CURRENT RESEARCH IN PRODUCT DESIGN FOR AUTOMATED ASSEMBLY

by

Mark Jakiela
Graduate Student

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Participating Faculty:

P. Papalambros
A.G. Ulsoy
R.A. Volz
T.C. Woo

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ABSTRACT

This paper reviews significant work done to date on product design to promote automated assembly. The paper is divided into three main sections: feeding and orienting components, assembly simplification, and parts mating/modification studies.

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INTRODUCTION

The paper is structured to discuss subtopics of product design for automated assembly rather than the work of specific individuals. The three major subtopics are:

1. Feeding and orienting of components prior to assembly.
2. Assembly simplification (reducing the number of parts).
3. Parts mating and modification studies.

A large portion of the paper discusses the work of Geoffrey Boothroyd of the University of Massachusetts at Amherst. This seemingly disproportionate emphasis is justified because Boothroyd's work concerns <u>part design</u> more than the work of other researchers. Boothroyd's studies of the economics of automated assembly, however, are not discussed. Two application examples of Boothroyd's "Design for Assembly" method are given in an appendix.

Finally, potential research directions are discussed and an extensive list of references is given.

FEEDING AND ORIENTING

Feeding and orienting are the assembly operations prior to mating the parts and fastening them together.

Boothroyd has done much to quantify the feeding and orienting properties of parts. His primary motivation is to optimize part design for feeding and orienting in a vibratory bowl feeder (figure (1)). Vibration caused by an oscillating magnetic

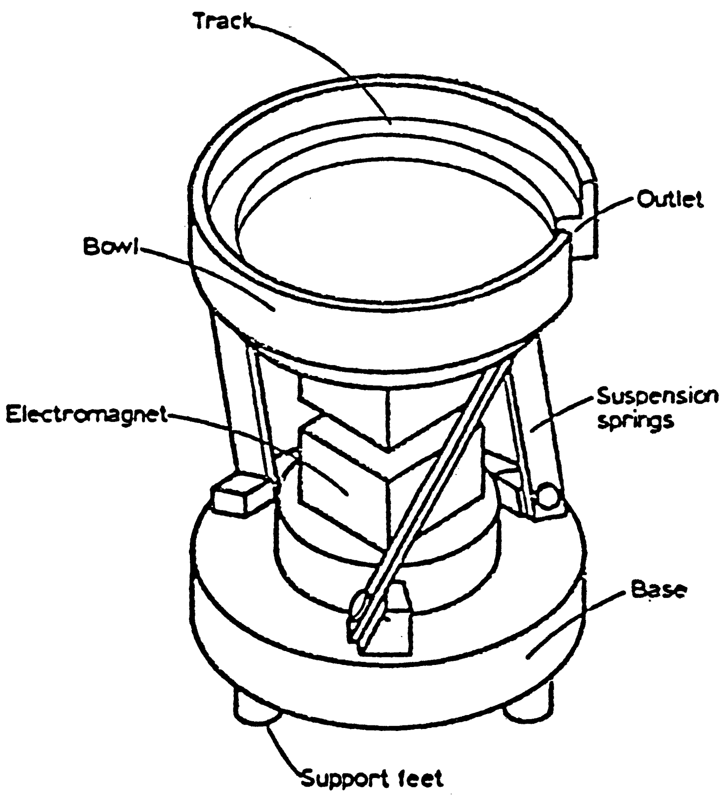


Figure (1): Vibratory bowl feeder[2].

field causes the parts to feed up a helix track on the inner wall of the bowl. On this track are the part orienting mechanisms. The left half of figure (2) shows a passive orienting mechanism. Parts that already are correctly oriented are allowed to pass through for assembly; parts that are improperly oriented are forced off the track back into the bowl. An active orienting mechanism (the rail ahown on the right), on the other hand, forcibly orients all the parts approaching it.

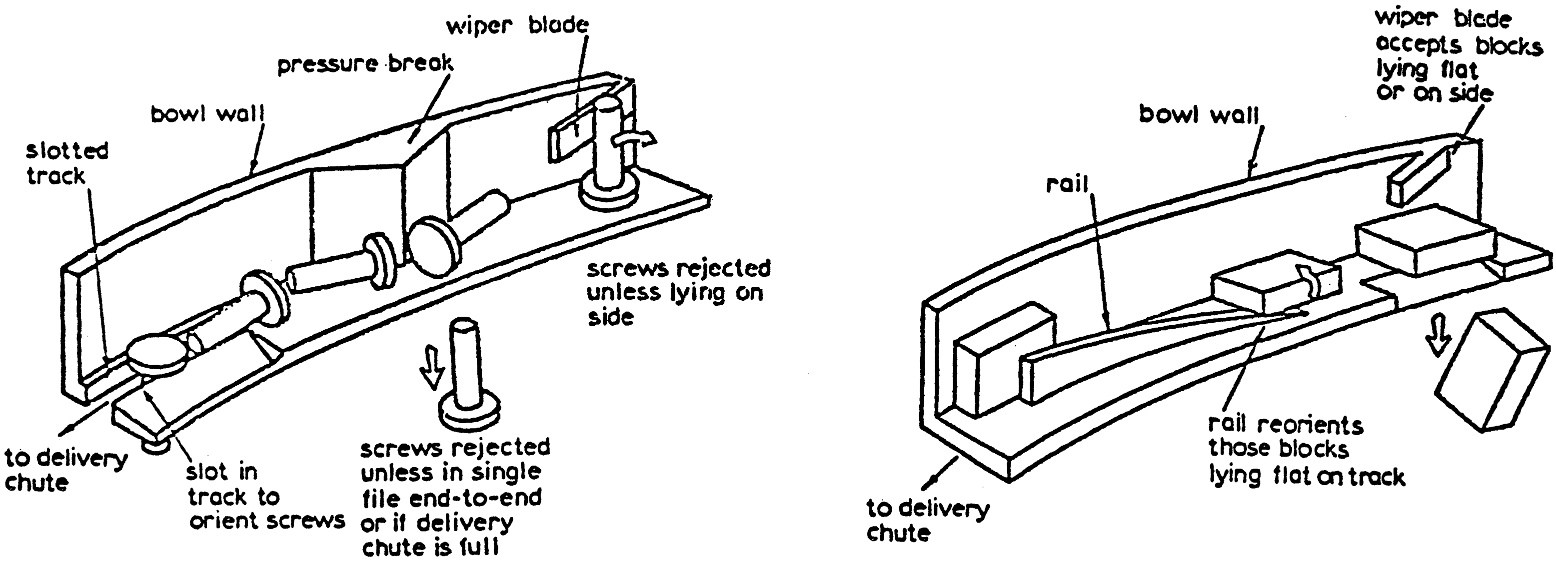


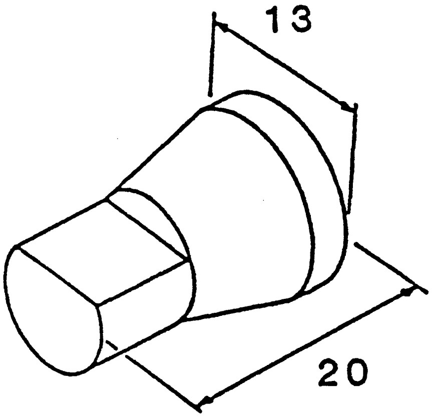
Figure (2): Passive (left) and active orienting mechanisms[2].

Boothroyd quantifies the "feedability" and "orientability" of a part with a five digit code based on the part size, part geometry, and other part properties. An example of this coding system is given below. This code number is essentially a figure of merit for the feeding and orienting properties of the part. The basic part design principles that lead to a desirable code number are actually quite simple:

1. Avoid parts that tangle and nest with each other.
2. Obtain perfect part symmetry if possible.
3. If perfect symmetry is not possible, exaggerate asymmetry.

Parts that tangle and nest will be very difficult to seperate from one another and begin on the feeding track. Parts that are symmetric have identical orientations that increase the probability of a correctly oriented part. A strongly asymmetric part facilitates the design of a suitable orienting mechanism.

Figure (3), along with the charts in appendix (1), gives an example of the Boothroyd coding system. The "envelope" of the part is the minimal cylinder or rectangular prism that would



Part with Feeding and Orienting

Code 22400 (OE = 0.37, CR = 1.5)

(dimensions in mm)

Figure(3): Example of Boothroyd coding system[1].

enclose the part. Because the envelope for this part is a cylinder with a length/diameter ratio of 1.54, we see from Chart (4) that the first digit is "2". The row and column numbers of chart (5) give respectively the second and third digits. Beta symmetry is defined as some symmetry with respect to the major axis of the envelope and alpha symmetry is defined as some symmetry with respect to an axis perpendicular to the major axis. Because this part has a beta symmetric chamfer the second Boothroyd digit is the appropriate row number "2". Because the part has a beta asymmetric projection in both the side and end surfaces, the third digit is found as the column number "4". The fourth and fifth digits describe non-geometric properties of the part. Using chart (7), because the part is non-flexible the fourth digit is the row number "0", and because the part is non-sticky the fifth digit is the column number "0". Hence, the entire Boothroyd code is "22400". Figure (4) shows an enlargement of the box of chart (5) specified by the second and third digits. Here we see the parameters OE (Orienting efficiency) and FC (partial Feeder Cost) highlighted. These two parameters are used in Boothroyd's economic modeling equations. Although a discussion of these equations is not pertinent to this paper, it is obvious that the orienting efficiency should be maximized and the partial feeder cost should be minimized.

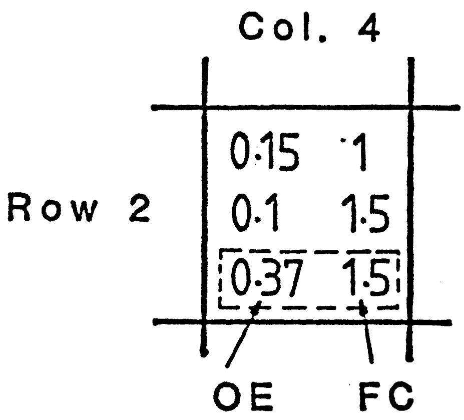


Figure (4): Appropriate box of chart (5)[1].

