University of Toronto
Faculty of Applied Science and Engineering
Final Examination, December 2001
Fourth Year - Programs 3, 4manu, 5ms

MIE 440F: Mechanical Design
Examiner: L. Shu
Exam Type: A
(No data other than information printed on examination paper permitted.)

- You may remove the last 2 pages (pictures) of the exam from the staple to help you work faster.
- Answer short-answer questions in 12 or fewer words per section. Verbosity will be penalized.

This is a 2.5-hour exam.
You may use a calculator.
Answer all parts of all questions.
To obtain the maximum credit on numerical problems, show all steps in your computations.
Point values are shown in [] for entire problems and parts of problems to help you allocate your time.
Clearly indicate your answers in the spaces provided on exam sheet.
If a question is ambiguous, state the necessary assumptions.

Student Last Name ____________________

Student First Name ____________________

Student ID number ____________________

Problem	*Points Possible*	Points Obtained
I. Design for Assembly	*90*	
II. Design for Injection Molding	*60*	
III. Design for Stamping	*40*	
IV. Design for End-of-Life	*40*	
V. Product Liability	*20*	
Total	*250*	

INSTRUCTIONS

You are studying for your final exams when you decide to take a break and head down to the local AYOF (Assemble Your Own Furniture) store. As you weave through the showroom maize, you trip over a stray unit called "Rulla," which you decide is your destiny to buy. You feel compelled to perform a design analysis on Rulla, because you love to apply what you learn in class to real life.

I. Design-for-Assembly [90]

As with all AYOF furniture, the Rulla requires assembly. Remove the last page from the back of the exam that contains the assembly diagrams. Calculate the assembly time of the Rulla by completing the table below.

- All dimensions in mm are given for smallest box/cylinder that surrounds part. • All parts weigh < 10 lb.
- All parts over 300mm require two hands to handle.

1. Snap polypropylene anchors (30 x 10 x 5) into non-circular holes in one half of polypropylene box
2. Assemble other half (430 x 400 x 210) of polypropylene box
3. Assemble polypropylene shelf (400 x 400 x 15), whose top and bottom surfaces are different, into tight-fitting groove in box
4. Note: Perform in order described, not shown in diagram
   a. Assemble by pressing steel caster-stems (7.5 dia x 50) into steel caster base
   b. Assemble by pressing polypropylene casters (50 x 50 x 40) into steel stems in steel caster base
5. Punch holes on top of box
6. Assemble caster-base assembly (450 x 400 x 150) to box using screws (5 dia x 12)

Do NOT include final inversion of assembly so that wheels are on bottom.

Part/ Opera -tion	Alpha	Beta	Handle Code	Handle Time	Insert Code	Insert Time	Handle + Insert Time	# times per-formed	Total Time	Additional Assumptions (none should be required)
1										
2										
3										
4a										
4b										
5										
6										
Totals										

What is the minimum number of parts for this product that satisfy DFA criteria for separate parts?

Sketch/describe each of these parts.

II. Design for Injection Molding [60]

1. To injection mold one of the two identical box halves, sketch the most cost-effective mold closure direction relative to the part below [2].

2. Calculate the ABSOLUTE tooling cost to injection mold one of the two identical box halves using the most cost-effective mold closure direction. Use only details apparent from the assembly instructions and diagram. Assume standard finish and tolerances. Also complete table on next page for die detail. [42]

Injection Molding and Die Casting

Original Design

(a) *Relative Die Construction Cost*

L/H > 4?

Basic Shape: $L =$ ______; $B =$ ______; $H =$ ______; => Box/Flat ______

Basic Complexity: 1st Digit = ______; 2nd Digit = ______ => $C_b =$ ______

Subsidiary Comp: 3rd Digit = ______; 4th Digit = ______ => $C_s =$ ______

T_a/R_a: 5th Digit = ______; 6th Digit = ______ => $C_t =$ ______

Total Relative Die Construction Cost, $C_{dc} = C_b C_s C_t =$ ______

(b) *Relative Die Material Cost:*

$L_m =$ ______; $B_m =$ ______; $H_m =$ ______; Die Closure parallel to Hm

$L_m/H_m =$ ______; thus, $C =$ ______

$M_{ws} = [0.006CH_m^4]^{1/3} =$ ______

$M_{wf} = 0.04L_m^{4/3} =$ ______

$M_a = (2M_{ws}+L_m)(2M_{ws}+B_m) =$ ______

$M_t = (H_m + 2M_{wf}) =$ ______

Thus, $C_{dm} =$ ______ and $C_d = 0.8C_{dc} + 0.2C_{dm} =$ ______

Absolute tooling cost:

Feature		Number of Features (n)	Penalty per Features	Penalty
Holes or Depressions	Circular		2n	
	Rectangular		4n	
	Irregular		7n	
Bosses	Solid (8)		n	
	Hollow (8)		3n	
Non-peripheral ribs and/or walls and/or rib clusters (6)			3n	
Side Shutoffs	Simple (9)		2.5n	
	Complex (9)		4.5n	
Lettering (10)			n	
			Total Penalty	

SMALL PARTS (L < 250 mm)

Total Penalty < 10 => Low cavity detail
10 < Total Penalty < 20 => Moderate cavity detail
20 < Total Penalty < 40 => High cavity detail
Total Penalty > 40 => Very high cavity detail

MEDIUM PARTS (250 < L < 480 mm)

Total Penalty < 15 => Low cavity detail
15 < Total Penalty < 30 => Moderate cavity detail
30 < Total Penalty < 60 => High cavity detail
Total Penalty > 60 => Very high cavity detail

LARGE PARTS (L > 480 mm)

Total Penalty < 20 => Low cavity detail
20 < Total Penalty < 40 => Moderate cavity detail
40 < Total Penalty < 80 => High cavity detail
Total Penalty > 80 => Very high cavity detail

1 in = 25.4 mm; 100 mm = 3.94 in

3. Why do you suppose the box and shelf are molded as 3 separate parts? [2]

4. Draw the most cost effective mold closure direction if the box and shelf were molded as a single part. [2]

5. If you look at the actual product, the box-half parts are hollow. Name the three components of cost for any manufactured part. State whether injection molding the box halves as hollow instead of solid will increase or decrease that component of cost, and why. [12]

	Cost component	Increase/ Decrease	Why
1			
2			
3			

III. Design for Stamping. [40]

If you wanted to mount Rulla to the wall, instead of using casters, two mounting brackets as shown on next last page of exam (remove) are used. Calculate the relative die construction cost to produce the bracket.

