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(54) Advanced forming techniques for superplastic forming

(57) This application describes a method for superplastic forming (SPF) of metallic parts in which a cutout is formed in the blank from which the parts will be formed, and a secondary sheet is located between the blank and the pressurized gas. The cutout area of the blank becomes stretched so that there is minimal thinning in the area near the periphery of the cutout(s) in the blank, the secondary sheet is required to carry the gas pressure and to form the parts.

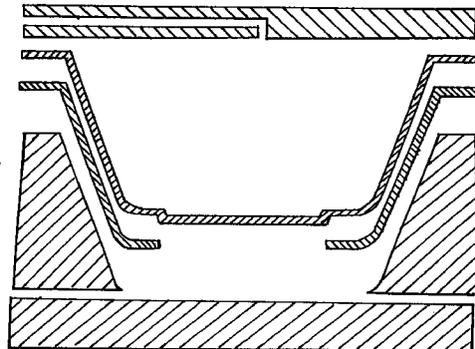


Fig 5D

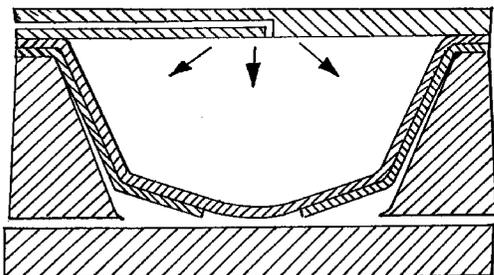
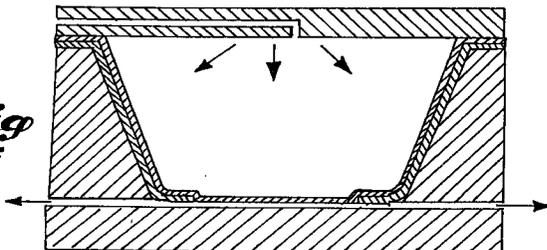


Fig 5E



EP 0 849 013 A1

Description

Background of the Invention

1. Field of the Invention

The present invention relates to techniques for superplastic forming of parts, and more particularly, for control of thinout in such parts.

2. Background of the Invention

Superplastic forming hereinafter (SPF) is a metal forming process used throughout the aerospace industry for manufacturing detailed parts and built-up structures. The design flexibility that is offered by SPF has resulted in substantial cost savings in the fabrication of detail parts and assemblies. Further savings have been apparent in the reduction of weight in aircraft. The prior art SPF process for manufacturing parts consists of several steps. These steps are illustrated in **FIGURES 1A to 1D** and can be summarized as follows: heating a die to an appropriate temperature for a particular metal alloy; placing a metal sheet, also referred to as a blank, in the die; closing a lid to the die; applying restraining forces to hold the die and lid together; applying a forming gas pressure to the blank in order to push the blank into the die cavity; completing the time required in the forming cycle; and removing the finished part from the die.

FIGURE 2 shows a schematic plan view of the die with the lid removed for illustration purposes. The blank or sheet **10** is supported in the regions **12** surrounding the sealed area **14** by the lower die **16**, as shown in **FIGURE 1A**. The double lines **18** outline the seal area, within which a part will be formed. The reason that the material does not thinout uniformly is that once the lid is closed or the SPF die, the periphery of the material is restrained such that the material is not allowed to "draw-in" the material outside of the seal area.

FIGURE 3 shows a schematic cross section view of a part formed by SPF. The dotted lines show where die part will be cut or trimmed. The run-out is in the die region outside of the net part area. A correctly designed die will optimize the run-out configuration so that thinout is minimized in the part area and maximized in the run-out material.

FIGURE 4 is a side elevation cross-section illustrating the thinout problem. For example, the part thicknesses at **20** and **22** are very thin, and could potentially be below the thicknesses specified by the Engineering drawing.

Summary of the Invention

The present invention defines a method of increasing part thickness in specific areas of SPF details by preferentially cutting out one or more areas of the start-

ing material "blank".

The cut-out area of the blank becomes stretched so that minimal thinning results in the area near the periphery of the cutout. The process utilizes a second sheet of material to push the cutout blank, with cutout(s), onto the die.

Brief Description of the Drawings

The foregoing aspects and many of the attendant advantages of this invention will become more readily appreciated by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

FIGURES 1A to 1D are a side elevation cross-section drawing of a prior art SPF in four consecutive modes of operation.

FIGURE 2 is a plan view of a die with lid removed. **FIGURE 3** shows a schematic cross section of a part formed by SPF.

FIGURE 4 is a schematic side elevation cross sectional view of a die and part manufactured by SPF. **FIGURES 5A to 5C** show a cross section of a die and part in six consecutive stages of the SPF process of this invention.

FIGURES 6A and 6B show how the secondary sheet of this invention can entrap the blank after forming.

FIGURE 7 is a schematic showing the axial and biaxial stresses around the cutout of this invention.

FIGURE 8 compares thickness data at various locations on SPF parts made using prior art techniques and using the techniques of this invention.

Figure 9A shows an orthogonal projection of one-half of a SPF part.

Figure 9B shows a method for manipulating die surfaces to arrive at the size of a cutout of this invention.

FIGURE 9C illustrates a plan view of the blank after manipulating and projecting the die surfaces of **Figure 9B**.

Description of the Preferred Embodiment

One of the greatest challenges associated with Superplastic Forming is predicting material thinout and then achieving that thinout during part fabrication. The material thinout challenge is inherent to the SPF process and stems from varying material thickness across the part area after SPF. Engineering drawings typically call out a minimum allowed material thickness across the entire part or in specific regions of the part.

The reason that material does not thinout uniformly is that once the lid is closed on the SPF die, the periphery of the material is restrained such that the material is not allowed to "draw-in" from the edges. As a result, the material that will become the part area must be

stretched from the material inside of the seal area.

During forming, the stretching of the material within the seal area progresses until the material eventually contacts the die surface. Upon contact, the material sticks to the die surface. The remaining material that has not yet contacted the die continues to stretch until it too contacts the die surface and sticks. Once the material is completely formed, the thinnest regions are generally those that are the last to form. These regions equate to the deepest areas of the die and radii, in particular spherical radii (corners).

Since material thinout is dependent on the die geometry, the die design is critical in achieving the proper material thinout. Of specific importance is the die "run-out", which is the die region outside the net part area. A correctly designed die will optimize the "run-out" configuration so that thinout is minimized in the part area and maximized in the "run-out" material.

Once the part area and "run-out" of the die have been machined and the rust SPF part is formed, there are only a few options for recourse if the part is too thin according to engineering drawing requirements. The two most common options are: (1) Start with a thicker gauge of blank material, (2) Preform the blank prior to forming it into the final part configuration.