Figure (5) shows examples of part redesign to imrove the Boothroyd code. Unfortunately, this figure is from an earlier Boothroyd publication[2] and these code numbers do not correspond to the charts given in appendix (1). The threaded stud is improved by making it symmetric; the fork gap is widened to prevent tangling; a non-functional hole is added to to the plate to achieve symmetry; and the cone on the pin is made more prominent to to increase orientability.

Finally, figure (6) shows examples of non-functional changes to promote feeding and orienting. The upper half of the figure shows how part design changes that prevent tangling increase feedability. The lower half shows how a non-functional change to the geometry of the part can allow easier orienting.

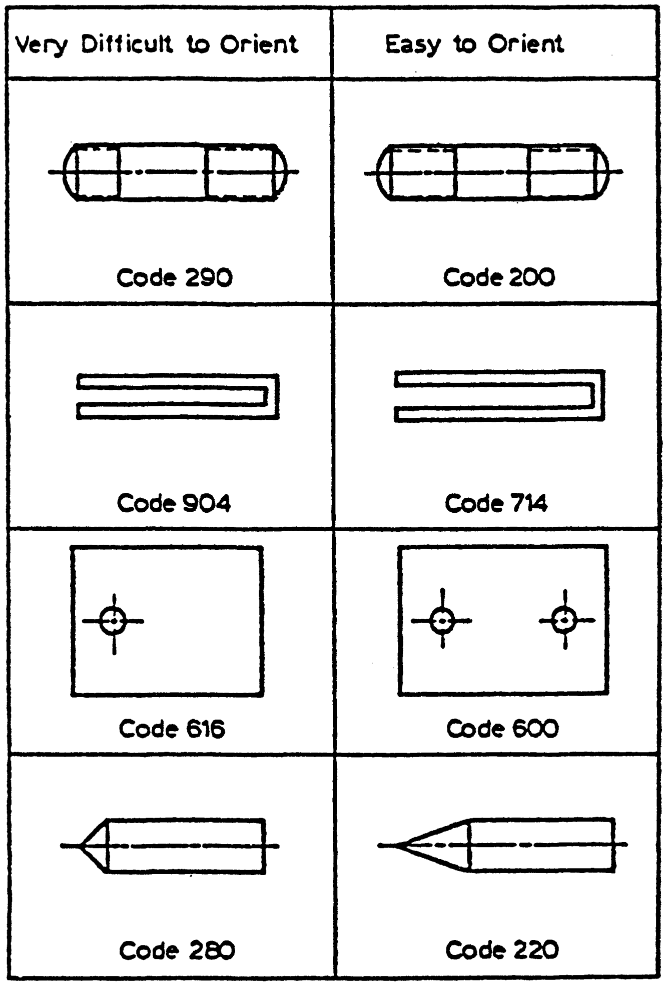


Figure (5): Improvements in Boothroyd code[2].

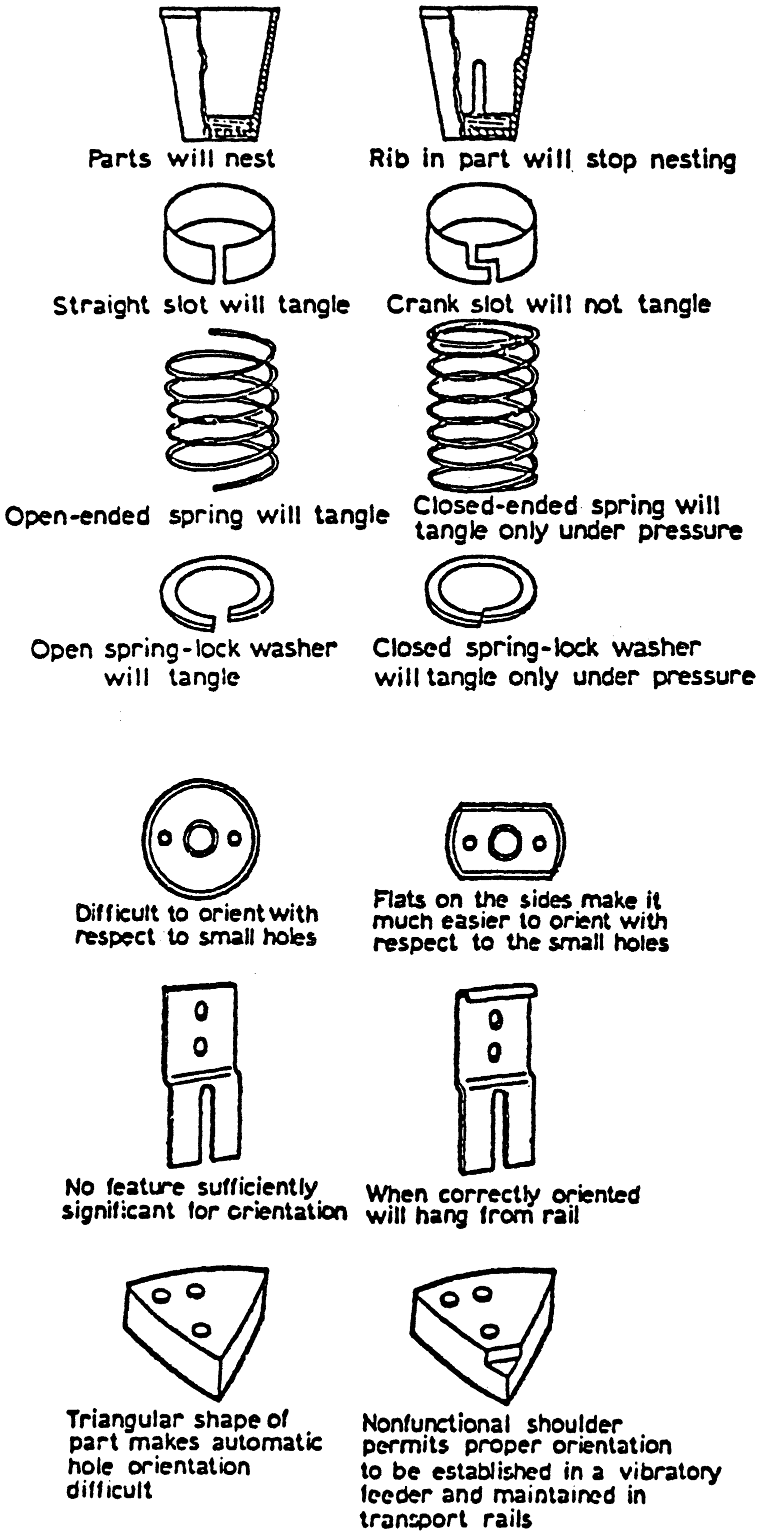


Figure (6): Nonfunctional changes to promote feeding and orienting[2].

SIMPLIFICATION

Assembly simplification encompasses two major ideas. First, to reduce the number of parts in the assembly, and second, to optimize the gross motions required to fit the parts together. This gross motion before part insertion is known as "part choreography".

Reducing the number of parts is one of the most effective ways to reduce the assembly cost. If the number of parts decreases, the assembly time and therefore the assembly costs also decrease. Reducing the number of parts, however, usually entails making the individual parts more complex. This might require more costly manufacturing operations (e.g. die casting) that nullify any expected savings. Appendix (2) gives an example of an industrial redesign with fewer parts of somewhat increased complexity that still effected a considerable savings. It is interesting to note that most of the parts eliminated were some type of fastener. This hints that the other major problem with reducing the number of parts is decreasing the "repairability" of the assembly. Perhaps in the near future disposable assemblies will become more common if they allow considerable reductions in assembly cost.

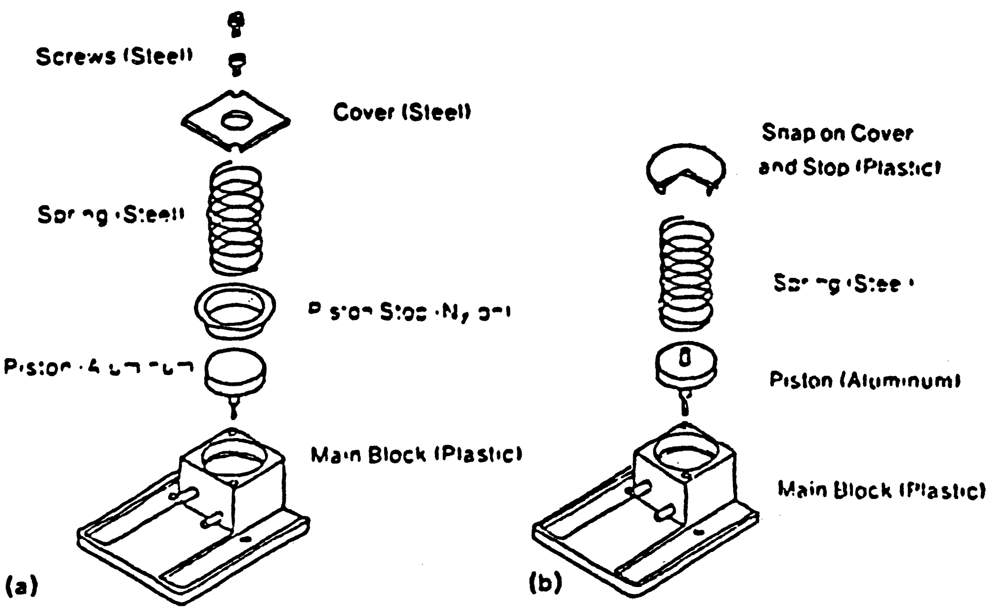


Fig 1 Pneumatic piston subassembly Current design (a) has 7 parts, the proposed design (b) has 4 parts

Figure (7): Reducing the number of parts[17].

The optimal choreography for most assemblies is to insert every part on the preceding part in a vertically downward direction. This has been called a "pancake structure". Figure (8) shows an automobile alternator assembled in this manner. There are several reasons why this choreography is favorable. First, gravity is used to secure the parts. This can simplify or eliminate many jigs and fixtures. Also, this choreography facilitates the design of a rotary index table assembly machine. The machine heads are easily designed to be directly above the assembly stations on the rotating table. Figure (9) shows that past practice is evidence of of these reasons. It is seen that direction (1) is the most frequent direction of insertion and that simple peg in hole and screwing insertions are the most common operations in this direction. Figure (10) shows a usual consequence of designing a pancake assembly. A large base part is required to interface with the work carrier and support the rest of the assembly.