Feature	Number of Features (n)	Opposite Directions? (Y/N)	Penalty
Standard Hole		n / n	
Non-standard Hole		2n / 2n	
Coin		3n / 3n	
Standard Emboss		(n+1) / n	
Non-standard Emboss		2(n+1) / 2n	
Extruded Hole		2(n+1) / 2n	
Lance Form		3(n+1) / 3n	
Curl		3(n+1) / 3n	
Curl		3(n+1) / 3n	
Hem		4(n+1) / 4n	
Semi-Perf		(n+1) / n	
Tab		3(n+1) / 3n	
Lettering		2(n+1) / 2n	
		Total Penalty	

Small Parts (L ≤ 100 mm)

Total Penalty ≤ 4 => Low Die Detail
4 < Total Penalty ≤ 8 => Medium Die Detail
Total Penalty > 8 => High Die Detail

Medium Parts (100 mm < L ≤ 200 mm)

Total Penalty ≤ 6 => Low Die Detail
6 < Total Penalty ≤ 12 => Medium Die Detail
Total Penalty > 12 => High Die Detail

Large Parts (L > 200 mm)

Total Penalty ≤ 10 => Low Die Detail
10 < Total Penalty ≤ 17 => Medium Die Detail
Total Penalty > 17 => High Die Detail

Relative Die Construction Cost

Flat Envelope: L_{ul} =______; L_{uw} =______; Die Complexity: ______________

Peripheral Complexity: L_{out} =______; $L_S = L_{out} / 2 (L_{ul}+L_{uw})$ = ______________

Shear Complexity:

1st Digit =______; 2nd Digit =______ => C_{b1} =______; N_{a1} = ______

Wipe Form Complexity:

3rd Digit =______; 4th Digit =______ => C_{21} =______; N_{a2} =__________

Contour Form: 5th Digit=______; 6th Digit =______ => C_{b3} =______; N_{a3} =__________

Effect of material:

7th Digit=______; F_{mc} =______; F_{mb} =______; F_{mf} =______

Effect of sheet thickness:

8th Digit =______; F_t =______; F_{dm} =______

Basic Complexity, $C_b = C_{b1}F_{mc} + C_{b2}F_{mb} + C_{b3}F_{mf}$ = ______________________

Total Relative Die Construction Cost, $C_{dc} = C_b F_t$ = ______________________

IV. Design for End-of-life [40]

Calculate the time required to disassemble Rulla for recycling based on information given in the assembly problem. By using the assembly data tables, we are assuming that disassembly will be related to assembly, e.g., a particular disassembly step is simply the reverse of the corresponding assembly step, i.e., the time it takes to untighten a screw is the same as it takes to tighten it.

1. Will all the assembly steps in Problem I be reversed to disassemble the product for recycling? Generally, why or why not? [3]

2. Generally, for a given assembly step, are the insertion code and time identical for the corresponding disassembly time? Why or why not? [3]

3. Generally, would the Alpha and Beta for disassembly be the same as for assembly? If so, why? If not, how would you determine Alpha and Beta? [3]

Description of Operation	Alpha	Beta	Handle Code	Handle Time	Insert Code	Insert Time	Handle + Insert Time	# times per-formed	Total Time
Totals									

V. Product Liability [20] – circle choice - partial credit may be awarded for less-clueless choices

In a post-exam *senioritis* (a burnout phenomenon commonly observed where fourth-year students are referred to as seniors) stupor, you use the Rulla in a manner for which it is clearly not intended, and you injure yourself. While you contemplate suing Rulla's manufacturer, you review the relevant concepts and cases.

1. Most likely, your case would be based on:
   a. tort
   b. strict liability
   c. common law
   d. b and c

2. Using as precedence the Lambert vs. Lastoplex Chemicals Co, Ltd. et al case (1971, Supreme Court of Canada), involving a mechanical engineer and some lacquer sealer,
   a. Your engineering license will be revoked because of your ill-advised actions on the Rulla
   b. Rulla's manufacturer would not be found at fault, because you as an engineer, should have known better
   c. All of the above
   d. None of the above

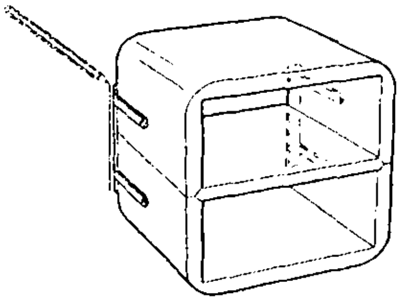
3. Tort
   i. is a fruity dessert
   ii. involves default on a contract
   iii. is intended to punish a wrong-doer
   iv. is intended to compensate victims
   v. requires demonstration of negligence
      a) ii and iii
      b) iii and iv
      c) iii, iv and v
      d) iv and v
      e) None of the above combinations

4. Strict liability means
   i. A strict and objective standard must be used to determine whether a manufacturer is negligent
   ii. A manufacturer does not have to be negligent to be liable
   iii. The damages incurred to a consumer must be severe
   iv. The engineer is found so negligent that the manufacturer is released from liability
   v. Manufacturers may be found liable when consumers injure themselves using product in manner not intended
      a) i and iii
      b) i and iv
      c) ii and v
      d) ii, iii and v
      e) i, iii, iv

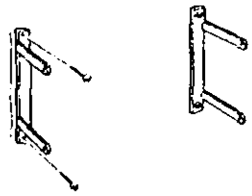
5. Common law means
   a. Laws are based on the results of previous cases
   b. Laws should be simple enough that the common person can understand them
   c. Commoners should be have the right to a jury of their peers, i.e., other commoners
   d. Engineers are not common and therefore an engineer suffering from misuse of a product releases the manufacturer from liability
   e. Placing warning labels on dangerous products releases manufacturers from liability because this is just common sense.

