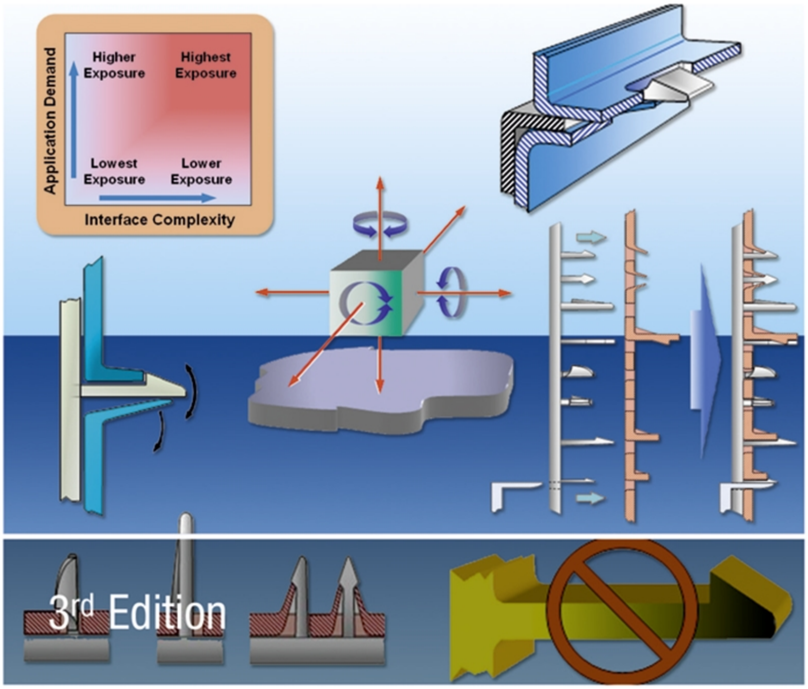
Paul R. Bonenberger

The First Snap-Fit Handbook

Creating and Managing Attachments for Plastic Parts



3rd Edition

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Foreword to Third Edition

Globalization resulted in the off-shoring of American manufacturing to low labor rate countries. In order to compete or just survive, the manufacturers of plastic products were forced to improve quality and reduce cost.

All aspects of the manufacturing process were scrutinized. Most of the plastics molding processes were or could be automated. The only manufacturing operations that were still labor intense were tool making and assembly.

This realization resulted in a new technology that came to be called *Design for Manufacturability* or DFM. This technology encompassed all aspects of the manufacturing process. However, the easiest and quickest savings were realized by improving assembly. Almost overnight the trade magazines were full of case studies and articles extolling the savings to be had by designing for manufacturability (or assembly). Conference speakers and seminar teachers begin explaining the advantages of replacing fasteners with molded-in attachment features.

In the midst of that frenzy, the University of Wisconsin recruited me to join Paul Bonenberger's multispeaker *Snap-Fits and Product Design* seminar. I remember telling the recruiter that I was not an expert on snap-fits. He replied they wanted me to talk about how to improve the design of the two plastic parts required for a snap-fit. Paul and the other speakers would cover the details of designing the actual snap-fit structures.

The first seminar was held in 1998. By that time I had been designing plastic parts for over forty years, and I had designed my share of snap-fits. I thought I already knew what I needed to know. In spite of that, I sat in on Paul's lecture. It quickly become evident that Paul and the other snap-fit speaker knew far more than I did about the design and development of snap-fits. They explained concepts and details that had never occurred to me. How could this be? I had far more experience than either of them in designing and developing plastic products. The answer to that question was that snap-fits are just one of the hundreds and hundreds of details that I and other designers have to take into account in the design and development of a new plastic product. Most designers will have only an occasional need to design a snap-fit and cannot devote a lot of time to that one detail.

Paul Bonenberger, on the other hand, worked at General Motors. That giant company generates an endless stream of potential snap-fit applications. Paul was not only there but was commissioned to do something about the *too many loose fasteners* in GM products. That was the beginning of his analysis of various types of snap-fits. GM provided the opportunity to try different methodologies and learn how they performed over time. Being in the right place at the right time allowed Paul to perfect the engineering that determines how snap-fits function.