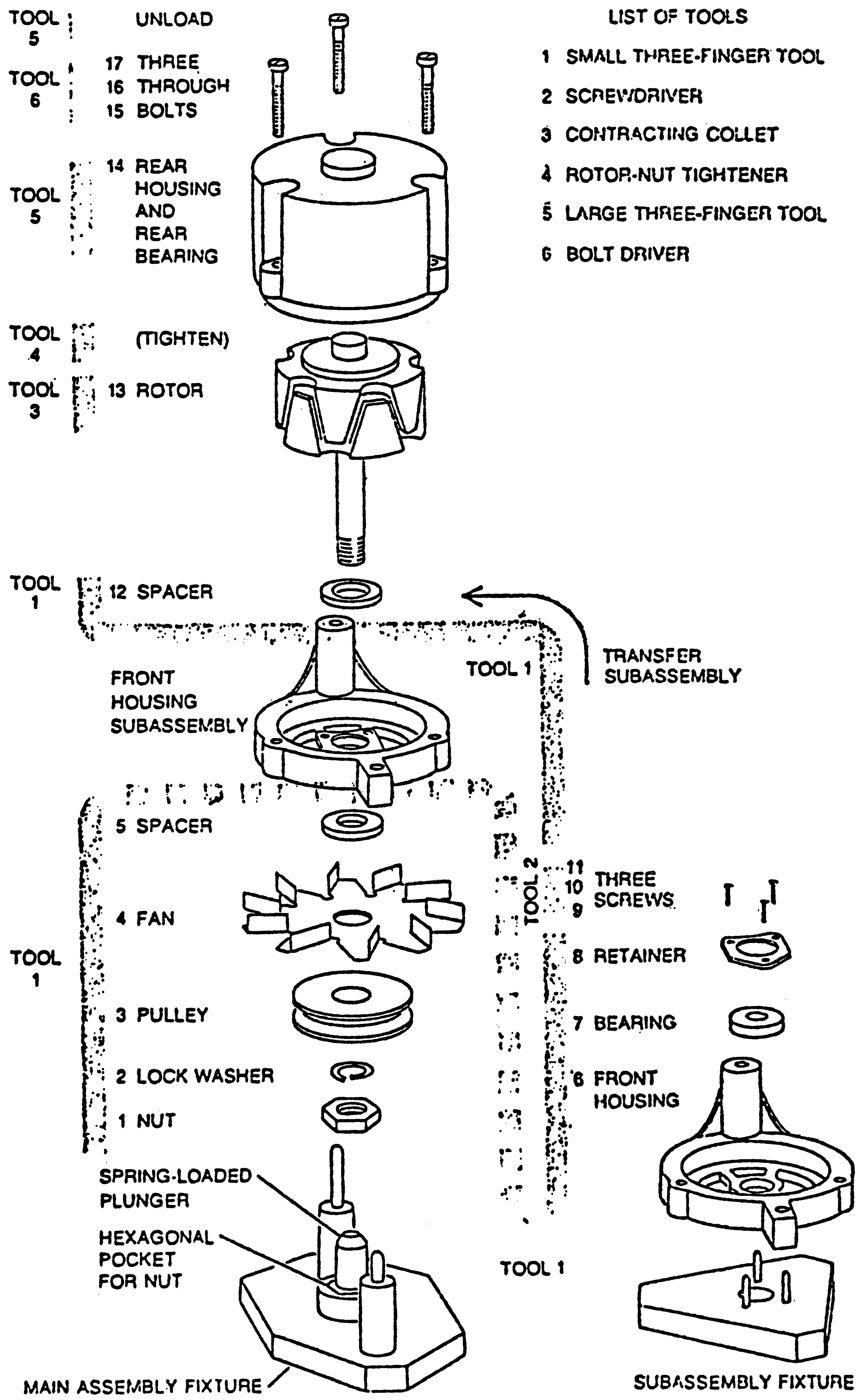
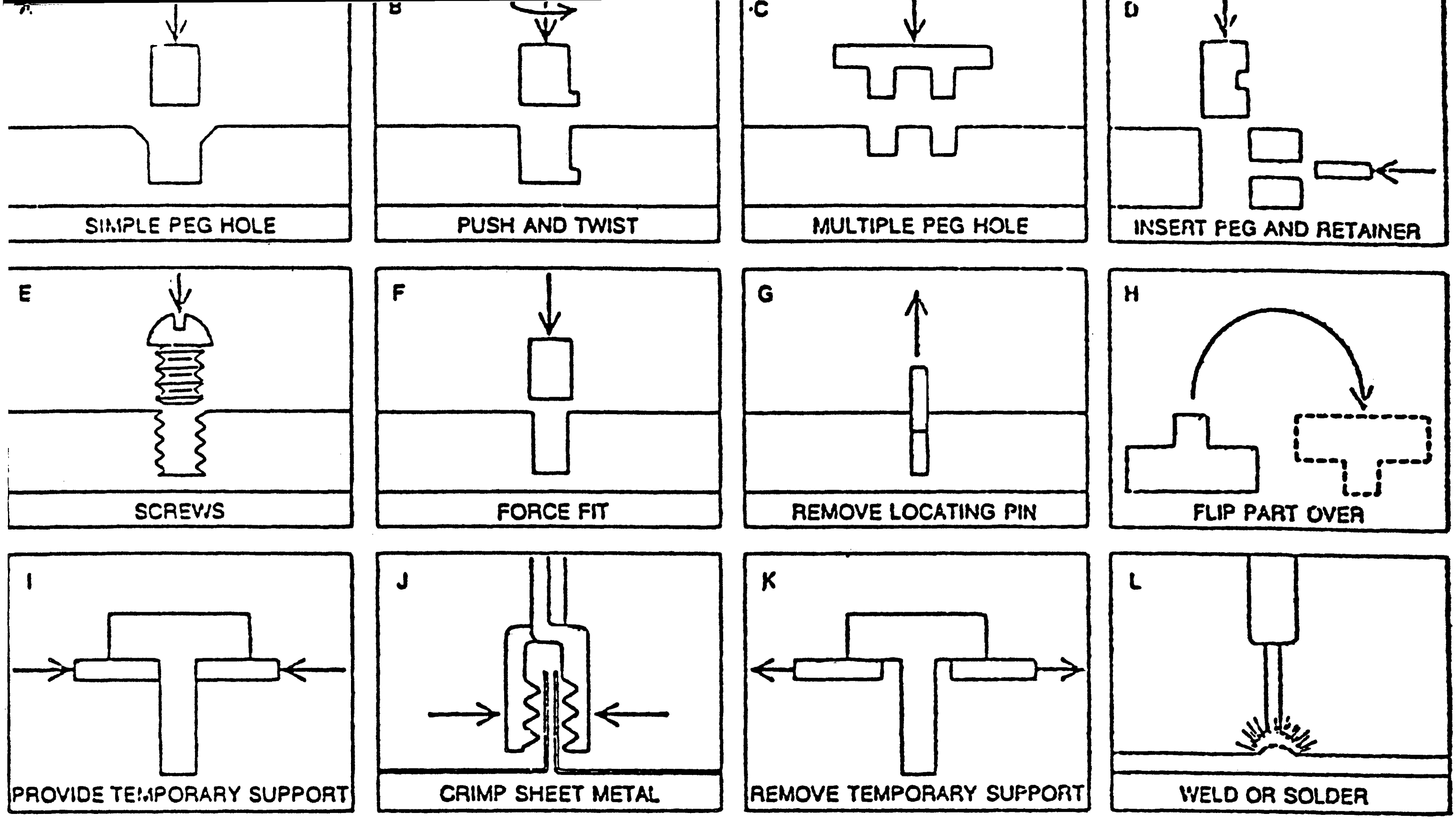


Figure (8): Part choreography showing pancake structure[5].