Use of mounting brackets for Rulla, now renamed Hänga

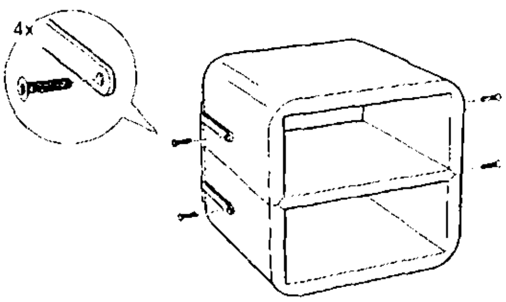
1.



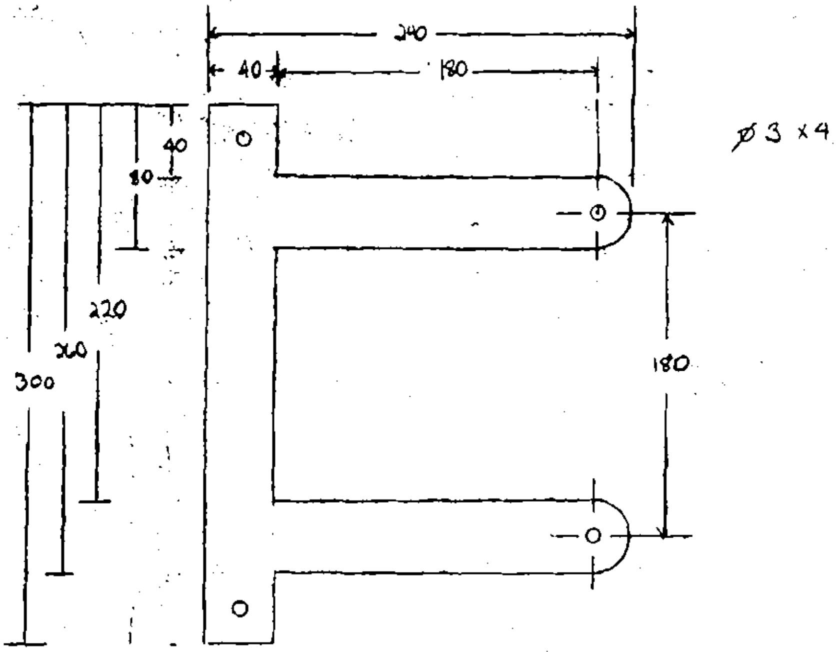
2.



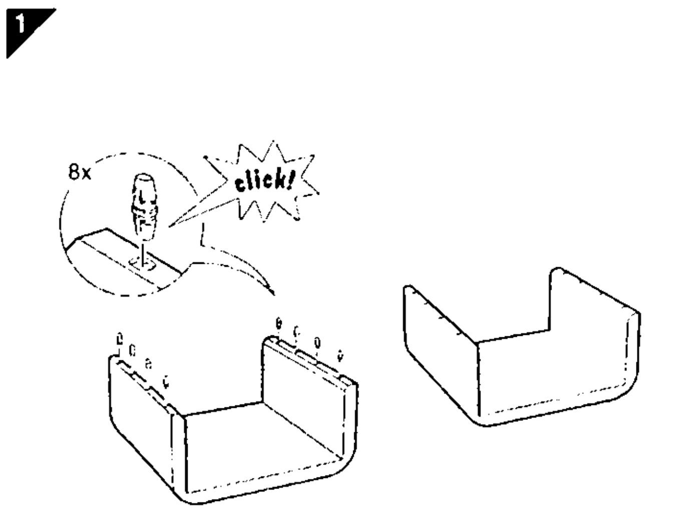
3.

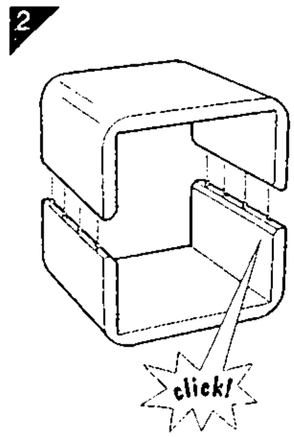


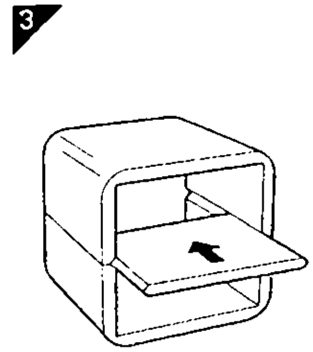
Assume that the positions of 2 holes are critical. Material is medium stainless, sheet thickness = 1.5mm

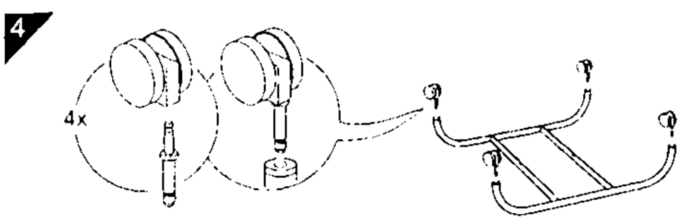


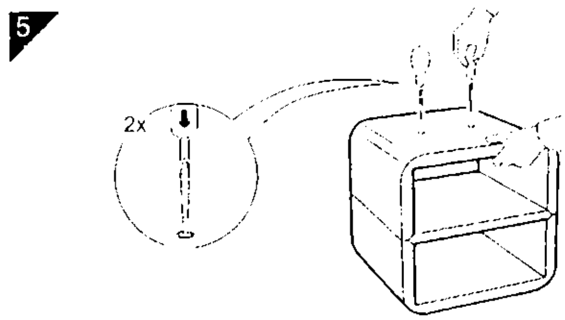
Assembly directions for Rulla

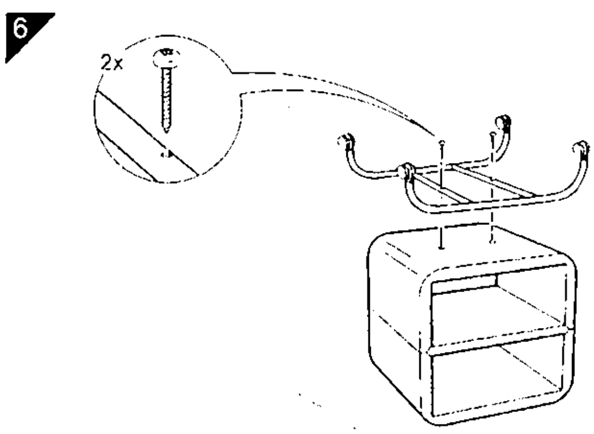




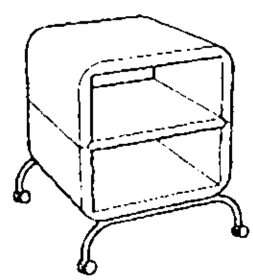








Completed Assembly:



MANUAL HANDLING—ESTIMATED TIMES (seconds)

Key:

ONE HAND

			parts are easy to grasp and manipulate					parts present handling difficulties (1)				
			thickness > 2 mm			thickness ≤ 2 mm		thickness > 2 mm			thickness ≤ 2 mm	
			size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm
			0	1	2	3	4	5	6	7	8	9
parts can be grasped and manipulated by one hand without the aid of grasping tools	$(\alpha+\beta) < 360°$	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
	$360° \le (\alpha+\beta) < 540°$	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
	$540° \le (\alpha+\beta) < 720°$	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
	$(\alpha+\beta) = 720°$	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

ONE HAND with GRASPING AIDS

				parts need tweezers for grasping and manipulation								parts need standard tools other than tweezers	parts need special tools for grasping and manipulation
				parts can be manipulated without optical magnification				parts require optical magnification for manipulation					
				parts are easy to grasp and manipulate		parts present handling difficulties (1)		parts are easy to grasp and manipulate		parts present handling difficulties (1)			
				thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm		
				0	1	2	3	4	5	6	7	8	9
parts can be grasped and manipulated by one hand but only with the use of grasping tools	$\alpha \le 180°$	$0 \le \beta \le 180°$	4	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7
		$\beta = 360°$	5	4	7.25	4.75	8	6	8.75	6.75	9	8	8
	$\alpha = 360°$	$0 \le \beta \le 180°$	6	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9
		$\beta = 360°$	7	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10

TWO HANDS for MANIPULATION

		parts present no additional handling difficulties					parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1)				
		$\alpha \le 180°$			$\alpha = 360°$		$\alpha \le 180°$			$\alpha = 360°$	
		size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm
		0	1	2	3	4	5	6	7	8	9
parts severely nest or tangle or are flexible but can be grasped and lifted by one hand (with the use of grasping tools if necessary) (2)	8	4.1	4.5	5.1	5.6	6.75	5	5.25	5.85	6.35	7

TWO HANDS required for LARGE SIZE

		parts can be handled by one person without mechanical assistance									two persons or mechanical assistance required for parts manipulation
		parts do not severely nest or tangle and are not flexible								parts severely nest or tangle or are flexible (2)	
		part weight < 10 lb				parts are heavy (> 10 lb)					
		parts are easy to grasp and manipulate		parts present other handling difficulties (1)		parts are easy to grasp and manipulate		parts present other handling difficulties (1)			
		$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$		
		0	1	2	3	4	5	6	7	8	9
two hands, two persons or mechanical assistance required for grasping and transporting parts	9	2	3	2	3	3	4	4	5	7	9

Figure 3.15 Classification, coding and database for part features affecting manual handling time (in seconds). (Copyright Boothroyd Dewhurst, Inc., reproduced with permission.)

MANUAL INSERTION—ESTIMATED TIMES (seconds)

Key:

PART ADDED but NOT SECURED

		after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)			
		easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly	
		no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)
		0	1	2	3	6	7	8	9
addition of any part (1) where neither the part itself nor any other part is finally secured immediately: part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10
due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

PART SECURED IMMEDIATELY

		no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		plastic deformation immediately after insertion						screw tightening immediately after insertion (6)	
				plastic bending or torsion			riveting or similar operation				
		easy to align and position with no resistance to insertion (4)	not easy to align or position during assembly and/or resistance to insertion (5)	easy to align and position during assembly (4)	not easy to align or position during assembly: no resistance to insertion	resistance to insertion (5)	easy to align and position during assembly (4)	not easy to align or position during assembly: no resistance to insertion	resistance to insertion (5)	easy to align and position with no torsional resistance (4)	not easy to align or position and/or torsional resistance (5)
		0	1	2	3	4	5	6	7	8	9
addition of any part (1) where the part itself and/or other parts are being finally secured immediately: part and associated tool (including hands) can easily reach the desired location and the tool can be operated easily	3	2	5	4	5	6	7	8	9	6	8
part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access or restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
due to obstructed access and restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

SEPARATE OPERATION

		mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-fastening processes	
		none or localized plastic deformation				metallurgical processes					
							additional material required				
		bending or similar processes	riveting or similar processes	screw tightening (6) or other processes	bulk plastic deformation (large proportion of part is plastically deformed during fastening)	no additional material required (e.g. resistance, friction welding, etc.)	soldering processes	weld/braze processes	chemical processes (e.g. adhesive bonding, etc.)	manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of part(s) etc.)	other processes (e.g. liquid insertion, etc.)
		0	1	2	3	4	5	6	7	8	9
assembly processes where all solid parts are in place	9	4	7	5	3.5	7	8	12	12	9	12

Figure 3.16 Classification, coding and database for part features affecting insertion and fastening (in seconds). (Copyright Boothroyd Dewhurst, Inc., reproduced with permission.)