This work also led to Paul's development of the Attachment Level Construct (ALC) concept that provides a proven method of managing the design and development of a successful snap-fit application. The ALC concept is the basis for this book.

Most designers have only an occasional need for a snap-fit. If the resulting structure does not function as required, the part design and the mold are modified to overcome the assembly's failure. They do not design enough snap-fits to develop a true understanding of how they function and how they fail. Fortunately Paul has done that work for us. His *The First Snap-Fit Handbook* contains what he has learned by concentrating on snap-fit design and development work. All of which has been fine-tuned by his teaching programs and tempered by his many years of hands-on experience.

If you already own an assembly book or two, you will be surprised by the *The First Snap-Fit Handbook*. It does not make the usual attempt to include all of the many assembly techniques and all of the different metal fasteners. Like the name says, this book concentrates on only snap-fits. If you have this book, you possess the best of what Paul Bonenberger has learned about snap-fits. I have no hesitation in recommending the third edition of this book to anyone interested in optimizing the design of snap-fit plastic assemblies.

Libertyville, Illinois *Glenn L. Beall*
2016

Preface to Third Edition

This third edition of *The First Snap-Fit Handbook* contains some content additions and clarifications and major organizational changes. These are the result of 12 years of teaching a class based on earlier editions of the book. Participant comments and questions influenced many changes to the class itself and many of those changes have found their way into this edition. Thanks to all who asked the tough questions and pointed out areas for improvement. I owe a special thanks to David Schattner who once arranged for me to teach a class at Lexmark, Inc. Since then, he has gone far beyond the call of duty in continuing to offer valuable suggestions for improvements to the book.

Content changes include:

- More emphasis on why the cantilever hook style lock should *not* be used in some applications. This topic was addressed indirectly in previous editions, but deserves more direct and emphatic attention.
- More discussion of the feature analysis procedures for other beam-based lock features, not just cantilever hooks.
- Elimination of unnecessary content.

Format changes include:

- Some graphic content has been made more understandable with supporting text.
- Side notes have been added for special or incidental information.
- Chapters have been divided and some subchapters have been rewritten and rearranged to improve content flow, reduce redundancy, and to better accomodate the use of the book as a design reference.

I believe these changes are improvements to the book's usability and I think the reader will agree. Because my goal is to continue to improve this book as a practical reference tool for plastic part and snap-fit developers; I am dedicating this effort to them.

I also hope to use the *fasteningsmart.net* website for occasional updates of snap-fit information and topics in this book. The reader might want to visit it occasionally.

Suggestions and comments are welcome and can be sent directly to the publisher and/or to the author at paulrb@fasteningsmart.net.

Many thanks to Cheryl Hamilton, my editor, and the rest of the Hanser team for their patience and help throughout this project.

Rochester, Michigan *Paul Bonenberger*
2016

Foreword to Previous Editions

Dr. Dewhurst of Boothroyd-Dewhurst, Inc. and the University of Rhode Island is a pioneer in Design for Assembly (DFA) practices.

Over the past decade we have seen a complete redefinition of the expected outcome of design for manufacture in the product development process. The term, design for manufacture (DFM), was often applied to a process of using rules or guidelines to assist in the design of individual parts for efficient processing. For this purpose the rule sets, or lists of guidelines, were often made available to designers through company specific design guides. Such information is clearly valuable to design teams who can make very costly decisions about the design of individual parts if these are made without regard to the capabilities and limitations of the required manufacturing processes. However, if DFM rules are used as the main principles to guide a new design in the direction of manufacturing efficiency, then the result will usually be very unsatisfactory. The end result of this guidance towards individual part simplicity will often be a product with an unnecessarily large number of individual functional parts, with a corresponding large number of interfaces between parts, and with a large number of associated items for connecting and securing. At the assembly level, as opposed to the manufactured part level, the resulting product will often be very far from optimal with respect to total cost or reliability.