The former option is the easier of the two options to implement and provides relatively quick results for thickness analysis. However, it is not a guarantee for achieving the correct minimum thickness since adding thickness to the starting blank does not equate to a sufficient thickness increase in the thinnest areas of the part. Furthermore, an increase in the starting material gauge adversely effects the part weight.

The latter option, designing a preform for the blank, carries a fair amount of risk. Designing a successful preform geometry potentially requires several iterations, an expensive and time consuming process. As with increasing the material gauge, preforming will not guarantee a successful part.

With this invention a third option becomes available for selectively increasing the material thickness in specific regions of the part. This option too, does not guarantee that the minimum material thinout will be attained. However, through a combination of increasing the starting gauge and utilizing this third option, the odds of attaining a successful part are significantly increased.

Depending on the part configuration, it is possible to minimize the material thinout by placing a strategically located cutout(s) in the starting blank. The typical applicable part configuration is one that has an area of the net trim that is internal to the part itself (i.e. a pocket or "bowl"). A simplified example would be a pan-shaped part that has the bottom of the pan cut away, resulting in a ring-shaped part.

Cutting out a hole(s) in the material allows for the hole(s) to enlarge as the material is stretched onto the tool surface. This enlarging takes the place of stretching and thinning the material if the holes were not present.

The basic concept is that the hole enables more axial stretching of the material and minimizes the biaxial stretching (ref. Figure 5). The end result is minimized material thinout in the axially stretched material. The thinout in areas of the hole that are stretched biaxially is also minimized (relative to not using the cutout(s), but to a lesser extent than the axially stretched regions (ref. Figure 6 and Data Table I).

Since the SPF process uses gas pressure to form the material, it is imperative that the sheet being formed does not have any holes through it. This requirement is in direct opposition to the process of this invention. Subsequently, a second sheet of material that does not contain any cutout locations, is required to form the blank (material with the cutout(s). This second sheet is placed between the blank and the die lid and becomes the membrane which can be pressurized and formed onto the tool geometry. While forming, this secondary sheet also forms the blank with the cutout(s). Once the blank is fully formed (die surface is in intimate contact with the entire blank), the blank and secondary sheet are separated and the secondary sheet is discarded..

There are three critical factors that must be dealt with to successfully utilize the disclosed process. Those factors are: (1) Location of cutout(s) on the blank, (2) Shape and Size of the cutout(s) on the blank, and (3) Indexing the blank to the tool.

Cutout Location: The location of the cutout(s) is optimized when the periphery of the cutout(s) is located as close as possible to the net trim of the part after forming. Locating the cutout(s) as such will maximize the material thickness at the trim line.

Shape and Size of the Cutout(s): The cutout(s) shape and size are critical in that an undersized cutout will result in unnecessary thinout. Conversely, all oversized cutout will result in undercutting the trim line of the part. While both sizing and locating the cutout(s), caution must be taken so that the formed blank does not become entrapped by the secondary sheet during the separation of the two sheets (ref. Figure 6B).

There are several methods for determining the proper location and size of the cutout(s) on the blanks. Besides trial and error, a highly accurate "best guess" can be made utilizing a model of the die surface. Among the most easily manipulated mode is a Computer Aided Drafting (CAD) model. Once generated, the tool surfaces can be projected or rotated to one plane so that the trim line of the part can be seen on that plane - the equivalent of a forming blank (ref. Figure 9). This planar trim line defines a preliminary location, size, and shape of the cutout(s). The final size and shape of the cutout can then be obtained by applying a reduction factor and corner radii to the preliminary size and shape.

Indexing the Blank to the Tool: Once the size, shape, and location of the cutout(s) have been determined, it is paramount that the blank be located to the die accurately. Without accurate, repeatable alignment, it is not possible to produce a consistent part. One

method of locating the blank to the die is through the use of "pins" or "posts" that extend from the die sealing surface. Holes can then be cut into the blank and secondary sheet to correspond to the pins in the die.

Description of Figures:

Figure 5: Illustrates the process steps for the Disclosed Invention

Prior to Figure 5A, the region(s) of the blank that are to be cutout must be removed. The location, size and geometry of the cutout(s) is of critical importance for the successful forming of the part. In addition, it is also critical that the blank be indexed to the die surface so that the cutout area(s) form into the desired areas of the die.

Figure 5A: This figure illustrates the die, die lid, material blank and the secondary sheet. Once the die is heated to the forming temperature for the particular material alloy, the blank and secondary sheet are placed on the surface of the die. The location of the secondary sheet is between the die lid and the blank.

Figure 5B: The blank and secondary sheet are "sandwiched" between the die and lid by means of a force applied to the lid.

Figure 5C: As gas pressure is introduced to tile top side of the secondary sheet, the secondary sheet and blank are formed into the die cavity.

Figure 5D: Forming continues as the gas pressure is increased.

Figure 5E: Upon completion of the forming cycle, the blank is in full contact with the die surfaces.

Figure 5F: The gas pressure is vented and the lid is removed. The blank and secondary sheet are separated and removed from the die.

Figure 6A: This figure illustrates the result of correctly calculating and locating the cutout(s) on the blank. In this instance, the secondary sheet does not entrap the blank when the two are separated.

Figure 6B: This figure illustrates the potential problem of material entrapment caused by incorrectly calculating the size and location of the cutout(s) on the blank. In this instance after forming, the edge of the cutout(s) became located on a near-vertical surface, creating entrapment of the blank by the secondary sheet.

This entrapment does not allow for separation of the blank and secondary sheet without cutting the two apart.

Figure 7: This figure illustrates tile types of stretching of the cutout periphery that take place during forming of the blank. Any straight line regions of the cutout periphery will undergo stretching in one direction (axial). Curved segments of the cutout will stretch in two directions (biaxial). In general, the axial stretching that takes place will result in less thinout than in the regions that are biaxially stretched.

Figure 8: This figure illustrates data obtained from

fabricated test parts. All parts started with the same material thickness and were measured in the same locations.

From the data it is possible to see that by cutting hole(s) in the blank, it is possible to achieve a 69% increase in as-formed material thickness, in comparison to parts formed without the invention process.

Figure 9: This figure illustrates how the basic geometry and location of the cutout(s) can be obtained. This key information be obtained through several methods. However; the easiest method is through the manipulation of Computer Aided Drafting (CAD) data of the die geometry. Use of such data is illustrated in this figure.

Figure 9A: This figure illustrates half of a symmetrical part. The dashed lines indicate surfaces of the die.

Figure 9B: This figure shows the axis about which the surfaces are rotated. Once the surfaces are rotated to the starting plane, a preliminary outline of the cutout can be determined. The edge of the surface rotated is determined by the net trim of the part.

