The functions of plastic injection moulding features

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The design of products requires engineers to be knowledgeable about basic features and their functions. This paper develops function/feature relation information used by designers in the plastic injection moulding domain. The basis for the findings are interviews with 27 industrial designers, mechanical design engineers, tool designers and plastics process engineers. These individuals discussed the design of 79 plastic parts with the first author. In doing so they used 11 different features to describe 53 basic functions.

Keywords: feature, function, plastic injection moulding

The term 'feature' has become a 'catch-all' term used in describing the various characteristics of an object. Ullman[1] concludes that 'it is nearly impossible to define the term consistently'. McGinnis[2] states in general that a feature is 'any particular or specific characteristic of a design object that contains or relates information about that object', while Aasland[3] asserts that a feature is 'primarily a 'chunk of geometry' (part of surface) distinguished by its ability to perform a function with one or more other features'. These views, along with those recently presented by Shah[4] in a comprehensive review of many current ideas on feature technology and terminology, all share the notion that features are central to design object modelling. Dixon[5] proposed designing-with-features where the designer models the object with primary features that are converted into secondary features with additional information. In his model, primary features are formed from concepts the designer desires to express and manipulate, while secondary features contain information about applications (e.g., manufacturing features are secondary features to manufacturing methods and tool shapes). Designing with features 'is a synonym for all design work involving predefined details, commonly details of shape, form features'[6]. Although features are used for many aspects of a design, the reasoning behind their usage has not been

1 **Ullman, D G** 'The evolution of function and behaviour during mechanical design' *Design Theory and Methodology – DTM '93 –*, ASME, DE-Vol 53 (1993) 91–103
2 **McGinnis, B D** 'An object oriented representation for mechanical design based on constraints' Masters Thesis, Department of Mechanical Engineering, Oregon State University (1990)
3 Conversions with Knut Aasland (Norwegian Institute of Technology, University of Trondheim, Norway) regarding the design theories, Oregon State University 1992–1993
4 **Shah, J J** 'Conceptual development of form features and feature modelers' *Research in Engineering Design* Vol 2 (1991) 93–108
5 **Dixon J R and Finger, S** 'A proposed taxonomy of mechanical design problems' *Proceedings ASME International Computers in Engineering Conference*, New York, August 1988, pp 41–55
6 **Sigurjónsson, J** 'A contribution to a theory for selecting pro-
continued on page 202

extensively investigated. For this study, features were considered to be the primary building blocks of a structure, i.e. the specific geometrical forms that satisfy the functional needs pertaining to a component.

Features are often considered to have few functions associated with them[7]. If this were true, then the capturing of a design's functional intent through the individual features within a CAD system would be straightforward. However, as will be shown, the data here suggest that there is a rich set of relationships between features and functions. Obtaining the functional information of each feature is necessary for incorporating design reasoning into the next generation CAD systems.

The term 'function' is defined as the behaviour or action that the feature must satisfy in order for the product to achieve its overall purpose. This definition implies that function describes the intent of the feature as seen by the designer. In general, function is expressed as a verb used by the designer to describe what the feature should so, and the feature is how the component will fulfil the desired function[8].

This paper aims to present the primary plastic injection moulding features with the corresponding functions used by experienced design engineers. The functions satisified by the features, along with statistics about them, give an overview of the most pertinent aspects of feature-based design.

The first section of this paper develops the background of the study, presenting the subjects along with the vocabulary they used for describing features and function. The second section presents detail findings for each type of feature found. This includes basic statistics from the study and discussion of the function and feature relationships found in the analysis. The paper concludes with recommendations for function/feature usage in CAD systems.

1 Background

During the design of plastic components four types of designers typically interact in the development of the product. *Industrial designers*, experts in human factors engineering, ergonomics and aesthetics, develop features that directly interact with the customer and provide overall form. *Mechanical design engineers* develop the components that make up the product. These components fulfill the functions that the customers specify. *Tool designers* add and modify features necessary for component manufacture. *Plastic process engineers* also affect the design and the features to ensure that the plastic material will flow and cool as needed by the tool designer.

continued from page 201
duction methods', Dissertation, University of Trondheim, The Norwegian Institute of Technology (1992)
7 **Salomons, O** 'Features, link between design and manufacturing?' Department of Production, Engineering, University of Twente (1991)
8 **Ullman, D G** *The mechanical design process*, McGraw Hill (1992)

Designers/engineers from each of these groups were interviewed to obtain information about the primary plastic injection moulding features and their corresponding functional characteristics. In this study, a total of 27 designers were interviewed at Hewlett Packard* about their injection moulding design practices. The subjects were: industrial designers (6), mechanical designers (16), tool designers (3), and plastic process engineers (2). These subjects ranged in experience from a novice with one year of injection moulding experience to expert designers with more than 20 years experience. The mechanical designers averaged 8.9 years of experience, industrial designers 6.5 years, tool designers 20 years, and plastic processing engineers, 6 years. The average overall experience was 8.9 years.