The alternative approach to part-focused DFM, is to concentrate initially on the structure of the product and try to reach team consensus on the design structure which is likely to minimize cost when assembly as well as part manufacturing costs are considered. With this goal in mind, Design for Assembly (DFA) is now most often the first stage in the design for manufacture evaluation of a new product concept. The activity of DFA naturally guides the design team in the direction of part count reduction. DFA challenges the product development team to reduce the time and cost required for assembly of the product. Clearly, a powerful way to achieve this result is to reduce the number of parts which must be put together in the assembly process. DFA is a vehicle for questioning the relationship between the parts in a design and for attempting to simplify the structure through combinations of parts or features, through alternative choices of securing methods, or through spatial relationship changes.

An important role of DFA is to assist in the determination of the most efficient fastening methods for the necessary interfaces between separate items in a design. This is an important consideration since separate fasteners are often the most labor-intensive group of items when considering mechanical assembly work. To reduce the assembly cost of dealing with separate fasteners, fastening methods, which are an integral part of functional items, should always be considered. For plastic molded parts, well-designed snap fits of various types can provide reliable high-quality fastening arrangements, which are extremely efficient for product assembly. It is not an overstatement to claim that snap-fitted assembly structures have revolutionized the manufacturing efficiency of almost all categories of consumer products.

In this context, *The First Snap-Fit Handbook* by Paul Bonenberger provides an extremely valuable resource for product development teams. The concept of complete snap-fit attachment systems, rather than isolated analyses of the mechanics of the snap-fit elements, represents a major advance in the design of integral plastic attachment methods. This concentration on "attachment level" rather than snap-fit "feature level" design has been developed and tested by Paul Bonenberger through years of solving attachment problems with product development teams at General Motors Corporation. This handbook contains the best blend of analysis and real-world design experience.

Wakefield, Rhode Island *Peter Dewhurst*
1999

Prefaces to Previous Editions

Preface to First Edition

This book is a reference and design handbook for the attachment technology called snap-fits or sometimes, integral attachments. Its purpose is to help the reader apply snap-fit technology effectively to plastic applications. To do this, it arranges and explains snap-fit technology according to an Attachment Level™ knowledge construct. The book is intended to be a user-friendly guide and practical reference for anyone involved with plastic part development and snap-fits. It is called The First Snap-Fit Handbook for two reasons: I believe it is the first book written that is devoted exclusively to snap-fits. I also hope it leads to increased interest and more books on the subject.

The reader should consider this book to be a "good start" in the ongoing process of understanding and organizing snap-fit technology. There is much more to be done, but one must begin somewhere. Although the original "attachment level" construct (created in 1990 and 1991) has proven to be fairly robust and complete, many details have evolved over the years as I learned more about the topic. The construct will continue to evolve and I encourage and welcome reader's comments on the subject; they will certainly help in the process.

My interest in the subject of snap-fits grew out of a very real need at General Motors. As a long-time fastening expert, I had typically been involved with threaded fasteners and traditional mechanical attachments. In the late 1980s and early 90s, as GM embraced design for manufacturing and assembly, the philosophies of Dr. Geoffrey Boothroyd and Dr. Peter Dewhurst [*Product Design for Manufacture and Assembly*, 1988, G. Boothroyd and P. Dewhurst, Department of Industrial and Manufacturing Engineering, University of Rhode Island, Kingston, RI] were formally adopted as the corporate direction, and were rolled out in a series of intensive training/workshop sessions. As a result, product designers and engineers began looking for alternatives to traditional loose fasteners, including threaded fasteners. Snap-fit attachments immediately became popular but we soon discovered that there was little design information available in the subject. Calculations for cantilever hook performance could be found in many supplier design guides or as software, but beyond that, no general snap-fit attachment expertise was captured in design or reference books. GM needed to bootstrap itself to a level of snap-fit expertise that was not written down anywhere. An intensive study of snap-fit applications resulted and eventually patterns of good design practices began to emerge. A "systems level" understanding of snap-fit attachments began to grow.

I called this systems level organization of snap-fits *attachment level* to emphasize its focus on the interface as a whole and to distinguish it from the traditional *feature level* approach. I have been teaching about snap-fits according to this attachment level model since 1991. The reaction after each class has been that attendees had indeed reached a new or better understanding of snap-fits. I trust and hope this book will have the same results for the reader.