Assembly 15

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Injection Molding

(1 in = 25.4 mm; 100 mm = 3.94 in)

SECOND DIGIT

Flat Parts: 5.37 / 6.28 (6) Box-Shaped Parts

BASIC COMPLEXITY

FIRST DIGIT					L ≤ 250 mm (4): zero	one	two	More than two	250mm < L ≤ 480mm: zero	one	two	More than two	L > 480 mm: zero	one	More than one
					Number of External Undercuts (5)				Number of External Undercuts (5)				Number of External Undercuts (5)		
					0	1	2	3	4	5	6	7	8	9	10
Parts Without Internal Undercuts (1)	Parts whose peripheral height from a planar dividing surface is constant (2)		Part in one half (3)	0	1.00 / 1.64	1.23 / 1.87	1.38 / 2.02	1.52 / 2.15	1.42 / 2.89	1.65 / 3.12	1.79 / 3.27	1.94 / 3.41	1.83 / 4.20	2.07 / 4.51	2.33 / 4.77
Parts Without Internal Undercuts (1)	Parts whose peripheral height from a planar dividing surface is constant (2)		Part not in one half (3)	1	1.14 / 1.86	1.37 / 2.09	1.52 / 2.24	1.66 / 2.38	1.61 / 2.99	1.84 / 3.22	1.99 / 3.37	2.13 / 3.51	2.09 / 4.42	2.32 / 4.66	2.58 / 4.92
Parts Without Internal Undercuts (1)	Parts whose peripheral height from a planar Dividing Surface is not constant - or - parts with a non-planar Dividing Surface (2)			2	1.28 / 1.92	1.51 / 2.15	1.66 / 2.29	1.80 / 2.44	1.81 / 3.38	2.04 / 3.61	2.19 / 3.76	2.33 / 3.90	2.34 / 5.01	2.58 / 5.24	2.84 / 5.50
Parts with Internal Undercuts (1)	On Only One Face of the Part	Parts whose ONLY Dividing Surface (2) is planar, or parts whose peripheral height from a planar dividing surface is constant		3	2.33 / 3.19	2.57 / 3.43	2.71 / 3.57	2.86 / 3.72	2.75 / 4.44	2.98 / 4.68	3.13 / 4.82	3.27 / 4.97	3.17 / 5.83	3.40 / 6.07	3.65 / 6.33
Parts with Internal Undercuts (1)	On Only One Face of the Part	Parts whose peripheral height from a planar Dividing Surface is not constant - or - parts with a non-planar Dividing Surface (2)		4	2.98 / 3.73	3.21 / 3.97	3.36 / 4.11	3.50 / 4.26	3.52 / 5.20	3.75 / 5.43	3.89 / 5.58	4.04 / 5.72	4.09 / 6.82	4.28 / 7.06	4.54 / 7.32
Parts with Internal Undercuts (1)	On More Than One Face of the Part	Parts whose ONLY Dividing Surface (2) is planar, or parts whose peripheral height from a planar dividing surface is constant		5	4.29 / 5.37	4.43 / 5.61	4.58 / 5.75	4.72 / 5.89	4.62 / 6.62	4.85 / 6.86	4.99 / 7.00	5.14 / 7.14	5.03 / 8.01	5.27 / 8.29	5.53 / 8.51
Parts with Internal Undercuts (1)	On More Than One Face of the Part	Parts whose peripheral height from a planar Dividing Surface is not constant - or - parts with a non-planar Dividing Surface (2)		6	5.37 / 6.29	5.60 / 6.52	5.74 / 6.66	5.89 / 6.81	5.90 / 7.74	6.13 / 7.98	6.28 / 8.12	6.42 / 8.27	6.43 / 9.37	6.67 / 9.60	6.93 / 9.86

Figure 11.1 Classification System for Basic Tool Complexity, C_b Notes (1)-(5) are found in Appendix 11A.

Feature		Number of Features (n)	Penalty per Features	Penalty
Holes or Depressions	Circular		2n	
	Rectangular		4n	
	Irregular		7n	
Bosses	Solid (8)		n	
	Hollow (8)		3n	
Non-peripheral ribs and/or walls and/or rib clusters (9)			3n	
Side Shutoffs	Simple (9)		2.5n	
	Complex (9)		4.5n	
Lettering (10)			n	
			Total Penalty	

SMALL PARTS (L < 250 mm)

Total Penalty < 10 => Low cavity detail
10 < Total Penalty < 20 => Moderate cavity detail
20 < Total Penalty < 40 => High cavity detail
Total Penalty > 40 => Very high cavity detail

MEDIUM PARTS (250 < L < 480 mm)

Total Penalty < 15 => Low cavity detail
15 < Total Penalty < 30 => Moderate cavity detail
30 < Total Penalty < 60 => High cavity detail
Total Penalty > 60 => Very high cavity detail

LARGE PARTS (L > 480 mm)

Total Penalty < 20 => Low cavity detail
20 < Total Penalty < 40 => Moderate cavity detail
40 < Total Penalty < 80 => High cavity detail
Total Penalty > 80 => Very high cavity detail

(1 in = 25.4 mm; 100 mm = 3.94 in)

Figure 11.16 Determination of Cavity Detail. Notes (8)-(10) can be found in Appendix 11A.

FOURTH DIGIT

THIRD DIGIT	SUBSIDIARY COMPLEXITY		EXTERNAL UNDERCUT COMPLEXITY: Without Extensive (7) External Undercuts (5)	With Extensive (7) External Undercuts (5)
			0	1
CAVITY DETAIL (6)	Low	0	1.00	1.25
	Moderate	1	1.25	1.45
	High	2	1.60	1.75
	Very High	3	2.05	2.15

Table 11.1 Subsidiary Complexity Rating, C_s, for Injection Molding. Notes (5) - (7) can be found in Appendix 11A on page 11-26.

SIXTH DIGIT

FIFTH DIGIT	SURFACE FINISH, R_a		TOLERANCES, T_a: Commercial	Tight
			0	1
	SPI 5-6	0	-	-
	SPI 3-4	1	1.00	1.05
	TEXTURE	2	1.05	1.10
	SPI 1-2	3	1.10	1.15

Table 11.2 Tolerance and Surface Finish Rating, C_t, for Injection Molding.