Claims

1. An improved method of forming a metal part by superplastic forming using a die, a pressurized gas, and a blank sheet of metal from which said part is made; said improvement comprising:
 - locating a secondary sheet in contact with said blank and also in contact with said pressurized gas; making a cutout in said blank to obtain thicker part material in specific locations when the pressurized gas is applied for an appropriate cycle time.
2. The method of claim 1 wherein said cutout is sized and located to minimize material thinout.
3. The method of claim 2 wherein said cutout is sized and located to increase in size when pressurized gas is applied for all appropriate cycle time.
4. An improved method of forming a metal part by superplastic forming in which die surfaces 1,2, and 3 outline the apapproximate location and size of cutouts by manipulation of Computer Aided Drafting (CAD) data of the die geometry.
5. An improved method of achieving thicker part material in predetermined regions of the Superplastic formed detail through the use of a blank with preselected cutout areas and is then formed onto the die surface by the secondary sheet, which does not contain any cutouts.
6. The method of claims wherein the part blank is aligned to die and other associated apparatus such

that the periphery of the cut-away aarea of the blank falls into a specific location of the tool surface.

7. The method of claim 5 determines that cutout geometry and cutout location on the blank material, wherein the surfaces are rotated into the starting plane.

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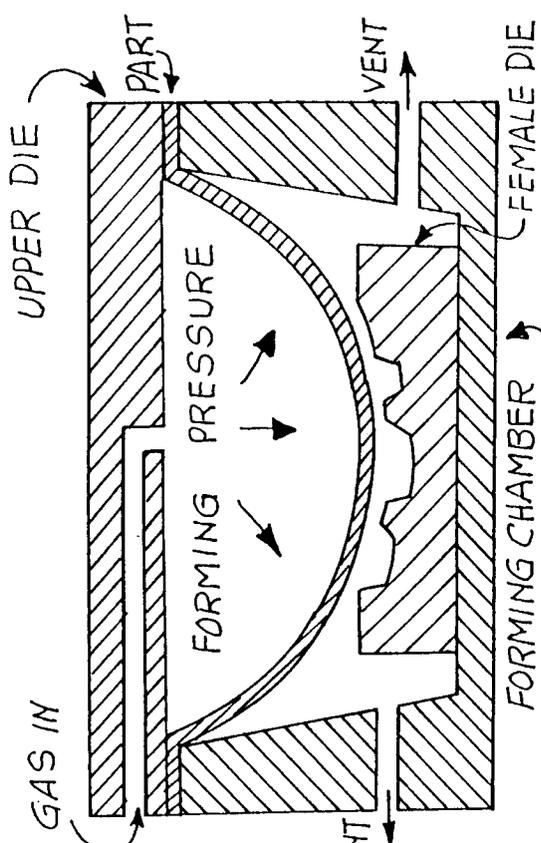