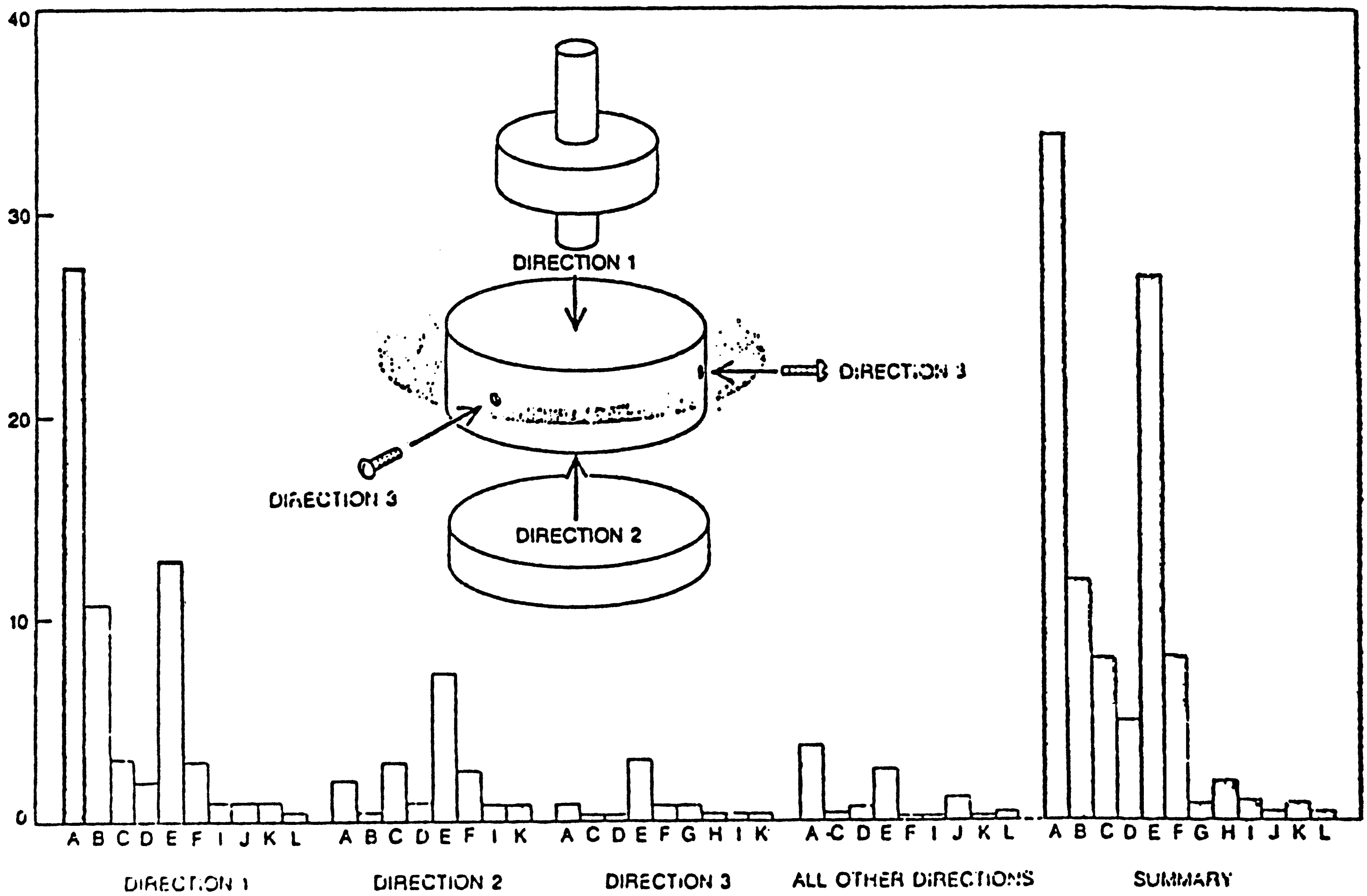


Figure (9): Evidence of pancake structure[5].

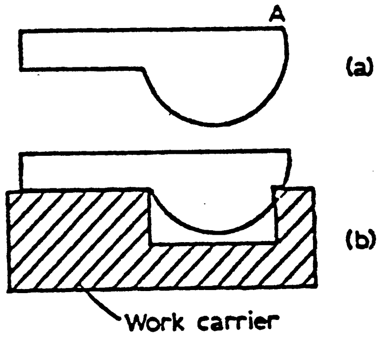


Figure (10): Large base part for pancake structure[2].

PARTS MATING AND MODIFICATION

Parts mating and modification studies concern how parts contact, fit, and fasten together. The term "mating" refers to the way two parts interface and the term "modification" refers to part redesign to optimize this interfacing.

What is called "insertion" is actually made up of two phases: location and insertion. "Location" is the process of aligning the parts within tolerable limits that will allow them to be moved to their final positions. The most common part design feature that promotes location is the ordinary chamfer. Figure (11) shows the simple function of the chamfer. In the upper sketch, insertion is impossible because of the lateral misalignment. In the lower sketch, on the other hand, the same misalignment is tolerable because of the chamfer. The net effect is to make the pins seem smaller during initial insertion, relying on some compliance in the system as the insertion is completed.

Looking even more closely at the interface between a peg and hole yields further, more specific, information. Figure (12) presents the definations of "wedging" and "jamming" derived by S. Simunovic of the Charles Stark Draper Laboratory. Both definitions depend upon angular misalignment. "Wedging" is defined as angular misalignment impeding insertion when the ratio L/D is less than the coefficient of friction of the interface. Further force applied anywhere on the end of the peg will only deform the peg or the hole or both. "Jamming" is defined as angular misalignment impeding insertion when the ratio L/D is greater than the coefficient of friction. Further force applied in the proper location will cause the insertion to continue.

The upper row of figure (13) shows some important effects related to these definitions. On the left it is seen how a lateral misalignment becomes an angular misalignment: the peg contacts the chamfer of the part and the compliance of the tool holding the peg allows it to tilt as it slides down the chamfer.

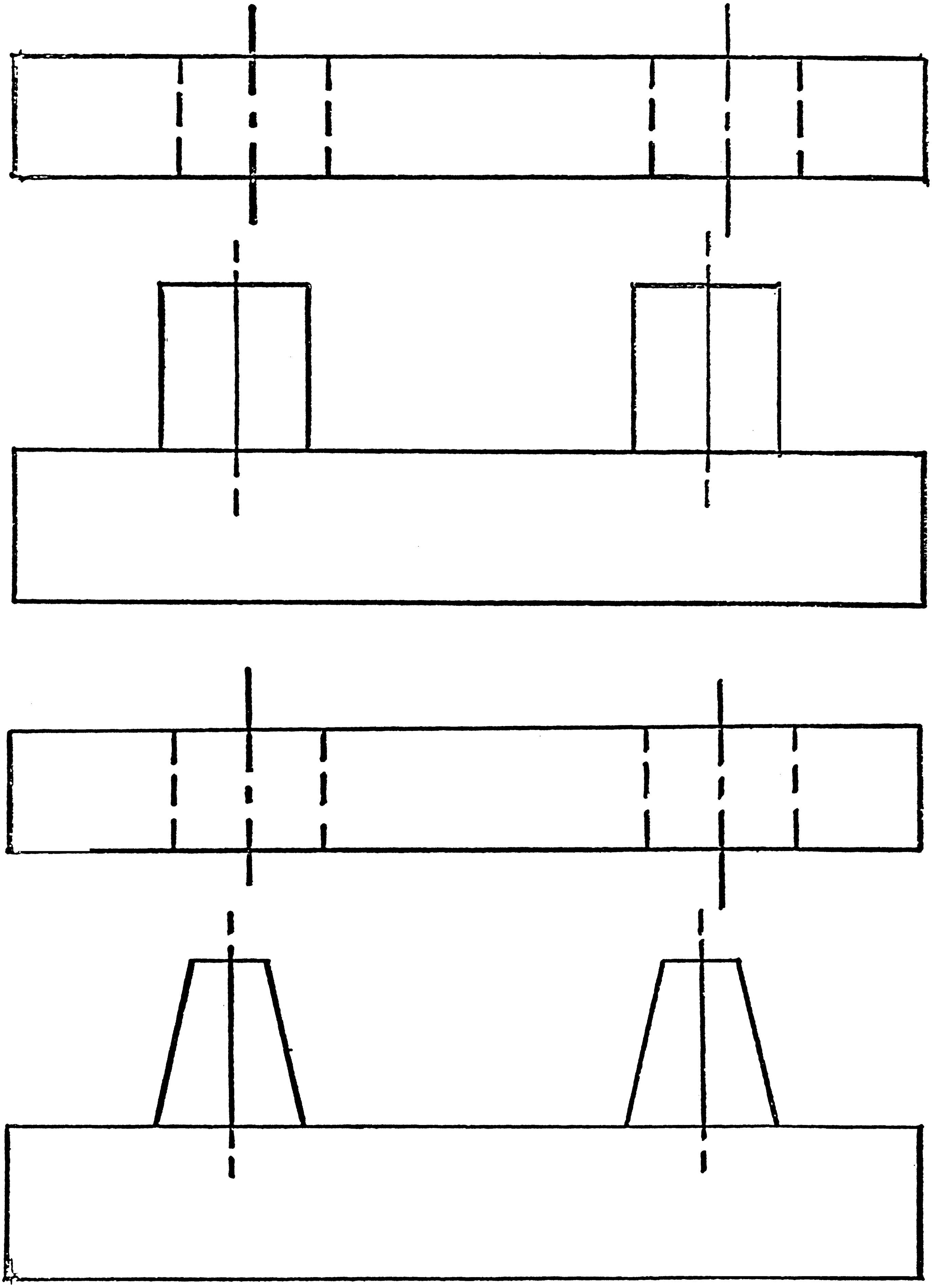


Figure (11): Function of a chamfer.

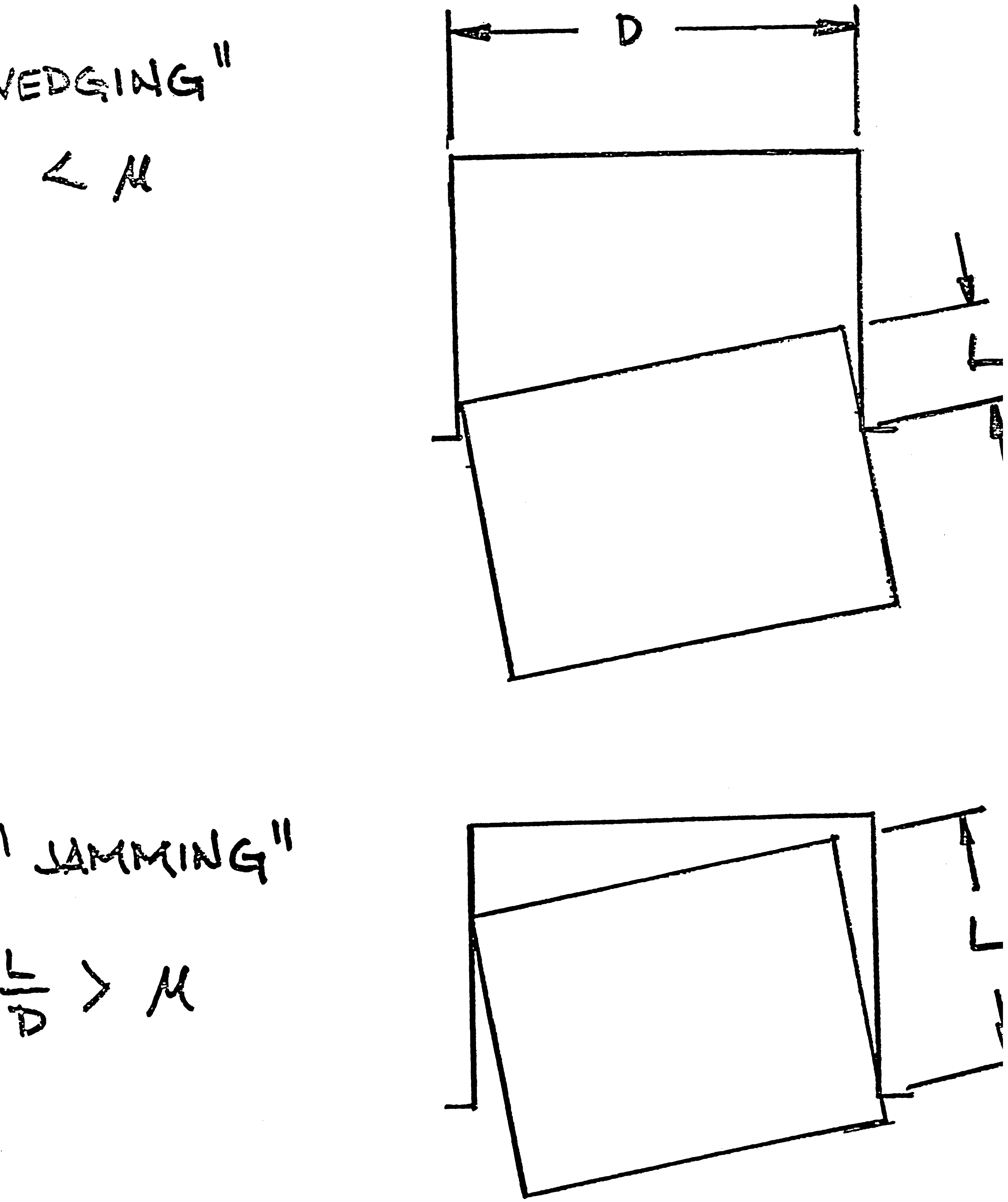


Figure (12): Wedging and jamming.