The Attachment Level Construct (ALC) was only a personal vision in 1990. I believed it had potential and that it represented a unique approach to understanding snap-fit applications but I needed much more than that to make it reality. I needed verification that I was not just reinventing or paraphrasing some existing but obscure snap-fit design practices; an extensive literature search verified that systems-level snap-fit practices were not documented anywhere. I also needed impartial validation that the model was indeed useful and worth pursuing. A colleague, Mr. Dennis Wiese, who was Manager of the Advanced Product Engineering Body Components Group at that time, provided that initial validation. He also gave moral support and generously provided resources including his own engineers and significant amounts of his own time for debate and discussion of the fledgling snap-fit design methodology. Those discussions, sometimes lively and always useful, drove the insights that helped shape the original attachment level model. Dennis was certainly the midwife of the attachment level approach and I cannot thank him enough for his help. Other GM people involved with the infant methodology included Florian Dutke, Tom Froling, Daphne Joachim, Colette Kuhl, Chris Nelander, Tom Nistor, Tim Rossiter, and Teresa Shirley.

Finally, Mike Carter, of GM University, deserves special thanks because in the early 1990s he asked me, *what are you fastening guys going to do about too many loose fasteners in our products?* That question was the beginning of my involvement with design for assembly. Mike, this book is your answer.

As pressure of other work grew, the development team dwindled back to one (me). In 1992, Tony Luscher, the project manager of a planned snap-fit program at Rensselaer Polytechnic Institute (RPI), and I learned of each other's work and made contact (once again, thanks to Mike Carter). The RPI program was originally designed around feature level research but Tony enthusiastically embraced the concept of attachment level thinking. Tony, with the concurrence of Dr. Gary Gabrielle, the project leader, modified the RPI program to include some aspects of the attachment level method. Tony's technical insights, contributed during many hours of personal discussion and through exchange of correspondence, helped drive more refinements to the method. Under his guidance, some work to apply and extend the methodology occurred under the RPI program. Tony is now a professor at the Ohio State University and he has carried his interest and enthusiasm for the subject to his new position. Tony and I shared a long-term vision for snap-fit technology: that attachment level thinking will lead to evolution of the snap-fit design and development process from an art to an engineering science.

The original motivation for the attachment level work was to provide support for Design for Manufacturing and Design for Assembly initiatives at General Motors. Joe Joseph, then the Director of the GM DFM Knowledge Center, supported my early efforts by providing a site for snap-fit training classes. This also gave the kind of validation needed to justify continued efforts to develop the methodology. Joe is now Dean of the Engineering College of the GM University and he continues to provide valued moral support. The patience and support of Jim Rutledge, Dave Bubolz, and Roger Heimbuch is also greatly appreciated. They provided an environment in which ongoing development work could flourish and gave me much encouragement. Tony Wojcik also deserves thanks because he first sent a publisher my way. That marked the beginning of the snap-fit book project.

I must also acknowledge the creative people who designed and developed the numerous snap-fit applications that I have studied. In products from around the world, the level of cleverness and creativity evident in many snap-fits is truly impressive. My admiration for and fascination with these designs helped to drive the original ideas behind the Attachment Level Construct in the following manner:

- *Observation*: There are many clever, well-designed, and complex snap-fit applications in existence; there are also many poor snap-fits.
- *Hypothesis*: Many snap-fit designers must possess tacit knowledge that allows them to develop good snap-fits; others do not.
- *Problem*: Snap-fit application design information could not be found as documented knowledge. Principles of good snap-fit application design were not written down anywhere.
- *Solution*: Discover the information and define it. Study successful snap-fit applications and look for patterns of good design practices. Capture and organize the concepts behind good snap-fit design.
- *Result*: A deep understanding of snap-fit concepts and principles organized in a knowledge construct.

I cannot claim credit for the clever snap-fit applications I describe here. Most were found on existing products or inspired by products. I simply interpreted them, inferred a logical process by which they could have been developed, and organized everything I found into a knowledge structure. The only new “invention” here is the construct itself. Hopefully, it will inspire readers to create their own product inventions.