The interviews with the engineers/designers covered a range of topics related to the development of their products. The goal of the interviews was to obtain detailed information about the subject's use of features in their designs, their plastics design process, and their basic plastic injection moulding design knowledge. All interviews were conducted on location with a tape recorder to obtain as much information as possible.

In adition to general information about the injection moulding process, the interviews elicited information about specific components designed and developed by the designers, technical information about the injection moulding design process, and any problems encountered. 79 injection moulded plastic parts were discussed with the subjects and are analysed in this study. On these 79 parts there were 2355 features discussed which have been categorized into 11 basic types providing 53 different functions.

In reviewing the recorded data, each noun encountered was considered as a reference to a feature. The subjects used many nouns to identify the features of the plastic parts. In this study these terms are grouped into 11 basic features (Table 1) which cover 80% of all the nouns used. They are listed with the most common nouns first. Other features not included on this list were rarely mentioned. These total 20% of the data and include live hinges, lettering/detailing (date stamping), undercuts, large flat parts, telescoping features, transitions, components on large flat parts, fillets, tapers, radii, corners draft, cosmetics, finishes and labels.

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* Developed from research by the first author at Hewlett Packard Laboratories (non-proprietary). No details concerning Hewlett Packard practices, methods, or procedures are discussed in this paper. All information contained herein could be derived from a detailed analysis of the actual production parts of each of the plastic injection moulded parts and the domain knowledge of the various professions.

Table 1 Features found in study

Walls
Holes (through and blind)
Ribs/gussets/louvers/bars/grates
Protrusions/projections/tabs/flanges
Bosses/pegs
Grooves/depressions/indents/pockets
Slots
Windows/cut-outs
Countersinks
Snap fits
Disks

As the noun used denotes the features, the verbs used by the subjects represented the function. Lists of action verbs used to indicate function can be found in Collins[9] and Fowler[10]. These lists served as a guide to reviewing the data taken. In the interviews a total of 53 different functions (verbs denoting the action of a feature) were found and are listed in Table 2.

2 *Function/feature data for plastic moulded parts*

In this section each of the 11 features and their associated functions are described in detail. Each feature obtained from interviews with the engineer/designers along with the functional characteristics, is presented in the following format:

Feature name: The feature name is the noun used to describe the feature along with any alternative terms for that feature as listed in Table 1

Table 2 Functions found in study

provide access	convey	link	slide
activate	cover	mount	space
actuate	create	orient	stabilize
aid	display	partition	strengthen
align	eject	pivot	support
allow	enclose	position	transfer
amplify	facilitate	prevent	transmit
assist	fasten	protect	view
attach	guide	receive	
avoid	hide	reduce	
conform to	hold	repel	
connect	join	restrain	
constrain	latch	rotate	
contain	limit	secure	

9 **Collins, J A, Hagan, B T and Bratt, H M** 'The failure experience matrix – a useful design tool' *Trans. ASME, Ser. B., J. Eng. Ind.* Vol 98 (1976) 1074–1079
10 **Fowler, T C** *Value analysis in design* Van Nostrand Reinhold, New York (1990)

Number of parts with feature:
The fraction of the 79 parts which have the feature. This is based on the subject's comments

Number of features per part:
This is the count of the instances of this feature on a part exhibiting the feature. This value is given as a range and average, and is based on the first author's examination of each part

Number of different functions the feature provides:
Of the 53 different types of function listed in Table 2, this is a count of how many were mentioned by the subjects in connection with the feature

Primary functions:
The five most frequently mentioned functions with their percentages are listed here

Average number of functions the feature provides on a part:
This is a count of the average number of functions for a part with the feature. For example, on average, walls provide 3.1 functions on any part having a wall feature

Following this information a basic description of the feature is presented. The features are listed in order of commonality (i.e. the most common first).