Eventually, the opposite side of the peg touches the opposite side of the hole causing two-point contact and possible wedging or jamming. In figure (d) of the top row is shown the resulting insertion "funnel". This can be defined as the locus of allowable angular misalignment as a function of the depth of the start of two-point contact. The center row of figure (13) shows the forces that arise as the insertion takes place. The bottom row shows the compliance required of the gripper and the force it puts on the part (a,b). In (c,d) it is seen that if the force was applied in the proper location it would promote insertion: (c) suggests that a good way of applying the contact force would be to pull the peg into the hole, allowing it to rotate about this lower point as the insertion proceeds.

This idea lead to the development, at the Charles Stark Draper Laboratory, of the Remote Center Compliance end effector (RCC) shown in figure (14). The device consists of cascaded independent translational and rotational compliance mechanisms. Lateral error or angular error or combinations of both can be tolerated. The effect is the desired result described above. The peg behaves as if it the force is applied at the pulling point, or "remote center". This idea of cascaded compliances is common to many end effectors, both instrumented and non-instrumented. Counterweights are added to the device to allow insertions not from directly above.

Finally, a brief example is given of a parts modification to promote assembly. Figure (15) shows a nonfunctional boss incorporated into the design to interface with the "V" jaws of the gripper. This allows a very simple gripper to handle both the pillars and boss/plate parts.

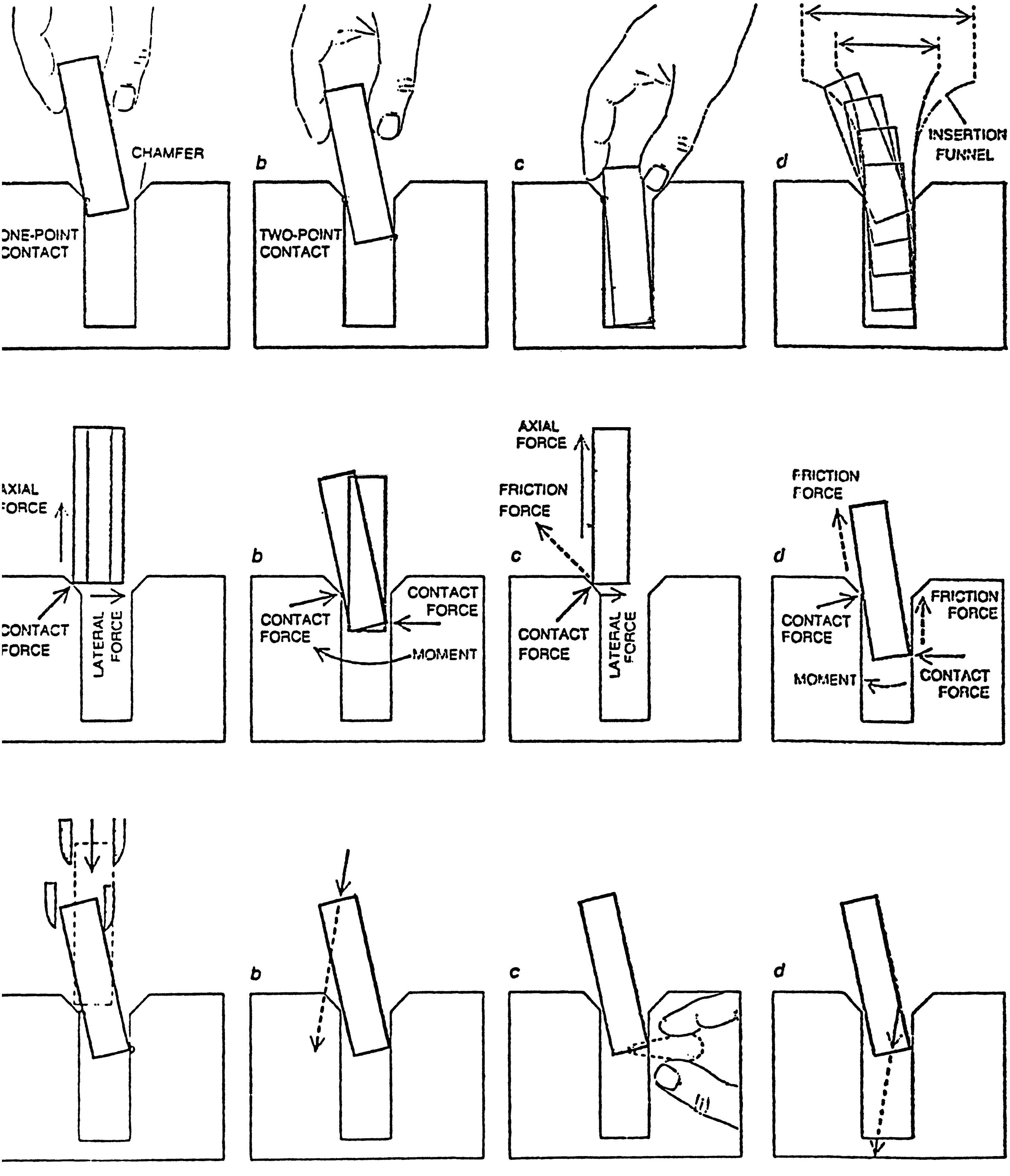


Figure (13): Insertion funnel and compliance[5].

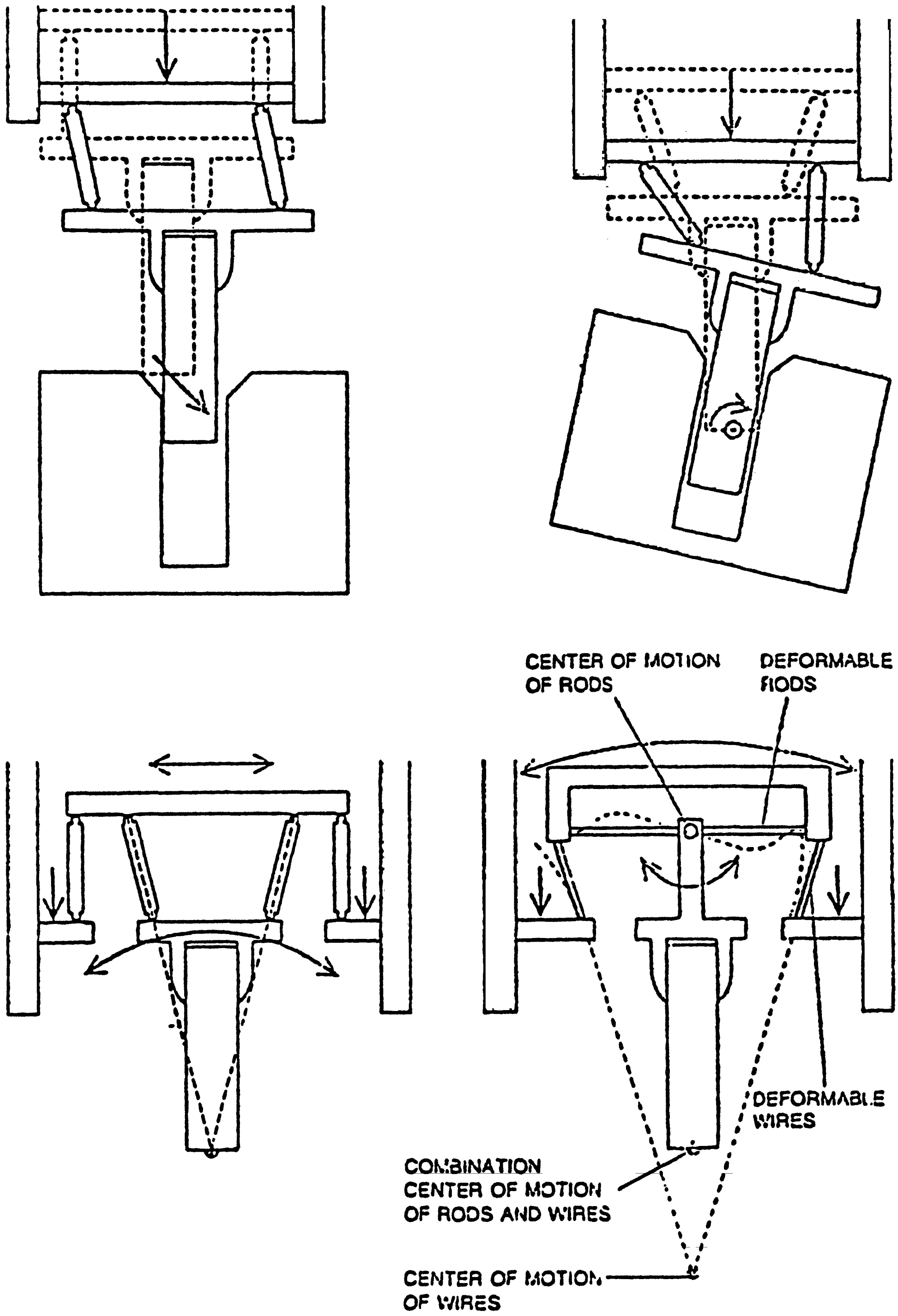


Figure (14): Remote center compliance device[5].