My wife and son have provided endless encouragement and understanding through the long process of writing this book, putting up with my long hours at the computer, and tolerating (barely) my monopolization of same.

With thanks and appreciation to all.

Rochester, Michigan *Paul Bonenberger*
1999

Preface to Second Edition

The first edition of this book introduced a systematic way of thinking about snap-fit attachments. By intent, it did not spend a lot of time or space on calculations of feature behavior because this information was available elsewhere. That information is still available in various resources, including online sources; therefore, no new calculations have been added. However, equations for locking feature analysis are available online. The reader should check Appendix A for resources providing snap-fit feature calculations.

This second edition is an opportunity to add clarification and more detail in some areas. Most significantly, a new chapter, "Creating a Snap-Fit Capable Organization – Beyond Individual Expertise" has been added. This chapter is targeted primarily toward engineering executives and managers. It explains how engineering organizations can and should leverage their individual snap-fit expertise into organizational capability for competitive advantage.

After publication of the first edition of *The First Snap-Fit Handbook*, I was approached by the Automotive Learning Center of the American Chemistry Council and asked to create a class based on the book. That was the start of a very satisfying relationship, one which has given me the opportunity to teach the subject of snap-fits to many individuals from a variety of industries. The interaction with class attendees, answering their questions and being required to clarify my thinking in response to their challenges, has been extremely valuable to me. This second edition is dedicated to them.

Rochester, Michigan *Paul Bonenberger*
2005

Contents

1 Introduction

This book presents information about snap-fit technology in a logical format for learning and understanding. Once the reader understands snap-fit technology, this book will provide design guidance as a reference handbook.

The book has multiple purposes:

- Teach the reader a practical method of thinking about and using snap-fit technology.
- Be a comprehensive product development reference for snap-fit solutions.
- Provide a place for readers to record their own snap-fit lessons-learned.
- Provide guidance for managers wishing to develop a sustainable culture of snap-fit expertise in their product development organizations.

Any scientific discipline has a need for a specific language for describing and summarizing the observations in that area [1].

Experience without theory teaches . . . nothing [2].

This book captures both the *language* and *theory* of snap-fits in a unique knowledge model that explains the snap-fit interface as a system. Readers with some snap-fit experience will find this model allows them to integrate their existing knowledge with new snap-fit information. Snap-fit novices will find the model makes understanding snap-fit technology easier. All readers will learn a practical way of thinking about and, most importantly, *using* snap-fits in product applications.

Snap-fit attachments are a *system*. It's time to start treating them that way.

The task of developing snap-fits generally falls on product engineers, designers, and developers (referred to collectively in this book as *developers*). A developer with little or no snap-fit experience can quickly find calculations in the literature for determining snap-fit lock behavior. However, next they will learn that while calculating lock feature behavior is important, it is not enough. Their learning will then go through a trial-and-error process during product testing and redesign. Sometimes design flaws are not discovered until a product is in the consumer's hands. In any case, product development through trial-and-error is time-consuming and potentially quite expensive. We want to avoid that.

Product developers may have access to someone with snap-fit experience, but their usefulness is generally limited to what they too have learned through trial and error.

A couple of bad experiences with snap-fits may cause a product developer or an entire organization to decide that snap-fits are not worth the trouble. This is unfortunate; to remain competitive, companies must utilize all possible design strategies. To ignore snap-fits as a legitimate attachment option is a mistake.

Reasons for using snap-fits include appearance, packaging, and tamper resistance. However, the most compelling reason is economic. When snap-fits replace loose fasteners and the associated assembly tools and tightening operations, significant cost savings are possible.

The increasing use of snap-fit technology parallels the growing use of plastics in products. Processing technologies have made production of complex shapes economically feasible. The advantages of ease of assembly and disassembly and the ever-increasing engineering capabilities of plastic materials now make snap-fit technology a serious candidate for applications once considered the domain of threaded or other mechanical fasteners.

The growth and advancement of rapid-prototyping technology has made the creation of accurate part models possible. These models provide early and meaningful evaluation of attachment concepts for more potential snap-fit applications.