Fig. 1C PRIOR ART

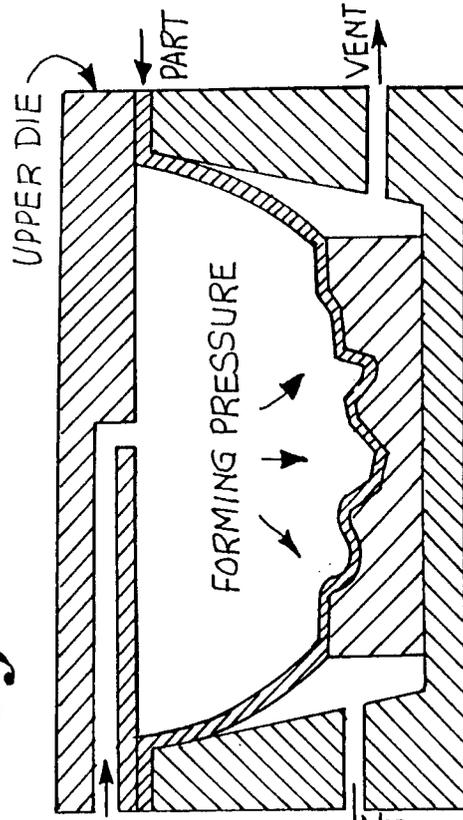


Fig. 1D PRIOR ART

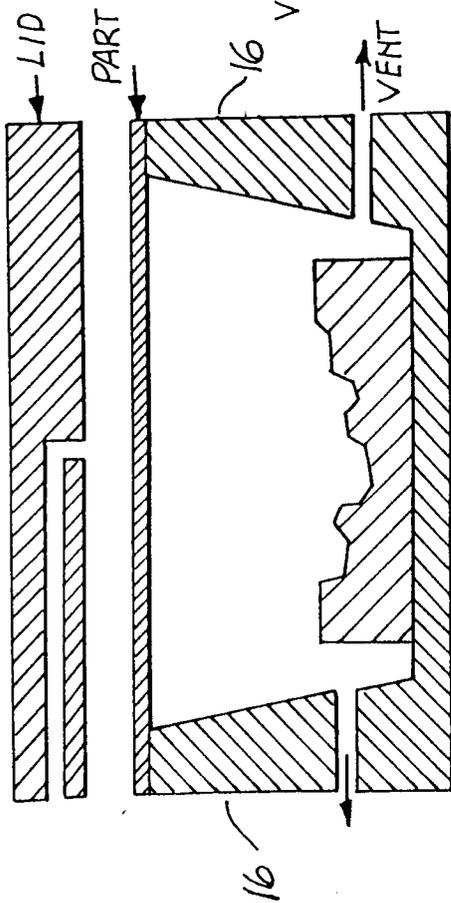


Fig. 1A PRIOR ART

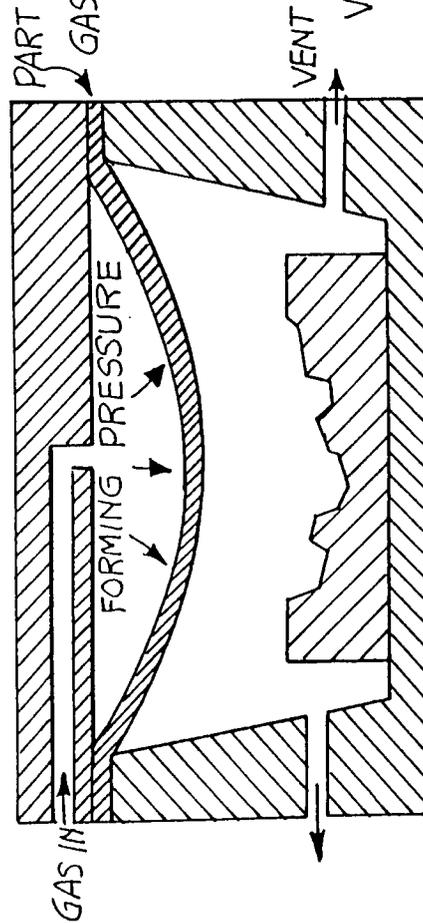


Fig. 1B PRIOR ART

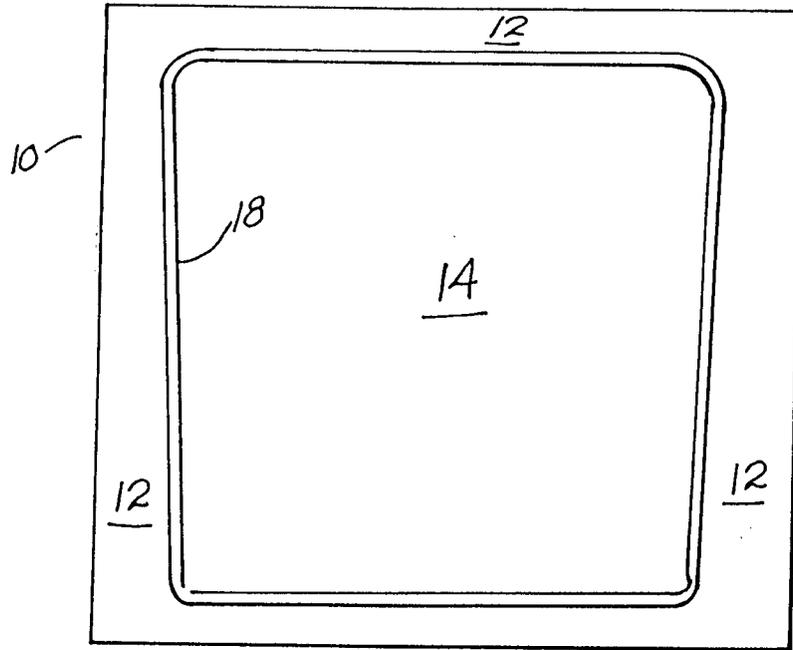