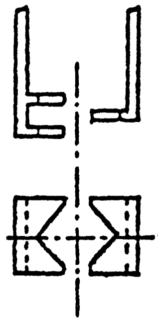


Figure 2. V jaw type gripper.

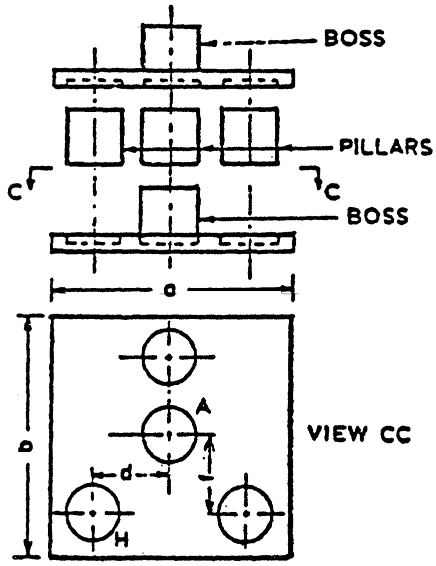


Figure (15): Part modification to promote parts mating[19].

RESEARCH DIRECTIONS

One of the areas the author is now investigating is the use of the Boothroyd data in a knowledge-based consulting system. The hope is that such a system would allow a designer to achieve a part with desirable assembly properties with a single design synthesis effort. This is in contrast to the more traditional iterative method of design, followed by Boothroyd analysis, followed by redesign.

Other areas include integrating the Boothroyd data into a group technology data base, the relationship of the Boothroyd data to a high level automated assembly programming language (such as IBM'S AUTOPASS), and part design to promote insertion (part design rather than end effector design).

SUMMARY

This paper has discussed product design to promote automated assembly. A strong foundation of research experience and experimental results has been created. Others must draw upon this knowledge to solve the problems that will arise as assembly is automated to a higher degree.

APPENDIX 1

Boothroyd Coding System for Automatic Handling and Assembly

On the following pages are reproductions of the Boothroyd automatic handling and assembly coding charts[1].

AUTOMATIC HANDLING

FIRST DIGIT

ROTATIONAL (1)	DISCS $L/D < 0.8$ (2)	0
	SHORT CYLINDERS $0.8 \le L/D \le 1.5$ (2)	1
	LONG CYLINDERS $L/D > 1.5$ (2)	2
NON-ROTATIONAL	FLAT $A/B \le 3$, $A/C > 4$ (3)	6
	LONG $A/B > 3$ (3)	7
	CUBIC $A/B \le 3$, $A/C \le 4$ (3)	8

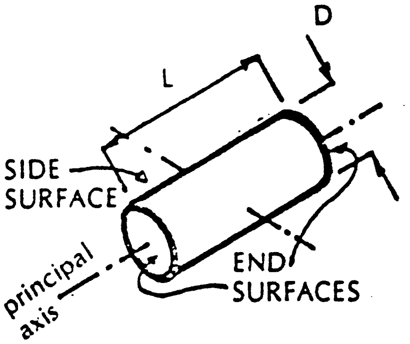
NOTES

1. A part whose basic shape is a cylinder or regular prism whose cross-section is a regular polygon of five or more sides is called a rotational part. In addition, triangular or square parts that repeat their orientation when rotated about their principle axis through angles of 120° or 90° respectively are rotational parts.
2. L is the length and D is the diameter of the smallest cylinder than can completely enclose the part.
3. A is the length of the longest side, C is the length of the shortest side and B is the length of the intermediate side of the smallest rectangular prism that can completely enclose the part.

AUTOMATIC HANDLING—DATA FOR ROTATIONAL PARTS
(first digit 0, 1 or 2)

KEY:

first digit	OE	FC
0	0.3	1
1	0.15	1.5
2	0.45	1.5



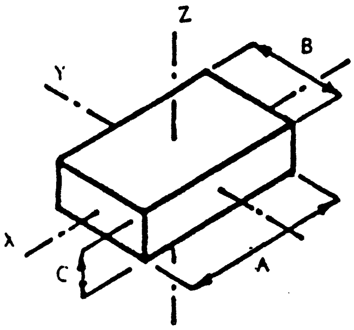
			part is symmetrical about its principal axis (BETA symmetric) (see note 2)	part is not BETA symmetric (code the main feature or features requiring orientation about the principal axis)						
				BETA asymmetric projections, steps, or chamfers (can be seen in silhouette)			BETA asymmetric grooves or flats (can be seen in silhouette)			slightly asymmetric or small features less than D/10 and L/10 OR holes or recesses which cannot be seen in outer shape of silhouette
				on side surface only	on end surface(s) only	on both side and end surface(s)	through groove or flat can be seen in end view	through groove can be seen in side view: on end surface	through groove can be seen in side view: on side surface	
			0	2	3	4	5	6	7	8
part is ALPHA symmetric (see note 1)		0	0.7 1 0.7 1 0.9 1	0.3 1 0.15 1 0.45 1	0.5 1 0.2 1 0.9 2	0.3 1 0.15 1 0.45 1	0.35 1 0.2 1 0.9 1	0.2 1 0.2 1 0.9 2	0.5 1 0.2 1 0.9 2	
part is not ALPHA symmetric (code the main feature or features requiring end-to-end orientation) (see note 1)	part can be fed in a slot supported by large end or protruding flange with center of mass below supporting surfaces	1	0.4 1 0.3 1 0.9 1	0.2 1 0.1 1 0.45 1	0.25 1 0.1 1 0.9 2	0.2 1 0.1 1 0.45 1	0.2 1 0.1 1 0.9 1	0.1 1 0.1 1 0.9 2	0.25 1 0.1 1 0.9 2	
	BETA symmetric steps or chamfers on external surfaces (see note 3)	2	0.4 1 0.3 1 0.75 1	0.15 1 0.1 1.5 0.37 1.5	0.25 1 0.1 1.5 0.25 3	0.15 1 0.1 1.5 0.37 1.5	0.35 1 0.2 1.5 0.5 1	0.1 1 0.05 1.5 0.5 3	0.25 1 0.1 1.5 0.5 2	—MANUAL HANDLING REQUIRED—
	BETA symmetric grooves holes or recesses (see note 3): on both side and end surface(s)	3	0.5 1 0.2 1 0.85 1	0.15 1 0.1 1.5 0.43 1.5	0.25 1 0.1 1.5 0.25 2	0.15 1 0.1 1.5 0.43 1.5	0.2 1 0.1 1.5 0.5 1	0.1 1 0.05 1.5 0.5 2	0.25 1 0.1 1.5 0.5 2	
	BETA symmetric grooves holes or recesses: on side surface only	4	0.5 1 0.1 1 0.85 1	0.15 1 0.1 1.5 0.43 1.5	0.25 1 0.1 1.5 0.25 2	0.15 1 0.1 1.5 0.43 1.5	0.2 1 0.1 1.5 0.5 1	0.1 1 0.05 1.5 0.5 2	0.25 1 0.1 1.5 0.5 2	
	BETA symmetric grooves holes or recesses: on end surface(s) only	5	0.5 1 0.2 1 0.6 1	0.15 1 0.1 1.5 0.27 1.5	0.25 1 0.1 1.5 0.25 2	0.15 1 0.1 1.5 0.27 1.5	0.2 1 0.1 1.5 0.45 1	0.1 1 0.05 1.5 0.45 2	0.25 1 0.1 1.5 0.45 2	
	BETA symmetric hidden features with no corresponding exposed features (see note 4)	6	0.6 1	0.27 1.5	0.25 2	0.27 1.5	0.45 1	0.45 2	0.45 2	
	BETA asymmetric features on side or end surface(s)	7		0.27 2	0.25 1 0.1 1.5 0.25 3	0.1 1 0.05 1.5 0.27 2	0.1 3	0.1 1 0.05 1.5 0.5 3	0.25 1 0.1 1.5 0.5 3	
	slightly asymmetric or small features; amount of asymmetry or feature size less than D/10 and L/10	8	—MANUAL HANDLING REQUIRED—							

AUTOMATIC HANDLING—
DATA FOR NON-ROTATIONAL PARTS
(first digit 6, 7 or 8)

Key

first digit	OE	FC
6	0.7	1
7	0.45	1.5
8	0.3	2

		A > 1.1B and B > 1.1C	A ≤ 1.1B or B ≤ 1.1C (code the main feature or features which distinguish the adjacent surfaces having similar dimensions)							
			steps or chamfers (2) parallel to —			through grooves (2) parallel to —			holes or recesses > 0.1B (cannot be seen in silhouette)	other - including slight asymmetry (3), features too small etc.
			X axis and > 0.1C	Y axis and > 0.1C	Z axis and > 0.1B	X axis and > 0.1C	Y axis and > 0.1C	Z axis and > 0.1B		
		0	1	2	3	4	5	6	7	8
part has 180° symmetry about all three axes (1)	0	0.8 1 0.9 1 0.6 1	0.8 1 0.9 1 0.5 1	0.2 1 0.5 2 0.15 2	0.5 1 0.5 1.5 0.15 1.5	0.75 1 0.5 1 0.5 1	0.25 1 0.5 1.5 0.15 1	0.5 1.5 0.6 1 0.15 1.5	0.25 2 0.5 1 0.15 2	MANUAL HANDLING REQUIRED