Feature name: Wall
Number of parts with feature: 76/79 (96%)
Number of features per part: 1–28, average=5.2
Number of different functions the feature provides: 34/53
Primary functions: *support* (27.8%)
cover (12.4%)
strengthen (7.7%)
hold (6%)
position (4.7%)
Average number of functions the feature provides on a part: 3.1

The wall is the basic structure for all objects, providing the general envelope and supporting or encasing other components. Creating proficient wall designs requires mechanical and tooling knowledge of the effects of change in wall thicknesses, plastic injection flow, and corresponding problems associated with warpage, sinks and other flaws. For example, a wall thickness specified for rigidity may choke the air flow between louvers, or be too thick to mould effectively. Wall design is influenced by design for manufacturer (DFM) guidelines[11] with respect to

11 Beals, G 'Solid and formed Part Design for injection moulding plastic products' Glenn Beals/ Engineering, Inc., Gurnee, IL (1985)

thicknesses and draft. Furthermore, at times they are tapered or stepped for proper flow control of the injected plastic to certain areas.

Feature name: Holes (through and blind)
Number of parts with feature: 52/79 (66%)
Number of features per part: 1–20 average = 4.6
Number of different functions the feature provides: 21/53
Primary functions: *attach* (17.6%)
position (17.6%)
mount (14.8%)
access (8.3%)
limit and *reduce* (5.6%)
Average number of functions the feature provides on a part: 1.9

The types of holes found in the study are: through, blind, round, square, irregular, open, slots, cross-holes and threaded holes. In general, most holes are specified by the mechanical design engineers for mechanical fasteners.

Feature name: ribs also known as **gussets, louvers, grills and grates**
Number of parts with feature: 48/79 (61%)
Number of features per part: 1–50 average = 9.0
Number of different functions the feature provides: 19/53
Primary functions: *strengthen* (31.6%)
support (16.9%)
guide (13.7%)
hold (7.4%)
position (6.3%)
Average number of functions the feature provides on a part: 2.0

Ribs increase the ridigity of a moulded part without increasing wall thickness, and may facilitate flow during moulding. Skillful use of reinforcing ribs can maintain or increase a part's stiffness while reducing the cycle time and amount of material used. Ribs are used in various ways by the industrial designer. As louvers, they contribute to a clean or cosmetically pure look. In addition to true louvers, fake or cosmetic louvers are used to create an illusion that vents are present. Occasionally, texture ribs are positioned where sinks form that are difficult to hide.

Ribs, according to the mechanical designers interviewed, are used for load bearing, spacing, supporting, stiffening, guiding, or for restraining, e.g. preventing paper from entering a location. The rib thickness is sometimes varied due to the recommendations of the tooling engineering from flow analysis of the part. Ribs are a major source of sinks found on adjacent walls; therefore, changing rib thickness is a common strategy for reducing or eliminating sinks.

Tool designers use ribs in ways similar to mechanical designers. First, in addition to common guidelines with respect to wall thickness and draft, ribs are sometimes used for ejection, by ejector pins, during the separation of the tool. These ribs, along with some walls, have ejectors on equal sides to prevent jamming from applied forces by preventing moments during ejecting. Ribs also fill faster during injection if a boss is on the end allowing trapped air to evacuate.

Other ribs are used for control of blush. Blush is a cosmetic flaw (dull spots) caused by improper plastic dispersion during injection. These ribs are put in by the tooling engineer whose responsibility it is to ensure the mould/tool achieves the desired cosmetic look.

A rib subset is the louver. Louvers (also known as grill bars or gates) are used for ventilation purposes. They are designed to prevent any visual aspect of the machine's interior from being seen, while also allowing for efficient passage of air (material) into and out of the machine.

Feature name: protrusions, projections, tabs, flanges
Number of parts with feature: 48/79 (61%)
Number of features per part: 1–48, average = 6.2
Number of different functions the feature provides: 25/53
Primary functions: *hold* (15.3%)
position (12.7%)
align (11.7%)
support (8.1%)
attach (7.2%)
Average number of functions the feature provides on a part: 2.3

Protrusions are like minature bosses. Some, called pip marks (tiny bosses/protrusions), are used for dimensioning and tolerancing. Similar pip marks, known as pins, are used for aligning or joining other components on the plastic part. Small dimples used for aligning labels are also included here. Very small protrusions in injection moulding are used for holding the part onto the core rather than the cavity at the separation of the mould. These are usually specified by the tool designer but in some rare cases are specified by the mechanical designer. Some protrusions are used with slots as printed circuit board card guides, while others are used for holding or retaining these boards.

Feature name: bosses/pegs (solid/hollow bosses, short ribs)
Number of parts with feature: 40/79 (51%)
Number of features per part: 1–34, average = 3.8
Number of different functions the feature provides: 19/53
Primary functions: *attach* (15.2%)
eject (13.2%)
mount (12.2%)
support (11.11%)
assist (9.1%)
Average number of functions the feature provides on a part: 2.5

In general, bosses are used by the mechanical design engineers for attaching other components and for ejecting the parts from the moulds. In addition to the main functions listed above, bosses are also used to limit the motion of other components, to position or hold either by actual screw-downs or by merely having a part brace against the boss, to locate or match adjoining components, dimension and tolerance drivers, and ejector pin push-offs. The ejector push-offs usually require bosses to strengthen the ribs or walls that are pushed against in part ejection. Uniform ejection of a feature may be accomplished by using adjacent bosses on each side of the component. With these many uses, the boss is therefore a primary feature for dimensioning and associated tolerancing and for stack-up problems.