Fig. 2

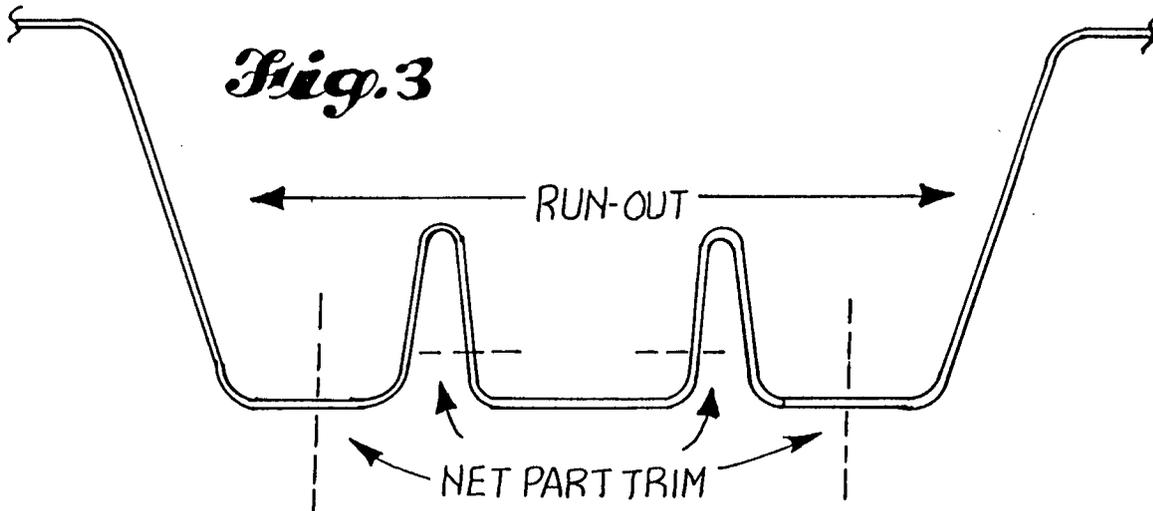


Fig. 3

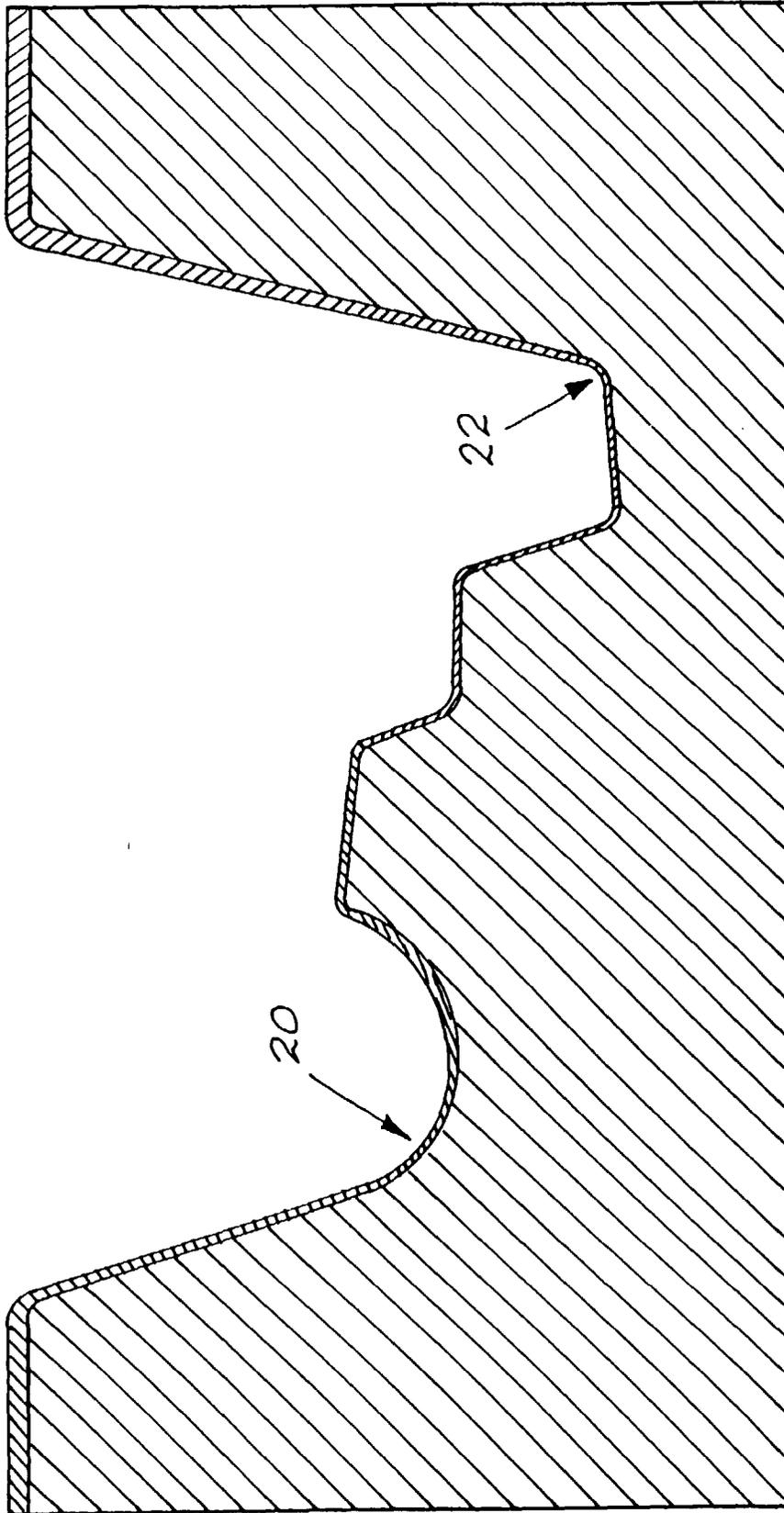


Fig. 4

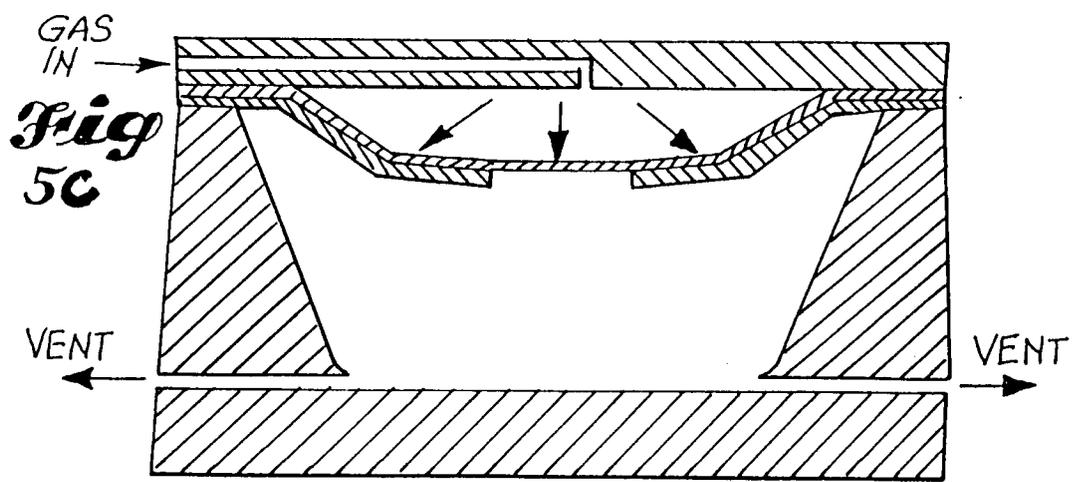
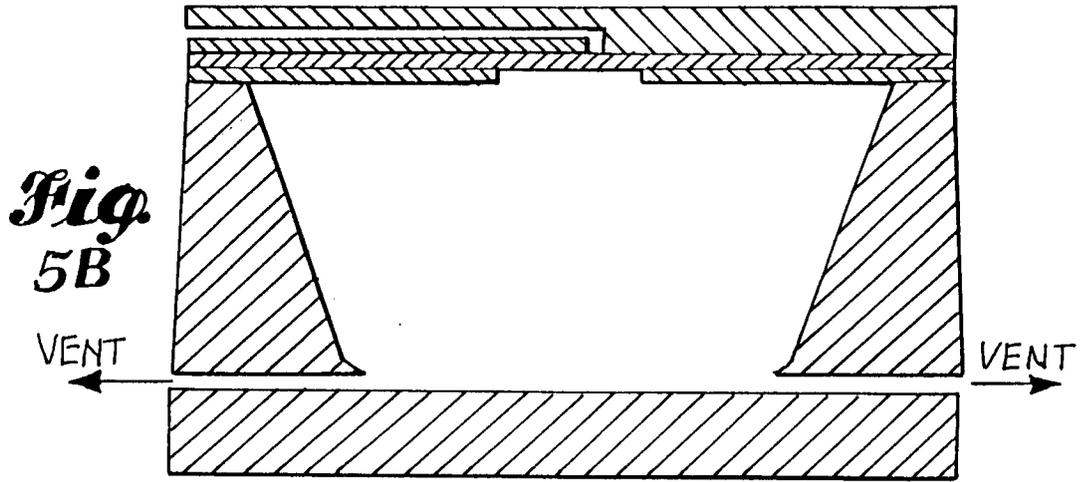
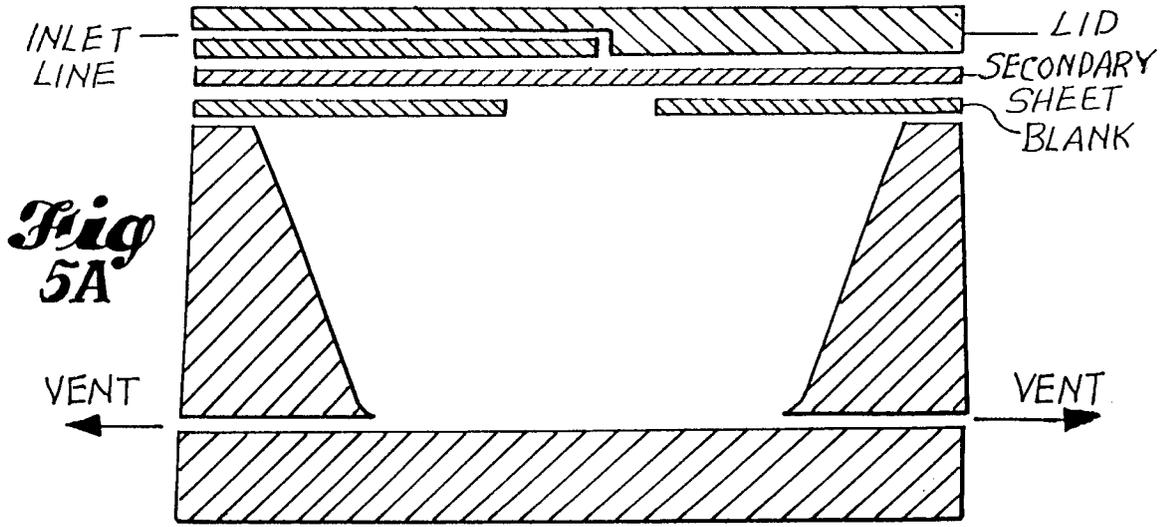