			code the main feature, or if orientation is defined by more than one feature, then code the feature that gives the largest third digit							
			steps or chamfers (2) parallel to -			through grooves (2) parallel to -			holes or recesses > 0.1B (cannot be seen in silhouette)	other - including slight asymmetry (3), features too small etc.
			X axis and > 0.1C	Y axis and > 0.1C	Z axis and > 0.1B	X axis and > 0.1C	Y axis and > 0.1C	Z axis and > 0.1B		
			0	1	2	3	4	5	6	7
part has 180° symmetry about one axis only (1)	about X axis	1	0.4 1 0.5 1 0.4 1	0.6 1 0.15 1 0.6 1	0.4 1.5 0.25 2 0.4 2	0.4 1 0.5 1 0.2 1	0.3 1 0.25 1 0.3 1	0.7 1 0.25 1.5 0.15 1	0.4 2 0.25 3 0.1 2	MANUAL HANDLING REQUIRED
	about Y axis	2	0.4 1 0.4 1 0.5 1	0.3 1 0.2 1 0.15 1	0.4 1.5 0.25 2 0.5 2	0.5 1 0.4 1 0.2 1	0.3 1 0.25 1 0.15 1	0.4 1 0.25 1 0.15 2	0.4 2 0.25 2 0.15 2	
	about Z axis	3	0.4 1 0.3 1 0.4 1	0.3 1 0.2 1 0.2 1	0.4 1.5 0.25 2 0.4 2	0.4 1 0.3 1 0.2 1	0.3 1 0.25 1 0.15 1	0.4 1.5 0.25 2 0.15 2	0.4 2 0.25 2 0.15 2	
part has no symmetry (code the main feature(s) that define the orientation) (4)	orientation defined by one main feature	4	0.25 1 0.25 1 0.15 1	0.15 1 0.1 1.5 0.14 1	0.15 1.5 0.24 2 0.15 1	0.1 1 0.2 1 0.1 1	0.15 1 0.1 1.5 0.05 1	0.1 1.5 0.15 2 0.1 1.5	0.1 2 0.15 3 0.08 2	
	orientation defined by two main features and one is a step, chamfer or groove	6	0.2 2 0.1 3 0.05 2	0.15 2 0.1 3.5 0.05 2	0.1 2.5 0.1 4 0.05 2.5	0.1 2 0.1 3 0.05 2	0.15 2 0.1 3.5 0.05 2	0.1 2.5 0.1 4 0.05 2.5	0.1 3 0.1 5 0.05 3	
	other - including slight asymmetry (3) etc	9	MANUAL HANDLING REQUIRED							

AUTOMATIC HANDLING—ADDITIONAL FEEDER COSTS, DC

FIGURES TO BE ADDED TO FC, OBTAINED FROM CHARTS 5 OR 6

					parts will not tangle or nest				tangle or nest but not severely				severely nest	severely tangle
					not light		light		not light		light			
					not sticky	sticky	not sticky	sticky	not sticky	sticky	not sticky	sticky		
					0	1	2	3	4	5	6	7	8	9
parts are small and non-abrasive	parts do not tend to overlap during feeding	not delicate	non-flexible	0	0	1	2	3	2	3	3	4	MANUAL HANDLING REQUIRED	
			flexible	1	2	3	4	5	4	5	5	6		
		delicate	non-flexible	2	1	2	3	4	3	4	4	5		
			flexible	3	3	4	5	6	5	6	6	7		
	parts tend to overlap during feeding	not delicate	non-flexible	4	2	3	3	4	4	5	4	5		
			flexible	5	4	5	5	6	6	7	6	7		
		delicate	non-flexible	6	3	4	4	5	5	6	5	6		
			flexible	7	5	6	6	7	7	8	7	8		

		very small parts					large parts				
		rotational		non-rotational			rotational		non-rotational		
		L/D≤1.5	L/D>1.5	A/B ≤ 3 A/C > 4	A/b > 3	A/B ≤ 3 A/C ≤ 4	L/D≤ 1.5	L/D > 1.5	A/B ≤ 3 A/C > 4	A/B > 3	A/B ≤ 3 A/C ≤ 4
		0	1	2	3	4	5	6	7	8	9
parts are very small or large but are nonabrasive	8	2	2	2	2	2	9	9	9	9	9

		parts will not severely tangle or nest									severely tangle or nest
		small parts					large parts		very small parts		
		orientation defined by geometric features			orientation defined by non-geometric features		orientation defined by geometric features	orientation defined by non-geometric features	orientation defined by geometric features	orientation defined by non-geometric features	
		non-flexible		flexible	do not overlap	overlap					
		do not overlap	overlap								
		0	1	2	3	4	5	6	7	8	9
abrasive parts	9	2	4	4			9		4		

AUTOMATIC INSERTION— RELATIVE WORKHEAD COST, WC

Key:

- *PART ADDED but NOT SECURED*
- *PART SECURED IMMEDIATELY*
- *SEPARATE OPERATION*

			after assembly no holding down required to maintain orientation and location (5)				holding down required during subsequent process(es) to maintain orientation and location (5)			
			easy to align and position (6)		not easy to align or position (no features provided for the purpose)		easy to align and position (6)		not easy to align or position (no features provided for the purpose)	
			no resistance to insertion	resistance to insertion (7)	no resistance to insertion	resistance to insertion (7)	no resistance to insertion	resistance to insertion (7)	no resistance to insertion	resistance to insertion (7)
			0	1	2	3	6	7	8	9
addition of any part (1) where no final securing is taking place (2)	straight line insertion	from vertically above	0	1	1.5	1.5	2.3	1.3	2	2	3
		not from vertically above (3)	1	1.2	1 6	1.6	2.5	1.6	2.1	2.1	3.3
	insertion not straight line motion (4)		2	2	3	3	4.6	2.7	4	4	6.1

				no screwing operation or plastic deformation immediately after insertion (snap or press fits, etc.)		plastic deformation immediately after insertion						screwing immediately after insertion	
						plastic bending			rivetting or similar plastic deformation				
						easy to align and position (6)	not easy to align or position (no features provided for the purpose)		easy to align and position (6)	not easy to align or position (no features provided for the purpose)			
				easy to align and position (6) no resistance to insertion	not easy to align or position and/or resistance to insertion		no resistance to insertion	resistance to insertion (7)		no resistance to insertion	resistance to insertion (7)	easy to align and position (6) no resistance to screwing	not easy to align or position and/or resistance to screwing (7)
				0	1	2	3	4	5	6	7	8	9
addition of any part (1) where final securing is taking place	straight line insertion	from vertically above	3	1.2	1.9	1.6	2.4	3.6	0.9	1.4	2.1	0.8	1.8
		not from vertically above (3)	4	1.3	2.1	2.1	3.2	4.8	1	1.5	2.3	1.3	2
	insertion not straight line motion (4)		5	2.4	3.8	3.2	4.8	7.2	1.8	2.8	4.2	1.6	3.6

		mechanical fastening processes (parts already in place)				non-mechanical fastening processes (parts already in place)				non-fastening processes	
		none or localized plastic deformation			bulk plastic deformation (large portion of the part deformed)	metallurgical processes			chemical processes (adhesive bonding etc.)	manipulation of parts or sub-assembly (orienting, fitting, adjustment etc.)	other processes (liquid insertion etc.)
						no addition of material (friction or resistance welding, etc.)	additional material required				
		bending or similar processes	rivetting or similar processes	screwing or other processes			soldering processes	welding or brazing			
		0	1	2	3	4	5	6	7	8	9
assembly process where all solid parts are in place or non solids added or parts are manipulated	9	1.6	0.9	0.8		1.2	1.1	1.1	0.8	1.5	

APPENDIX 2

Application Examples of Boothroyd's Design for Assembly System

The first example[1] shows a redesign and the associated reduction in assembly costs. Note that assembly costs were cut by approximately a factor of nine but manufacturing costs were not considered.

The second example[18] shows an actual industrial application of the Design for Assembly System. Here it is important to note that the <u>total product cost</u> was reduced by 36%.

First example[1]