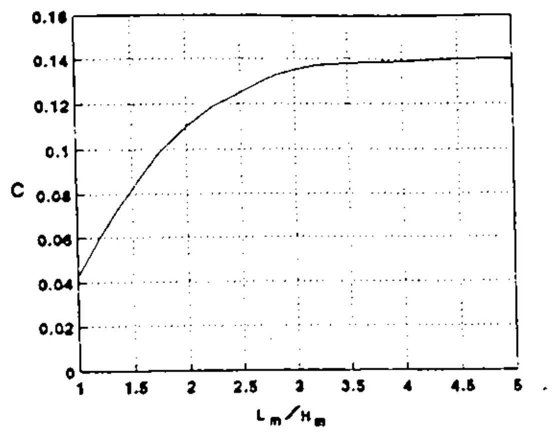


Figure 11.19

Value of C for Use in Equation 11.16.

(If $L_m / H_m < 1$, then use the value of H_m / L_m to determine C.)

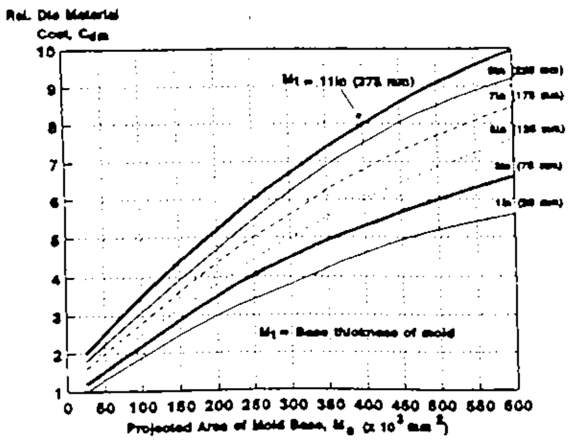


Figure 11.20

Relative Die Material Cost, C_{dm}

Table 15.1 Data for the Reference Part	
Material	Polystyrene
Material Cost (K_p)	1.46×10^{-4} cents/ mm^3 (1)
Part Volume (K_p)	1244 mm^3
Die Mat Cost (K_{dmo})	\$980 (2)
Die Construction Time (Includes design and build hours)	200 hours
Labor Rate (Die Construction)	\$30/hr (2)
Cycle Time (t_o)	16 seconds (2)
Mold Machine Hourly Rate (C_{ho})	\$27.53 (3)

(1) *Plastic Technology*, June 1989.
(2) Data from collaborating companies, 1989.
(3) *Plastic Technology*, July 1989.

Table 15.2 Relative Material Prices, C_{mr}, for Thermoplastics. Based on material prices in *Plastics Technology*, June 1990.

Material	C_{mr}
ABS	1.71
Acetal	2.92
Acrylic	1.54
Nylon 6	2.79
Polycarbonate	2.96
Polyethylene	0.71
Polypropylene	0.62
Polystyrene	1.00 (Reference)
PPO	2.33
PVC	0.62

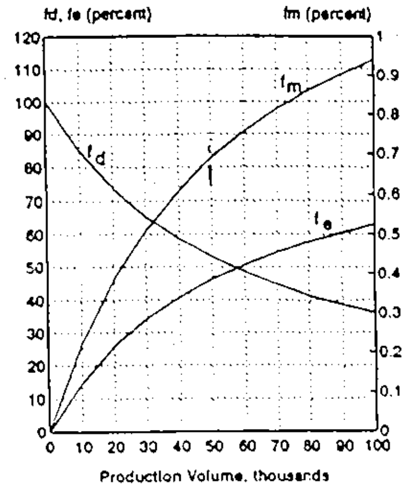


Figure 15.23 Variation of f_d, f_e and f_m With Production Volume in Injection Molding.

Table 15.5 Machine Tonnage and Relative Hourly Rate (Data published in *Plastic Technology*, June, 1989.) Injection Molding.

Machine Tonnage	Relative Hourly Rate
< 100	1.00
100 - 299	1.19
300 - 499	1.44
500 - 699	1.83
700 - 999	2.87
> 1000	2.93

3/5

Injection Molding

1 in = 25.4 mm; 100 mm/25.4 mm = 3.94 in	C_{b1} = 1.00; N_{a1} = 2		SECOND DIGIT						
			$L_{st} < 100$ mm (9)		$100 < L_{st} < 200$ (9)		$200 < L_{st} < 450$ (9)		$L_{st} > 450$ (9)
			$L_s < 1.4$ (10)	$L_s > 1.4$ (10)	$L_s < 1.4$ (10)	$L_s > 1.4$ (10)	$L_s < 1.4$ (10)	$L_s > 1.4$ (10)	
			0	1	2	3	4	5	6
Unfolded parts(1) with uniform sheet thickness less than or equal to 6.5 mm, with or without non-peripheral features(2) whose direction is parallel to the sheet thickness(3) with or without holes whose diameter is greater than the sheet thickness, without significant projections(4)	Parts with LOW die detail(5)	0 Parts without closely spaced features(6), narrow projections or narrow cutouts(7).	1.00 2	1.20 2	1.30 2	1.50 2	1.56 2	2.45 2	Use Sheet Metal Fabrication
		1 Parts with only one type of closely spaced protruding feature(8). - OR - Parts with closely spaced non-protruding features and/or narrow cutouts and/or narrow projections(7), without closely spaced protruding features	1.29 4	1.49 4	1.59 4	1.79 4	1.88 4	2.77 4	
		2 Parts with more than one type of closely spaced protruding feature(8), with or without closely spaced non-protruding features, narrow cutouts or narrow projections - OR - Parts with only one type of closely spaced protruding feature with closely spaced non-protruding features and/or narrow cutouts and/or narrow projections	1.58 5	1.78 5	1.88 5	2.08 5	2.20 5	3.09 5	
	Parts with MEDIUM die detail(5)	3 Parts without closely spaced features(6), narrow projections or narrow cutouts(7).	2.33 5	2.53 5	2.63 5	2.83 5	3.32 5	4.21 5	
		4 Parts with only one type of closely spaced protruding feature(8). - OR - Parts with closely spaced non-protruding features and/or narrow cutouts and/or narrow projections(7), without closely spaced protruding features	2.62 6	2.82 6	2.32 6	3.12 6	3.54 6	4.53 6	
		5 Parts with more than one type of closely spaced protruding feature(8), with or without closely spaced non-protruding features, narrow cutouts or narrow projections - OR - Parts with only one type of closely spaced protruding feature with closely spaced non-protruding features and/or narrow cutouts and/or narrow projections	2.91 7	3.11 7	3.21 7	3.41 7	3.55 7	4.05 7	
	Parts with HIGH die detail(5)	6 Parts without closely spaced features(6), narrow projections or narrow cutouts(7).	2.96 6	3.16 6	3.26 6	3.46 6	3.60 6	4.49 6	
		7 Parts with only one type of closely spaced protruding feature(8). - OR - Parts with closely spaced non-protruding features and/or narrow cutouts and/or narrow projections(7), without closely spaced protruding features	3.25 7	3.45 7	3.55 7	3.75 7	3.92 7	4.81 7	
		8 Parts with more than one type of closely spaced protruding feature(8), with or without closely spaced non-protruding features, narrow cutouts or narrow projections - OR - Parts with only one type of closely spaced protruding feature with closely spaced non-protruding features and/or narrow cutouts and/or narrow projections	3.54 8	3.74 8	3.84 8	4.04 9	4.24 8	5.13 9	
Unfolded parts(1) without uniform sheet thickness, or unfolded parts with uniform sheet thickness greater than 6.5 mm, or unfolded parts with non-peripheral features (2) whose direction is not parallel to the sheet thickness(3) or unfolded parts with holes whose diameter is less than the sheet thickness, or unfolded parts with significant projections(4), or unfoldable parts(1)		9	Parts like this are not usually stamped and/or can not generally be stamped						