Fig
5D

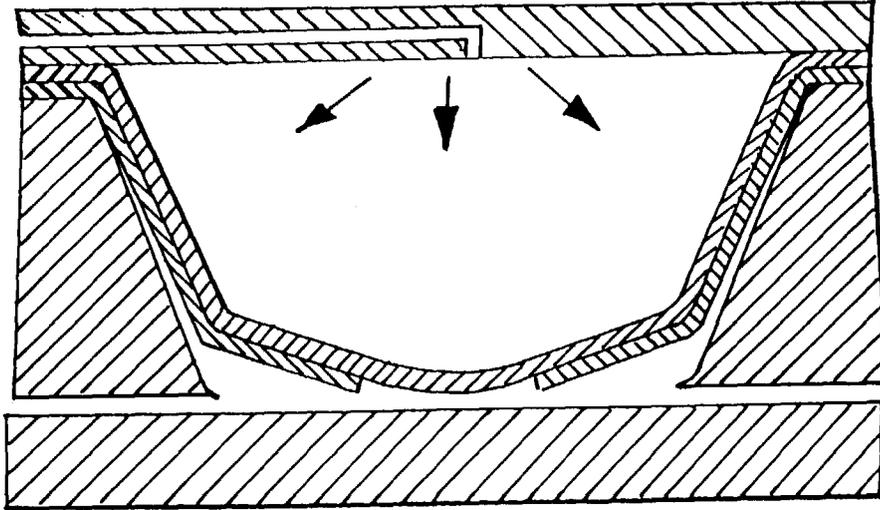


Fig
5E

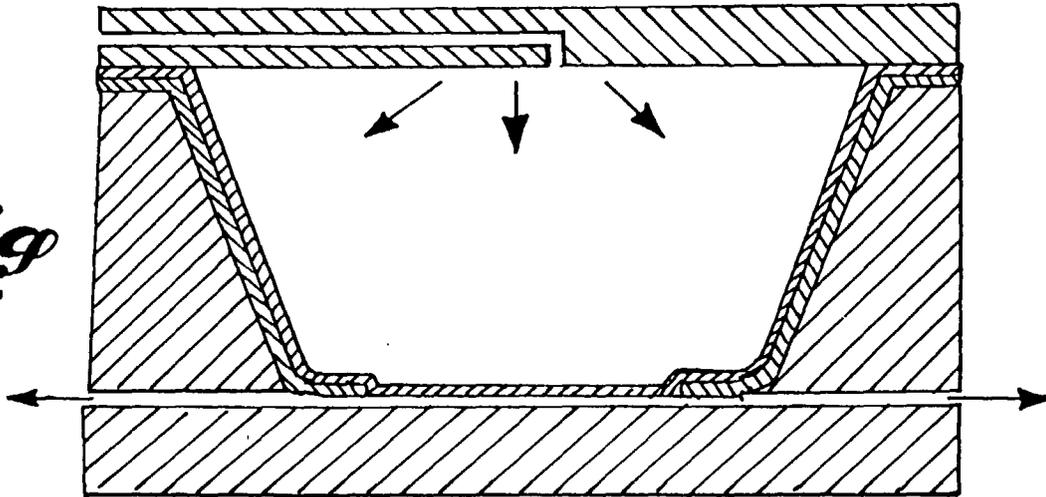
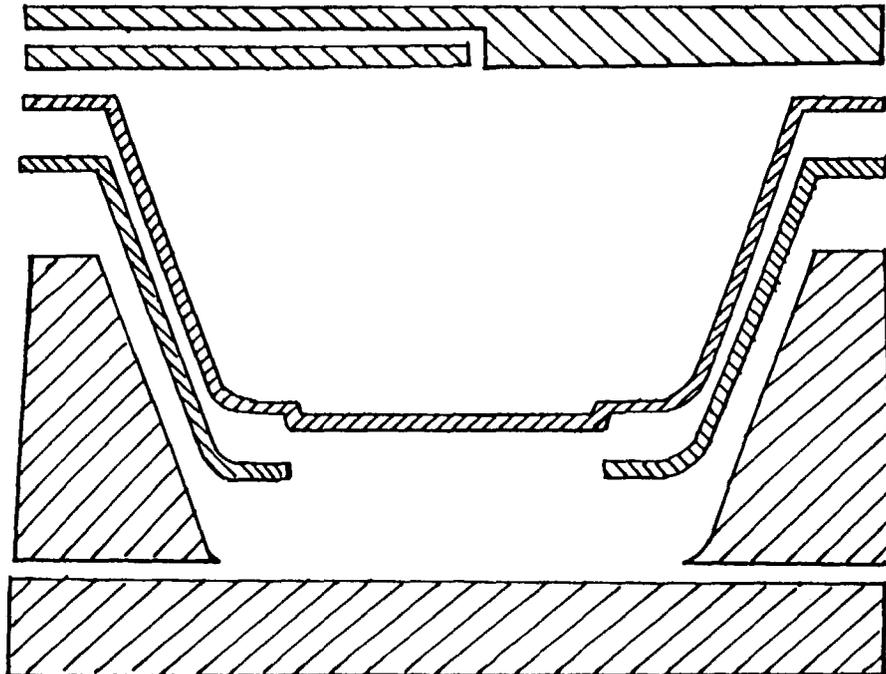
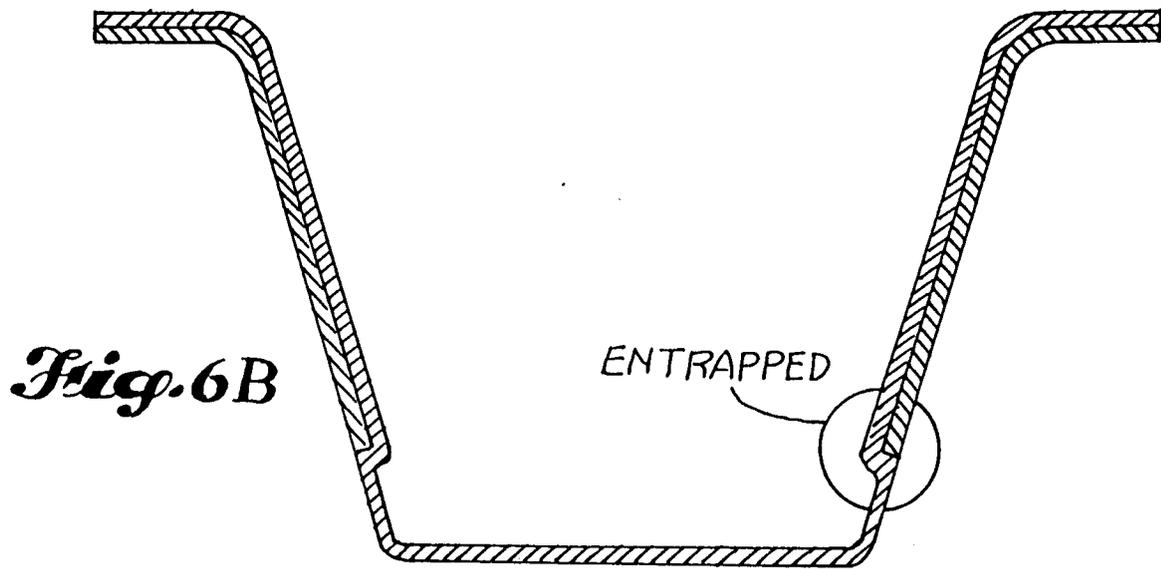
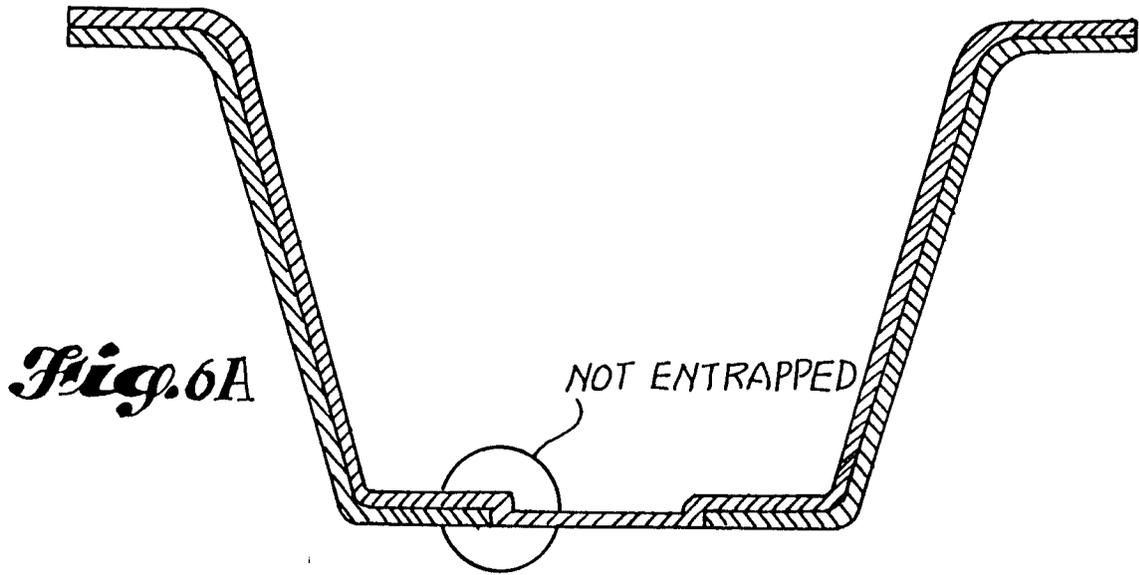