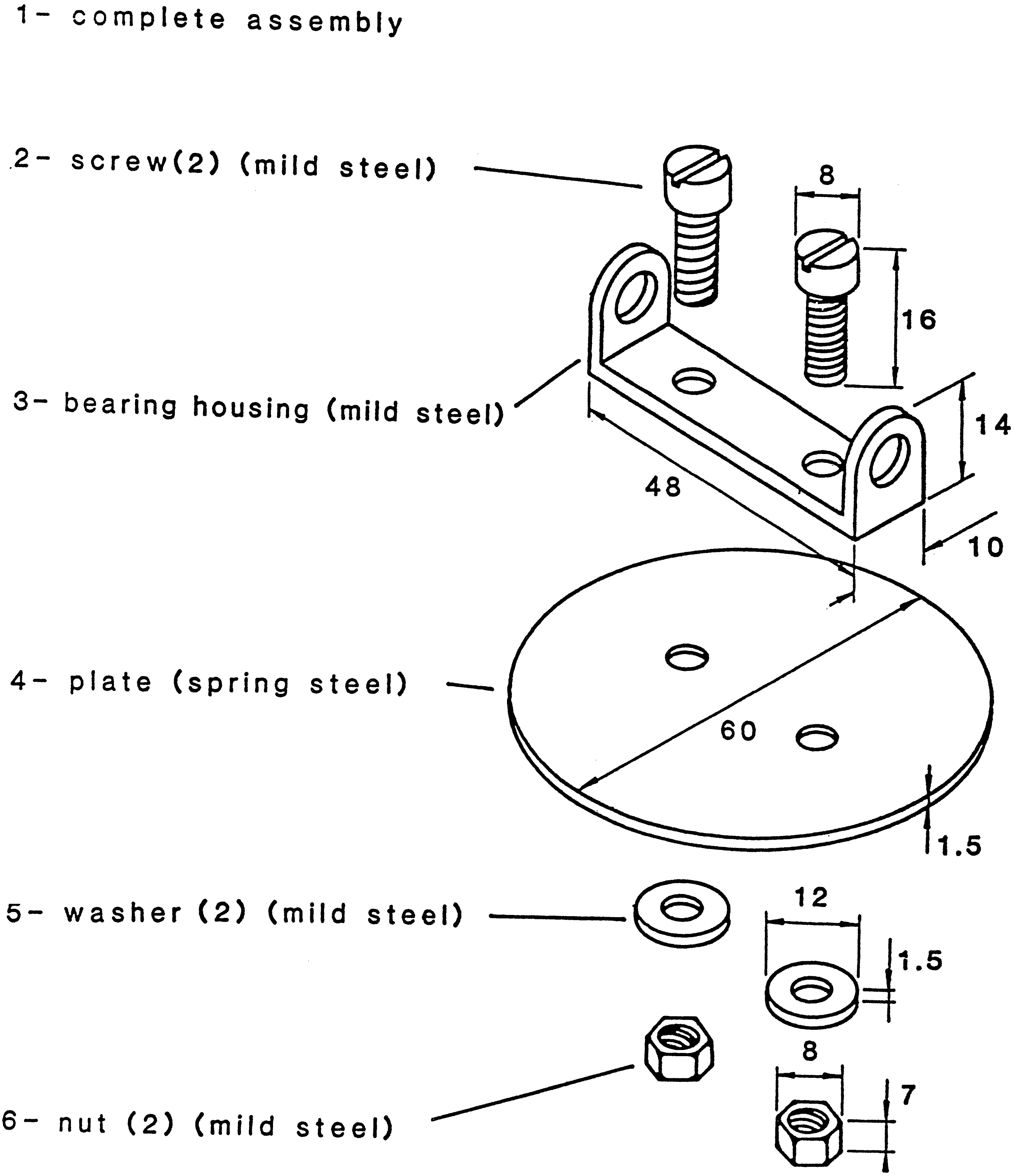


Figure 10 Diaphragm Assembly

(dimensions in mm)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	required rate of assembly FR (per minute): 30
part I.D. No	number of times operation is carried out simultaneously	five-digit automatic handling code	orienting efficiency, OE	relative feeder cost, CR = FC + DC	maximum basic feed rate, FM	difficulty rating for automatic handling, DF	cost of automatic handling per part, CF = 0.03 x DF	two-digit automatic insertion code	relative workhead cost, WC	difficulty rating for automatic insertion, DI	cost of automatic insertion per part, CI = 0.06 x DI	operation cost, cents (2) x [(8) + (12)]	figures for estimation of theoretical minimum parts	Name of Assembly: Diaphragm Assembly
6	2	10000	0·7	1	131	2	0·06	00	1	2	0·12	0·36	1	nut
5	2	00000	0·7	1	87·5	2	0·06	00	1	2	0·12	0·36	0	washer
4	1	00800	Manual assembly required									3·42	1	plate
3	1	72500	0·25	1	7·81	7·68	0·23	08	2	4	0·24	0·47	0	bearing housing
2	2	11000	0·3	1	56·3	2	0·06	39	1·8	3·6	0·22	0·56	0	screw
												5·17 (CA)	2 (NM)	design efficiency = $\frac{0.09 \times NM}{CA}$ = 0·034

Column 6: $FM = 1500 \times \frac{OE}{Y}$, Y = part 'size'

Column 7: $DF = \frac{60}{FR} \times CR$ if $FR < FM$; $DF = \frac{60}{FM} \times CR$ if $FR \geq FM$

Column 11: $DI = \frac{60}{FR} \times WC$ if $FR < 60$; $DI = WC$ if $FR \geq 60$

Figure 11 Worksheet for Diaphragm Assembly

1	2	3	4	5	6	7	8	9	Name of Assembly
part I D No	number of times the operation is carried out consecutively	two-digit manual handling code	manual handing time per part	two-digit manual insertion code	manual insertion time per part	operation time, seconds (2) x [(4) + (6)]	operation cost, cents 0.4 x (7)	figures for estimation of theoretical minimum parts	Diaphragm Assembly
4	1	13	2.06	08	6.5	8.56	3.42		plate
						TM	CM	NM	design efficiency = $\frac{3 \times NM}{TM}$ =

Figure 12 Manual Assembly of Diaphragm Plate

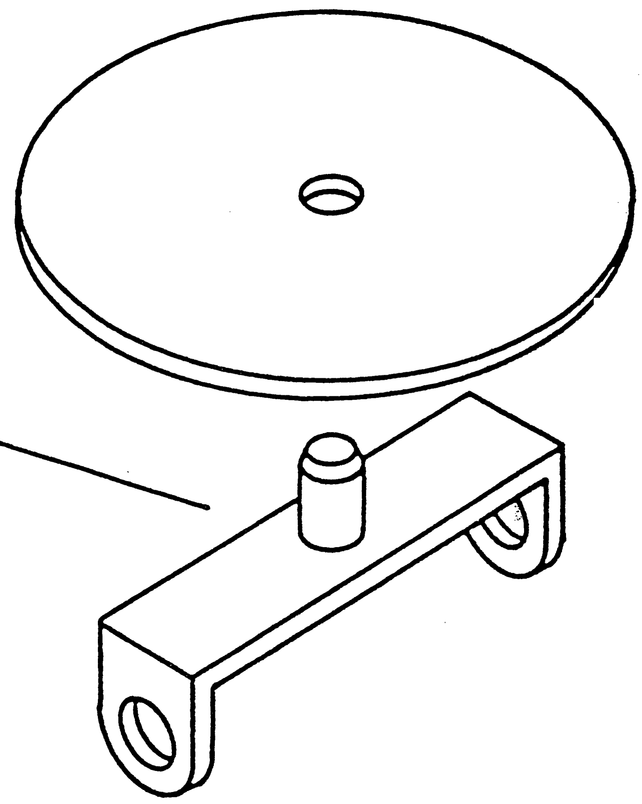


Figure 13 Re-design of

Diaphragm Assembly

1	2	3	4	5	6	7	8	9	10	11	12	13	14	required rate of assembly FR (per minute): 30
part I.D. No	number of times operation is carried out simultaneously	five-digit automatic handling code	orienting efficiency, OE	relative feeder cost, CR = FC + DC	maximum basic feed rate, FM	difficulty rating for automatic handling, DF	cost of automatic handling per part, CF = 0.03 x DF	two-digit automatic insertion code	relative workhead cost, WC	difficulty rating for automatic insertion, DI	cost of automatic insertion per part, CI = 0.06 x DI	operation cost, cents (2) x [(8) + (12)]	figures for estimation of theoretical minimum parts	Name of Assembly: Diaphragm Assembly (re-design)
3	1	82000	0·5	1	15·6	3·85	0·12	00	1	2	0·12	0·24	1	bearing housing
2	1	00000	0·7	1	17·5	3·43	0·10	00	1	2	0·12	0·22	1	plate
								91	0·9	1·8	0·11	0·11		separate fastening operation
												0·57 (CA)	2 (NM)	design efficiency = $\frac{0.09 \times NM}{CA}$ = 0·32

Column 6: $FM = 1500 \times \frac{OL}{Y}$; Y = part 'size'

Column 7: $DF = \frac{60}{FR} \times CR$ if $FR < FM$; $DF = \frac{60}{FM} \times CR$ if $FR \geq FM$

Column 11: $DI = \frac{60}{FR} \times WC$ if $FR < 60$; $DI = WC$ if $FR \geq 60$

Figure 14 Worksheet for Re-design of Diaphragm Assembly

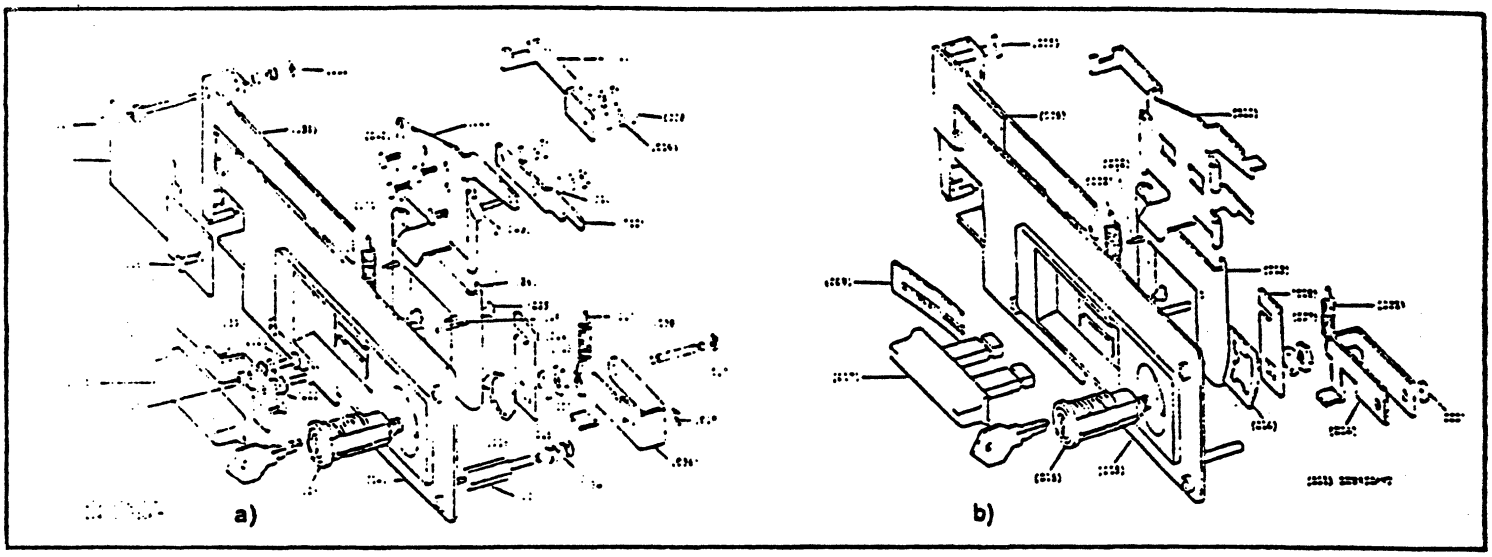


Fig. 1. Latch Mechanism: (a) existing design, (b) proposed re-design for ease of assembly.

Table 1 Redesign of Xerox Latch Using the UMass System				
	Old Design	New Design	Savings	% Change
Manual Assembly Efficiency	4.8%	22.5%		
Total Number of Parts Theoretical Min Number of Parts	62 10	17 10	45	73%
Estimated Assembly Time (Min.)	6 90	1.48	5.42	79%
Estimated Assembly Cost	$2 76	$0.59	$2.17	79%
Estimated Parts Cost	$9.80	$7.44	$2.36	24%
Total Product Cost	$12.56	$8.03	$4.53	36%

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