Figure 12.1 Classification System for Shearing and Local Features

1 in = 25.4 mm; 100 mm/25.4 mm = 3.94 in

C_{b2} = 0.79; N_{a2} = 2

FOURTH DIGIT

THIRD DIGIT				1	2	3	4	5	6	7	8	9	10	11	12
				$L_b < 100$ mm (17)				100 mm $< L_b < 200$ mm (17)				200 mm $< L_b < 450$ mm (17)			
				Parts without side-action features(18)		Parts with side-action features(18)		Parts without side-action features(18)		Parts with side-action features(18)		Parts without side-action features(18)		Parts with side-action features(18)	
				Parts without features near the bend line(19)	Parts with features near the bend line(19)	Parts without features near the bend line(19)	Parts with features near the bend line(19)	Parts without features near the bend line(19)	Parts with features near the bend line(19)	Parts without features near the bend line(19)	Parts with features near the bend line(19)	Parts without features near the bend line(19)	Parts with features near the bend line(19)	Parts without features near the bend line(19)	Parts with features near the bend line(19)
Parts with straight bends(11) without multiple plate pieces(12) without primary plane connected on all sides by overbend planes(13)	All bends in the same direction (14)	Parts with all bend angles < 90°(16)	1	0.79 2	0.99 3	1.79 4	1.99 5	0.94 2	1.23 3	1.94 4	2.23 5	1.20 2	1.49 3	2.20 4	2.49 5
		Parts with 90° < bend angles < 105°	2	1.40 3	1.60 4	2.40 5	2.60 6	1.79 3	2.38 4	2.79 5	3.08 6	2.05 3	2.34 4	3.05 5	3.34 6
		Parts with bend angles > 105°(16)	3	1.54 3	2.14 4	2.94 5	3.14 6	2.22 3	2.51 4	3.22 5	3.51 6	2.48 3	2.77 4	3.48 5	3.77 6
	All bends not in the same direction (14)	Parts with all bend angles < 90°(16)	4	1.07 3	1.27 4	2.07 5	2.27 6	1.34 3	1.63 4	2.34 5	2.63 6	1.60 3	1.89 4	2.60 5	2.89 6
		Parts with 90° < bend angles < 105°	5	1.68 5	1.88 6	2.68 7	2.88 8	2.19 5	2.48 6	3.19 7	3.48 8	2.45 5	2.74 6	3.45 7	3.74 8
		Parts with bend angles > 105°(16)	6	2.22 5	2.42 6	3.22 7	3.42 8	2.62 5	2.91 6	3.62 7	3.91 8	2.88 5	3.17 6	3.88 7	4.17 8
	Parts with two bend stages (15)	Parts with all bend angles < 90°(16)	7	1.26 3	1.46 4	2.26 5	2.46 6	2.05 3	2.34 4	3.05 5	3.34 6	2.31 3	2.60 4	3.31 5	3.60 6
		Parts with 90° < bend angles < 105°	8	1.87 5	2.07 6	2.87 7	3.07 8	2.90 5	3.19 6	3.90 7	4.19 8	3.16 5	3.45 6	4.16 7	4.45 8
		Parts with bend angles > 105°(16)	9	2.41 5	2.61 6	3.41 7	3.61 8	3.33 5	3.62 6	4.33 7	4.62 8	3.59 5	3.88 6	4.59 7	4.88 8
	Parts with more than two bend stages (15)	Parts with all bend angles < 90°(16)	10	1.86 5	2.06 6	2.86 7	3.06 8	3.16 5	3.45 6	4.16 7	4.45 8	3.42 5	3.71 6	4.42 7	4.71 8
		Parts with 90° < bend angles < 105°	11	2.47 7	2.67 8	3.47 9	3.67 10	4.01 7	4.30 8	5.01 9	5.30 10	4.27 7	4.56 8	5.27 9	5.56 10
		Parts with bend angles > 105°(16)	12	3.01 7	3.21 8	4.01 9	4.21 10	4.44 7	4.73 8	5.44 9	5.73 10	4.70 7	4.99 8	5.70 9	6.00 10
Parts without straight bends(11), or parts with multiple plate pieces(12), or parts with a primary plate connected on all sides by overbend planes(13)			13	Parts like this can not be wipe formed											

Figure 12.2 Classification System for Wipe Forming (Bending). Notes (14) - (19) can be found in Appendix 12.A

