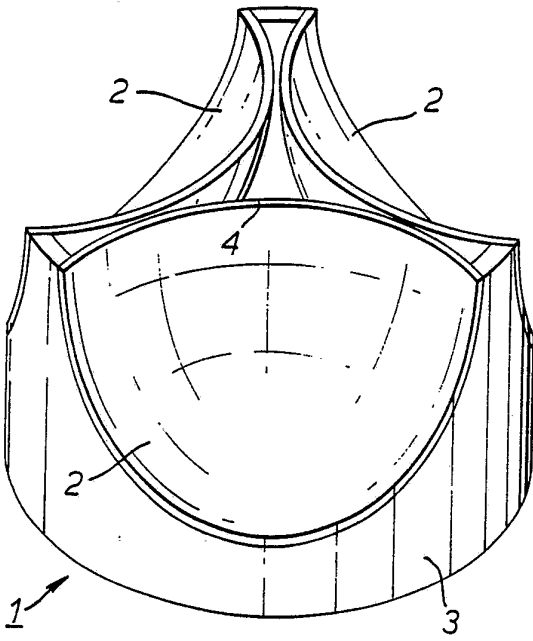




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<p><b>(54) Title:</b> ARTIFICIAL HEART VALVE</p> <div style="text-align: center;">  </div> <p><b>(57) Abstract</b></p> <p>A flexible leaflet heart valve (1) to replace natural aortic or pulmonary valves of the heart, includes a frame (3) and flexible leaflets (2) attached to the frame (3). Each flexible leaflet (2) forms part of a surface of revolution having its axis of revolution substantially orthogonal to the direction of blood flow through the valve (1). The valve (1) has improved opening characteristics under low flow conditions, and allows a large range of leaflet geometries for the same size valve.</p>		

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**ARTIFICIAL HEART VALVE****BACKGROUND OF THE INVENTION**

The present invention relates to artificial heart  
5 valves, and more particularly to flexible leaflet heart  
valves which are used to replace the natural aortic or  
pulmonary valves of the heart.

Conventionally, ball or disk valves are used to  
replace natural mitral or tricuspid aortic or pulmonary  
10 valves of the heart. These artificial valves comprise a  
rigid frame defining an aperture and a cage enclosing a  
ball or a disk. When blood flows in the desired direction,  
the ball or disk lifts away from the frame allowing the  
blood to flow through the aperture. The ball or disk is  
15 restrained by the cage by struts or by a pivot. When blood  
tries to flow in the reverse direction, the ball or disk  
becomes seated over the aperture and prevents the flow of  
blood through the valve. The disadvantage of these valves  
is that the ball or disk remains in the blood stream when  
20 the blood flows in the desired direction, and this causes  
a disturbance to blood flow.

More recently, flexible leaflet valves have been  
proposed which mirror natural heart valves more closely.  
These valves have a generally rigid frame and flexible  
25 leaflets attached to this frame. The leaflets are arranged  
so that, in the closed position, each leaflet contacts  
its neighbour thereby closing the valve and preventing the  
flow of blood. In the open position, the leaflets  
separate from each other, and radially open out towards  
30 the inner walls of an artery in which the valve is located.  
The leaflets are either made from chemically treated animal  
tissue or polyurethane material. The leaflets must be  
capable of withstanding a high back pressure across the  
valve when they are in the closed position, yet must be  
35 capable of opening with the minimum pressure across the  
valve in the forward direction. This is necessary to

ensure that the valve continues to correctly operate even when the blood flow is low, and to ensure that the valve opens quickly when blood flows in the desired direction.

A wide range of geometries are used to describe natural aortic valve leaflets during diastole, but these geometries cannot be used for valves made from pericardial or synthetic materials due to the approximately isotropic properties of such materials compared to the highly anisotropic material of the natural valve. Consequently, different geometries have to be used to form flexible leaflet heart valves made from pericardial or synthetic materials with isotropic mechanical properties.

Conventional flexible leaflet heart valves have three substantially identical leaflets mounted onto the frame. The leaflets have a range of designs, both in the geometry of the leaflet and the variations in thickness of the leaflets. Original flexible leaflet heart valves incorporate leaflets which are spherical or conical when in the relaxed state, that is when no pressure is acting on the leaflet. More recently, cylindrical and ellipsoidal leaflets have been proposed. These leaflet geometries are formed with an axis of revolution in a plane generally parallel to the blood flow through the valve.

## 25 DISCLOSURE OF THE INVENTION

According to the present invention, a flexible leaflet heart valve for controlling the flow of blood comprises a substantially rigid frame and a plurality of substantially identical flexible leaflets mounted on the frame, characterised in that each flexible leaflet forms part of a surface of revolution having its axis of revolution lying in a plane substantially orthogonal to the direction of blood flow through the valve, and a shape defined by the equation:

35

$$z^2 + y^2 = 2R_1 (x - g) - \alpha (x - g)^2$$

where:  $g$  is the offset of the leaflet from the axis of the frame;  
 $R_L$  is the radius of curvature of the leaflet at  $(g, 0, 0)$ ; and  
5  $\alpha$  is the shape parameter and is greater than 0 and less than 1.

A flexible leaflet valve according to the present invention has improved opening characteristics under low  
10 flow conditions. The shape of the leaflets is such that the radius of curvature of the leaflet continuously increases in two directions away from the centre point of the free edge. By varying the radius of curvature, the leaflet shape may be varied and still fit within the frame.