While toys and small appliances have long made extensive use of snap-fits, the technology is now applied in virtually every product field including medical devices, automotive components, small and large appliances, electronics, and numerous consumer goods. Snap-fit technology is also being extended to structural applications [3–5].

Although commonly associated with plastic parts, snap-fits are also possible in metal-to-metal and plastic-to-metal applications. Keep this in mind as you read this book, and look for opportunities to use snap-fits in metal as well as plastic applications.

1.1 Reader Expectations

This book is not what a reader is likely to expect in a book about snap-fits.

Because snap-fit technology has traditionally been viewed as nothing more than lock feature calculations, readers may expect this book to be full of equations for calculating snap-fit lock behavior. *It is not*. This book includes those calculations but there is much more to snap-fit application development than just calculations.

Material property and part processing information is presented here only to the extent needed to support understanding of the snap-fit development process. Many excellent books and references are available on those topics and this book would serve no purpose repeating that material.

The reader must understand that experience with threaded fasteners, the most common method of mechanical attachment, is not transferable to understanding or developing snap-fit attachments. New ways of thinking about the attachment must be learned. There is more discussion of this subject in the next section.

The reader should expect to acquire a deep intuitive or gut-level understanding of snap-fits. You will learn how to *think* about snap-fits to solve routine as well as unique snap-fit design issues during product development.

After studying some sophisticated snap-fit applications, one cannot help being impressed and maybe intimidated. It’s OK to be impressed, but do not be intimidated. With the knowledge in this book and through experience, every reader will gain the knowledge needed to create world-class snap-fits.

The reader will find that, occasionally, information may appear more than once in different chapters. This is intentional; information is repeated because of its importance or because it is being presented in a different context. Sometimes repetition is unavoidable because of the multiple interactions between elements and design concepts, and repetition is needed to ensure clarity and understanding of these interactions.

1.2 Harmful Beliefs

Seven common beliefs about snap-fit technology are described here. In this book, you will learn why these beliefs are wrong and how these beliefs interfere with developing cost-effective and reliable snap-fit attachments. You, the reader, may hold some of these beliefs. You will also find that your peers, management, and suppliers may likely hold some of these beliefs as well. Some of these beliefs will manifest themselves as a fear of using snap-fits. Other beliefs can have the opposite effect, leading to the misconception that snap-fits are so simple they require little or no thought at all. The harmful beliefs are:

- **The battery cover syndrome.**

  Most people are familiar with snap-fits thanks to their usage on common applications like remote control battery covers and toys. This can lead to two common and erroneous beliefs: (1) Snap-fits are only appropriate for simple or noncritical applications and (2) Snap-fits are trivial and easy to design.

- **Snap-fits are a materials technology.**

  Because snap-fits are generally found in products made from polymers, there is a belief that polymer experts (including resin suppliers) can be the design resource for snap-fit applications. Polymer experts should certainly be a primary resource for material properties, but they should not necessarily be expected to be the primary source for product design. Many polymer suppliers do have a wealth of experience in product design, and there is no reason not to use them as a secondary resource. Even when a supplier is, by contract, providing the primary design work, it is still up to you, the customer, to ensure the design, including the snap-fits, is done properly.

  This author would be very pleased to find the attachment level design principles appearing in plastic supplier design guides, but it hasn't happened yet.

- **Cantilever hooks represent snap-fit technology.**

  The cantilever hook style locking feature seems to be everywhere, but it is not representative of all snap-fit technology. When asked to create a snap-fit attachment, many developers will default to this style because of its familiarity. Many other lock feature styles exist as attachment options *and are often a better choice.*

- **All I need to do is design the locking feature.**

  A snap-fit attachment is an interface system and it must be developed as such. Many well-designed lock features fail to perform as expected because the systemic aspects of the part-to-part interface have been ignored.

- **Experience in other fastening methods transfers to snap-fits.**

  No, that experience does not transfer. Snap-fit attachments are *fundamentally different* from all other fastening methods. New and different knowledge is required to understand and apply snap-fit technology to product development.
- **Every snap-fit application is a new invention.**

  With snap-fits, the same fundamental rules of design are true for a finite number of common part-to-part combinations. Once those basic combinations are understood, a new application can be designed around existing and well-understood basic principles and rules.
- **I can do the attachment after I do everything else.**

  The attachment concept must be developed simultaneously with the parts that are being attached. Certain design details can wait until later, but getting the basic snap-fit concept right early in the development process is critical to the attachment's success.