Fig
5F





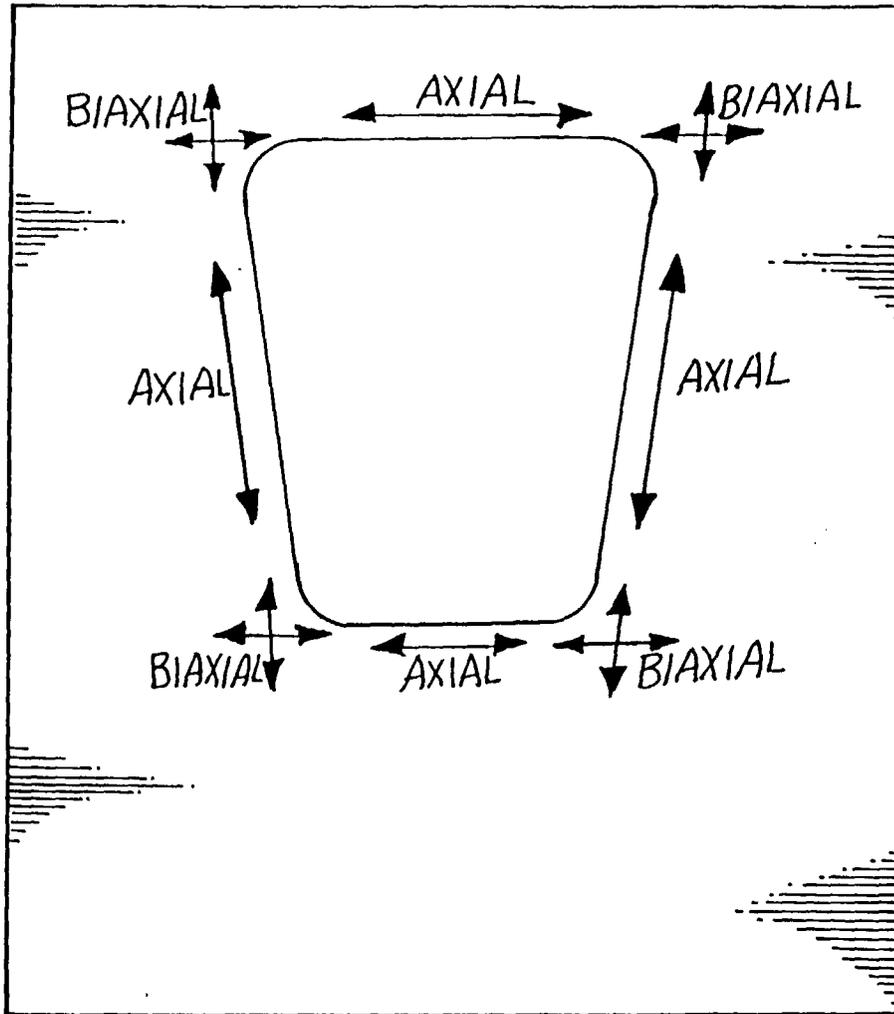
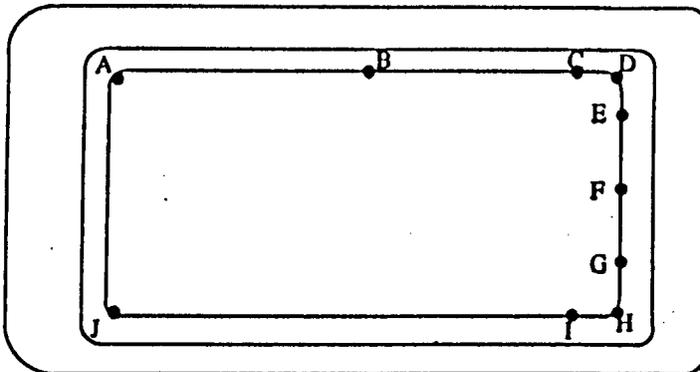