Additionally, bosses at times are used for flow assists through the walls or for injector points. Bosses used for spacing, inserts, support or attachment places typically are much thicker than the wall thickness. Consequently, the centre is cored out to the wall to prevent sinks from occurring in adjoining walls. Additionally, some bosses serve to locate components when the tooling engineer creates his assembly drawing. Bosses also reinforce small stressed areas, providing sufficient strength for assembly with inserts or screws. Bosses are frequently tapped with screw threads for products that require adjustment or numerous reassemblies.

Feature name: grooves, depressions, indents, pockets
Number of parts with feature: 36/79 (46%)
Number of features per part: 1–50 average = 4.1
(without the single part with 50 grooves, average = 2.7)
Number of different functions the feature provides: 27/53
Primary functions: *conform to* (12.7%)
assist (7.4%)
position and *reduce* (7.3%)
attach/guide/limit/mount (5.5%)
Average number of functions the feature provides on a part: 1.5

Grooves are commonly used as a cosmetic features and, as such are often dictated by corporate guidelines. In this study the term 'conform to' implies that the features function is to cosmetically follow the shape of another feature such as a wall. This feature is also used for alignment and local positioning. The tooling engineer may use grooves for flow control, restricting flow in various directions and/or evenly spreading the flow in others.

Indents are usually used for design-for-assembly (DFA) as in lead-ins, guides or aligners. Indents along with tapers and lips are commonly used for self-indexing, i.e., they present a one-way fit, forcing the parts to align themselves.

Feature name: slots
Number of parts with feature: 36/79 (46%)
Number of features per part: 1–97, average = 10.3
Number of different functions the feature provides: 22/53
Primary functions: *guide* (14.8%)
prevent (11.5%)
hold (9.8%)
transfer (9.8%)
access (8.2%)
Average number of functions the feature provides on a part: 1.5

Slots are used to guide or transfer air and prevent objects from entering sensitive areas. Slots may also be used for cosmetics and typically have standard thicknesses (e.g., 3 mm).

Feature name: windows, cut-outs (through and blind)
Number of parts with feature: 35/79 (44%)
Number of features per part: 1–10, average = 2.8
Number of different functions the feature provides: 14/53
Primary functions: *access* (29.2%)
align (15.3%)
view (13.9%)
position (11.1%)
guide (2.8%)
Average number of functions the feature provides on a part: 1.5

Through windows are primarily used to access other parts of the machine. They also provide viewing access to other features or components. It should be noted that the size of the window may affect warpage of the part.

Tool designers create windows with as few slides as possible in the tool. In cases where windows are used for snaps access, the design of the mould is for the fewest number of movable parts. If windows are adjacent, the tool is designed with one slide containing multiple reliefs.

Blind windows are used for label aligning, and some also have a 45° chamfer for proper label positioning. Some small square windows are for positioning rubber feet. Recessed windows also protect, by preventing the label from inadvertently being peeled off during use.

Feature name: countersink, counterbore
Number of parts with feature: 17/79 (21%)
Number of features per part: 1–8, average = 2.6
Number of different functions the feature provides: 11/53
Primary functions: *hide* (32%)
assist (16%)
attach (12%)
conform to (8%)
reduce (8%)
Average number of functions the feature provides on a part: 1.5

Countersinks are a subset of holes, but due to their prevalence they were grouped independently. In most cases, countersinks are used for hiding screw heads or assisting in leading in screws, snaps or other features into a hole. Countersinks were also used to attach shorter screw lengths or to reduce sinks that form in bosses from excess material.

Feature name: snap fits
Number of parts with feature: 16/79 (20%)
Number of features per part: 1–14, average = 4.2
Number of different functions the feature provides: 6/53
Primary functions: *hold* (44.8%)
secure (20.7%)
attach and *fasten* (13.8%)
position (10.3%)
mount (3.5%)
Average number of functions the feature provides on a part: 1.8

Snap fits are typically used to hold or secure two parts together. They are designed for flexibility, therefore, width and length must be carefully controlled during design. Some snap fits are designed to snap in and out easily for DFA and designed for disassembly since customers may at times be required to make modifications themselves. Depending upon the part, snaps may need to be accessible, coming apart as easily as they go together. In current designs, snaps are considered desirable since they replace visible attachment components such as screws. The design of snap fits requires either material spreading or bending of the snap or the frame into which it locks. A cheaper design can be created using snaps if they are designed without the use of tooling slides but are created upon separation of the core and cavity. Snaps are only intended to keep two parts from separating, not for holding two parts together tightly. They should be under no stress in the snap position and tolerance on the snap should be loose.