Stamping 4/5

Feature	Number of Features (n)	Opposite Directions? (Y/N)	Penalty
Standard Hole		n / n	
Non-standard Hole		2n / 2n	
Coin		3n / 3n	
Standard Emboss		(n+1) / n	
Non-standard Emboss		2(n+1) / 2n	
Extruded Hole		2(n+1) / 2n	
Lance Form		3(n+1) / 3n	
Curl		3(n+1) / 3n	
Curl		3(n+1) / 3n	
Hem		4(n+1) / 4n	
Semi-Perf		(n+1) / n	
Tab		3(n+1) / 3n	
Lettering		2(n+1) / 2n	
		Total Penalty	

Small Parts (L < 100 mm)
Total Penalty ≤ 4 => Low Die Detail
4 < Total Penalty ≤ 8 => Medium Die Detail
Total Penalty > 8 => High Die Detail

Medium Parts (100 mm ≤ L ≤ 200 mm)
Total Penalty ≤ 6 => Low Die Detail
6 < Total Penalty ≤12=> Medium Die Detail
Total Penalty >12=> High Die Detail

Large Parts (L > 200 mm)
Total Penalty ≤10=> Low Die Detail
10 < Total Penalty ≤17=> Medium Die Detail
Total Penalty >17=> High Die Detail

Figure 12.24 Determination of Die Detail

SIXTH DIGIT

1 in = 25.4 mm
100 mm/25.4 mm = 3.94 in

C_{ds} — 1.05
N_{a3} — 2

FIFTH DIGIT					$L_t \le 100$ mm (26): Parts without side-action features (18): Parts without features on/near the form (27)	Parts without side-action features (18): Parts with features on/near the form (27)	Parts with side-action features (18): Parts without features on/near the form (27)	Parts with side-action features (18): Parts with features on/near the form (27)	100 mm < L_t (26): Parts without side-action features (18): Parts without features on/near the form (27)	Parts without side-action features (18): Parts with features on/near the form (27)	Parts with side-action features (18): Parts without features on/near the form (27)	Parts with side-action features (18): Parts with features on/near the form (27)
					1	2	3	4	5	6	7	8
Parts with non-straight bends(11), or radius forms (20), or shallow draws(21), without deep draws or multiple plane connections(12), or non-circular, stepped or tapered recesses(22), or curved channels, or doubly curved sections(23).	Parts with non-straight bends(11), without radius forms(20), without shallow draws(21).			1	1.05 / 2	1.44 / 3	2.05 / 3	2.40 / 4	Sufficient data not available for such parts			
	Parts with radius forms(20), without non-straight bends (11), without shallow draws(21)	Radius form angle ≤ 180° (24)	RA ≤ 15 (25)	2	1.12 / 3	1.60 / 4	2.17 / 4	2.65 / 5				
			RA > 15 (25)	3	1.37 / 2	1.85 / 3	2.42 / 3	2.90 / 4				
		Radius form angle > 180° (24)		4	Four slide form tools used							
	Parts with shallow draws(21), without radius forms(20), without non-straight bends(11).			5	1.29 / 4	1.71 / 5	1.71 / 5	2.55 / 6				
Parts with multiple plane connections(11), or non-circular, or stepped or tapered recesses(22), or curved channels or doubly curved sections(23), or deep draw, or any combination of non-straight bends (11), or radius forms(20), or shallow draws(21).				6	Parts like this are not considered here							

Figure 12.5 Classification System for Contour Forming. Notes (11) - (27) can be found in Appendix 12.A

Table 12.1 Classification System for Part Material

Material	Digit 7	F_{mc}	F_{mb}	F_{mf}	Comments
Soft CRS, Low C	0	1.00	1.0	1.0	1008-1012 tempered rolled or annealed last
Soft Red Metal	1	0.98	1.0	1.0	C23000 (red brass) annealed; C26000 (cartridge brass) annealed
Hard Red Metal	2	0.99	1.1	1.2	C23000 (red brass) cold rolled; C26000 (cartridge brass) cold rolled
Soft Al Alloy	3	1.00	1.0	1.0	1100-0; 5052-0
Hard Al Alloy	4	1.00	1.1	1.2	1100-H18; 5052-H18
Hard CRS, Low C	5	1.01	1.1	1.2	1008-1012 half-hard (Rockwell 70-85; tensile strength 380-520 Mpa
Medium Stainless	6	1.02	1.1	1.2	302 annealed
Hard Stainless	7	1.04	1.1	1.2	304 cold rolled

Table 12.2 - Classification System for Sheet Thickness

t (mm)	Digit 8	F_t	F_{dm}
0.125 - 3	0	1.0	1.0
< 0.125	1	1.7	1.0
> 3	2	1.0	1.4

Table 12.3 Determination of Number of Stations Required [2]

Number of Active Stations, $N_A = N_{a1} + N_{a2} + N_{a3} =$

Number of Idle Stations, $N_I = N_{I1} + N_{I2} + N_{I3} =$

(a) For $L_{uw} \le 25$ mm
$N_{Ij} = 1.5\,(N_{aj} - 1),\ j = 1, 2, 3$

(b) For $25\ \text{mm} < L_{uw} < 125$ mm

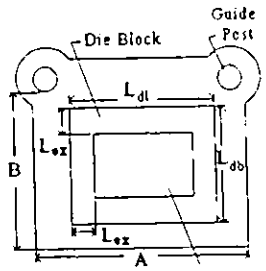
$N_{I1} = 0$ (part without curls)
$N_{I1} = 2$ (part with curls)
$N_{I2} = (N_{a2} - 1)$
$N_{I3} = (N_{a3} - 1)$

(c) For $L_{uw} \ge 125$ mm, $N_{I1} = N_{I2} = N_{I3} = 0$

Total Number of Stations, $N_S = N_A + N_I$

Table 12.4 Die Block and Die Set Size [2]

Bottom Plate of Die Set



Area occupied by all stations

Die Block Size (mm)

$L_{dl} = N_s L_{uw} + 2 L_{cx} =$
$L_{db} = L_{ul} + 2 L_{cx} =$

where $L_{cx} = 25$ if $N_s L_{uw} \le 75$
$L_{cx} = 37$ if $75 < N_s L_{uw} < 250$
$L_{cx} = 50$ if $N_s L_{uw} \ge 250$

Die Set Size:
$A = L_{dl} + 25 =$
$B = L_{db} + 25 =$
$S_{ds} = AB =$

Stamping 5/5