Fig 7

PART FORMED WITHOUT ADV. FORMING TECHNIQUE



Part No.	Measurement Location @ Part Trim									
	A	B	C	D	E	F	G	H	I	J
	.035	.044	.023	.016	.025	.032	.026	.016	.023	.036
1	.040	.080	.047	.029	.039	.050	.039	.035	.037	.043
2	.043	.081	.041	.025	.038	.044	.037	.022	.040	.039
3	.039	.074	.039	.027	.036	.038	.034	.024	.039	.041
4	.040	.075	.042	.024	.035	.040	.036	.026	.042	.045
	.041	.078	.042	.026	.037	.043	.037	.027	.040	.042
	17.1	77.3	82.6	62.5	48.0	34.4	42.3	68.8	73.9	16.7

Data Table 1: Material Thickness After Forming

% INCREASE

AVG. PARTS
#1 #2 #3 #4

Fig. 8

Fig. 9A

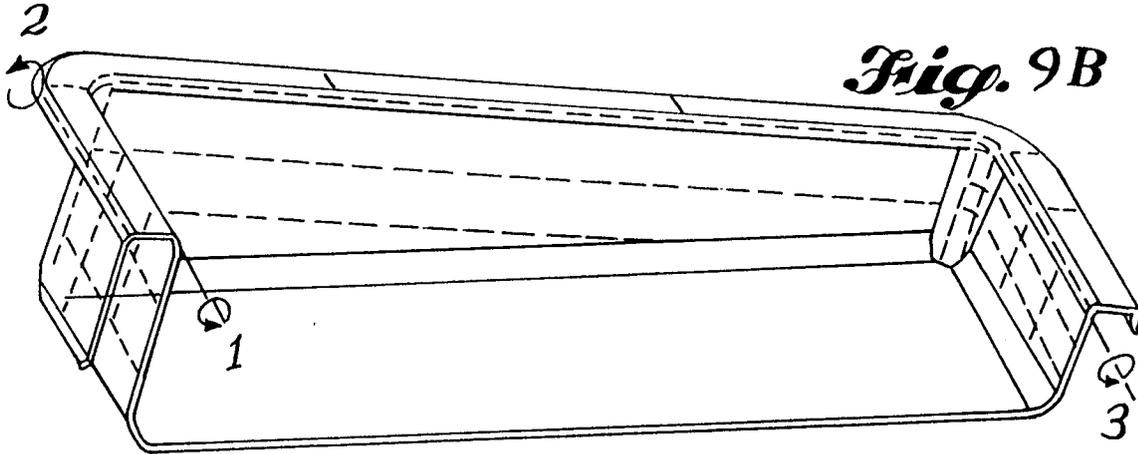
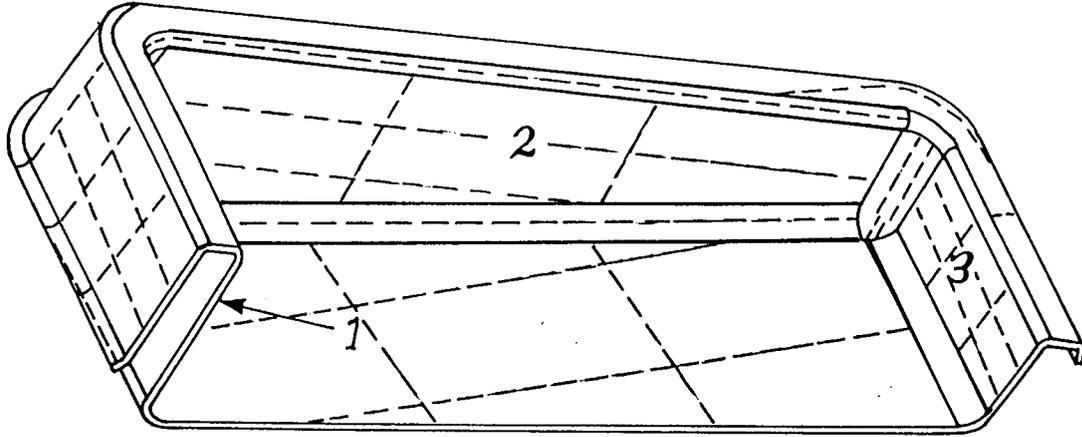
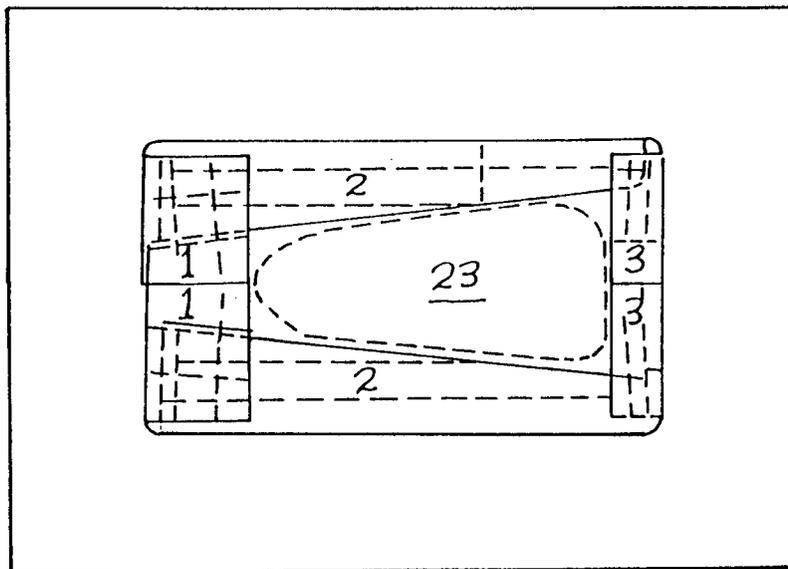


Fig. 9C





European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 97 20 3563

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	US 4 984 348 A (CADWELL GILBERT C) 15 January 1991 * the whole document * ---	1, 4, 5	B21D26/02
A	US 4 748 837 A (KUROSAWA HIROSHI ET AL) 7 June 1988 * column 4, line 45 - column 5, line 58; figures 7-13 * ---	1, 5	
A	US 5 419 170 A (SANDERS DANIEL G ET AL) 30 May 1995 * figures * -----		
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			B21D
Place of search	Date of completion of the search	Examiner	
THE HAGUE	30 March 1998	Ris, M	
CATEGORY OF CITED DOCUMENTS		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			

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