Snap fits are difficult to design, since usually they require slides to be added to the tool, which increases the cost of the tool, unless snaps are incorporated into the separation of the tool. Snaps made outside the part are preferred, since they can be removed, repaired and replaced easily.

Feature name: disks and rings
Number of parts with feature: 9/79 (11%)
Number of features per part: 1–10, average = 3.1
Number of different functions the feature provides: 7/53
Primary functions: *strenthen* (46.2%)
support (15.4%)
align (7.7%)
space (7.7%)
reduce (7.7%)
Average number of functions the feature provides on a part: 1.4

Disks are not a commonly used feature. One use cited in the interviews is for the feet of a product. These feet replace the rubber feet that are normally specified when environmental conditions would cause the rubber to deteriorate.

A subset of 'disks' is rings. They are used to reduce (material/sinks) and strengthen with the transmission of energy and material. Rings are used specifically for reducing sinks. When more than two walls come together, the extra material may cause a sink. To reduce this possibility, a ring or a boss with a hole in it joins the ribs together.

Key data from the previous section is summarized in Table 3.

The plastic injection moulding parts which were analysed possess functions that were used by each of the four professions. Most of the functions were common to all of the professions. The exceptions tended toward

Table 3 Summary of feature information

Feature name	*% of parts with feature*	*Average no. of features/part*	*No. of different functions*	*Average no. of functions feature provides per part*
Wall	96	5.2	34	3.1
Hole	66	4.6	21	1.9
Rib	61	9	19	2
Protrusion	61	6.2	25	2.3
Boss	51	3.8	19	2.5
Groove	46	4.1	27	1.5
Slot	46	10.3	22	1.5
Window	44	2.8	14	1.5
Countersink	21	2.6	11	1.5
Snap	20	4.2	6	1.8
Disk/ring	12	3.1	7	1.4

very specific aspects of the individual profession, e.g. the tool designer's use of the function *eject*. Data on functions and their correlation to features in the study are listed in Table 4.

It is evident in this table that the primary functions for the design of these plastic parts are to: *support, position, hold, attach* and *strengthen* other components. These five functions constitute 43% of the 934 uses of features mentioned by the designers.

Table 4 Functions and their instances

Function	*No.*	*Function*	*No.*	*Function*	*No.*
support	107	protect	13	link	2
position	80	view	12	control	2
hold	79	transfer	11	slide	2
attach	66	shield	10	connect	2
strengthen	66	prevent	9	activate	2
mount	55	hide	8	receive	2
align	43	contain	7	constrain	1
guide	38	transmit	7	convey	1
provide access	36	allow	6	amplify	1
conform to	34	join	6	avoid	1
limit	31	enclose	6	pivot	1
assist	30	aid	6	display	1
cover	29	locate	5	latch	1
reduce	26	orient	3	rotate	1
space	22	repel	3	actuate	1
secure	18	partition	3	facilitate	1
eject	16	create	3	stabilize	1
restrain	15	fasten	2		

3 *Conclusions and recommendations*

In this study, 53 different functions were found for the parts analysed. These functions were primarily fulfilled through use of 11 different features. On average, each feature provides about two functions each time it is used. The large number of functions found and the use of features to provide multiple functions contrast with Salomons' finding that there is not an extensive set of functions at the feature level[7]. His finding was based on his opinion that components and features are related to 'working principle related functions', so that each feature filled only a single purpose. As seen here, reality is not so simple.

The average number of different functions that a feature may provide is 19. This statistic alone leads to conclusions about what feature/function relationships are necessary to be included in the next generation of CAD systems. First, a new generation CAD system should include feature-based design, based on functional reasoning. This system should focus on features that have a high frequency of use, along with the functions they fulfill. This would allow designers to utilize their natural design methods in developing a product through the fulfillment of its functions. Secondly, a system utilizing features and functions could allow a design's functional reasoning to be captured, but only with features and functionality embedded in the system. Thirdly, once the features and functionality are contained within the system, the product under development could be understood more completely by evaluating the multifunctional aspects of certain features. Fourthly the features and corresponding functionality could help designers from one discipline understand features specified by designers from another, and thus avoid design conflicts. Only by introducing functionality into CAD systems can feature-based design be effectively used.