These beliefs are discussed in more detail in Chapter 15.

1.3 Snap-Fit Technology

A snap-fit is the entire part-to-part interface.

The terms *snap-fit* and *integral attachment* are often used interchangeably because snap-fit lock features are molded or formed as integral features of parts. To avoid confusion, we will stick with the term *snap-fit*.

In the traditional meaning of the term, snap-fit referred to only the lock features.

In this book, the term snap-fit refers to the *entire attachment interface* (see Fig. 1.1), of which the lock feature(s) is only one element.

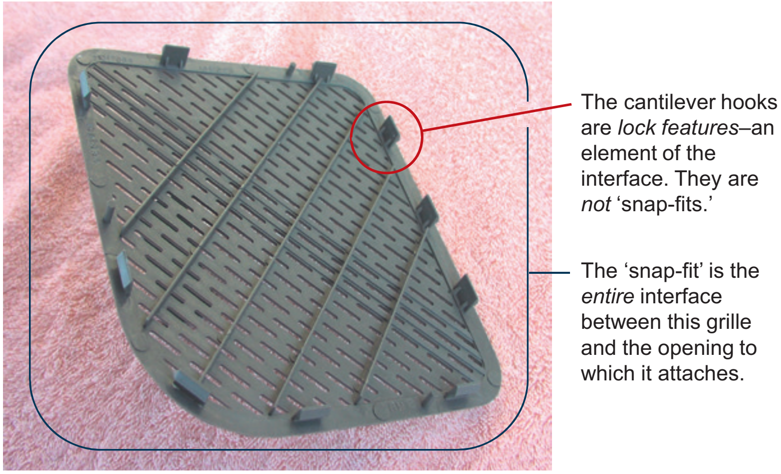

Figure 1.1 A snap-fit is the entire attachment interface, not just the locks

Snap-fit applications range from the very simple to the very complex. Some snap-fits hold one part to another and little or no force is transmitted across the interface. In other applications, snap-fit attachments must be strong and extremely reliable, see Fig.1.2.

Figure 1.2 Snap-fit application examples

1.4 Snap-Fits and Loose Fasteners

A snap-fit is different from loose threaded fasteners and other mechanical or chemical attachment methods in that it requires no additional pieces, materials, tools, or operations to carry out the part joining function.

The choice between snap-fits or loose fasteners is a major decision point in product development. Chapter 3, Section 3.3, discusses this decision in depth. Neither snap-fit nor threaded fastener technology is inherently good or bad; both have their place in product design based on informed decisions about the best attachment for the application.

Without intending insult to threaded fastener technology (the author spent 30 years as a threaded fastener subject matter expert), we can think of a threaded attachment as a *brute force* approach to connecting parts. The fastener's strength makes it easy to ignore or forget some of the finer points of interface design and behavior. A retention problem can often be fixed by simply using a higher strength material for the fastener, tightening it to a higher clamp load, specifying a larger fastener, or adding more fasteners. Indeed, a major advantage of a loose fastener is that its strength is independent of the joined components. This is not the case with snap-fits.

Experience with threaded fasteners **does not** transfer to snap-fits.

With a snap-fit application, we do not have the luxury of selecting a fastener material and strength that is independent of the joined components. Most of the time, material selection is driven by other application considerations, not by attachment requirements. One must work with the material(s) selected for the parent components. Processing requirements can also restrict design options because the attachment features must be formed with the part. The subtleties of interface design and behavior must be well understood and reflected in the design. A snap-fit application, therefore, must be a more *elegant* method of attachment than a bolted joint.

1.5 Snap-Fits as Interface Systems

The key word here is *system*. In any assembly of individual components, part-to-part attachment occurs across an interface. A successful product development process must treat that interface as a system and it must be developed as the parts themselves are being developed. To start, we will define two major areas of snap-fit technology: *feature level* and *attachment level*.