15 The value of  $\alpha$  may be in the range of 0.2 to 0.8, but is preferably in the range 0.4 to 0.6, and more preferably is about 0.5.

Preferably,  $x$  is in the range of 0 to  $R_L$ ,  $y$  is in the range between  $-R_L$  and  $+R_L$ , and  $z$  lies in the range  
20  $-1.8 R_L$  to  $+0.2 R_L$ .

The valve preferably includes three leaflets, and in this case the valve closure is preferably effected by the surface adjacent the free edge of each leaflet making sealing contact with the two neighbouring leaflets. The  
25 frame on which the leaflets are mounted is preferably circular in cross-section, and has a size dependent upon the size of the aorta or pulmonary artery in which the valve is to be used.

Preferably, each leaflet is made from a polyurethane  
30 material, and has a variable thickness, preferably between 0.15 mm and 0.25 mm.

#### BRIEF DESCRIPTION OF THE DRAWINGS

An example of a flexible leaflet heart valve according  
35 to the present invention will be described with reference to the accompanying drawings, in which:-

Figure 1 shows an overall view of the valve;

Figure 2 shows a plan of the valve; and,

Figure 3 shows a cross section of one leaflet of the valve taken along the line A - A shown in Figure 2.

#### 5 DESCRIPTION OF PREFERRED EMBODIMENT

As shown in Figure 1, a flexible leaflet heart valve 1 includes three flexible leaflets 2 which are substantially identical to each other. The leaflets 2 have a free edge 4. The leaflets 2 are mounted symmetrically on a frame 3. The valve 1 is positioned in an artery with the axis of the frame 3 generally co-axial to the axis of the artery, and hence in the same direction as the blood flow along the artery. The leaflets 2 form part of a paraboloid having its axis of revolution lying in a plane orthogonal to the direction of blood flow.

Using cartesian geometry with the  $z$  direction being the direction of blood flow, the  $y$  direction orthogonal to this and extending from the centre of the free edge 4 of the leaflet 2, and the  $x$  direction being orthogonal to both the  $y$  and  $z$  directions, then the shape of the leaflet is represented by the equation:

$$z^2 + y^2 = 2R_L (x - g) - \alpha (x - g)^2$$

25 where:  $g$  is the offset of the leaflet from the axis of the frame as shown in Figure 3;  
 $R_L$  is the radius of curvature of the leaflet at  $(g, 0, 0)$  as shown in Figure 2; and  
 $\alpha$  is the shape parameter, and is greater than 0  
 30 and less than 1.

If  $\alpha = 1$  the geometry of the leaflet 2 will be spherical. When  $\alpha = 0$ , the surface will be parabolic. However, for  $0 > \alpha > 1$ , the leaflet shape has a variable radius of curvature having its axis of revolution in the  $x, y$  plane. This allows leaflets to be produced having a

shape to give the required properties which also fits within any given frame.

The valve radius,  $R_f$ , as shown in Figure 3, and  $R_l$  are both in the range of 5 mm to 20 mm,  $g$  is in the range of 0 to 3 mm and  $\alpha$  is 0.5.

Leaflets of this shape open radially away from the centre of the frame out towards the wall of the artery with a very low pressure, typically below 1 mm Hg. This is important as if the valve 1 fails to open at low pressures, the blood will cease to circulate. The shape of the leaflets 2 also ensures that they rapidly close when the blood tries to flow in the reverse direction, therefore quickly preventing the blood from flowing in this direction.

Various sizes of frame 3 may be used depending upon the size of the artery. Due to the leaflets 2, a frame radius  $R_f$  of about 13.5 mm produces a valve having an effective orifice area of approximately 2.5 cm<sup>2</sup>. This typically allows approximately 4.5 litres per minute of blood to flow through, at which rate, the valve 1 has a closing regurgitant volume of less than 3 ml per stroke.

Although not shown, the valve may have only two or more than three flexible leaflets 2.

The precise size and shape of the leaflets 2 depends upon the particular size of vessel in which the valve 1 is to be used. In particular, the shape parameter  $\alpha$  of the leaflets 2, may be varied to produce a set of valves 1 of substantially the same size but different shapes to suit most applications. Alternatively, a set of heart valves 1 may be produced all of which have the same shape, but have different sizes for particular applications.

C L A I M S

1. A flexible leaflet heart valve for controlling the flow of blood in an artery comprising a substantially rigid frame (3), and a plurality of substantially identical flexible leaflets (2) mounted on the frame (3), characterised in that each flexible leaflet (2) is formed from part of a surface of revolution having its axis of revolution lying in a plane substantially orthogonal to the direction of blood flow through the valve (1), and a shape defined by the equation:

$$z^2 + y^2 = 2R_L (x - g) - \alpha (x - g)^2$$

- where:  $g$  is the offset of the leaflet from the axis of the frame;  
 $R_L$  is the radius of curvature of the leaflet (2) at  $(g, 0, 0)$ ; and  
 $\alpha$  is the shape parameter and is greater than 0 and less than 1.

2. A flexible leaflet heart valve according to claim 1, in which  $\alpha$  is in the range 0.2 to 0.8.
3. A flexible leaflet heart valve according to claim 1 or 2, in which  $\alpha$  is within the range 0.4 to 0.6.
4. A flexible leaflet heart valve according to any of the preceding claims, in which  $\alpha$  is substantially 0.5.
5. A flexible leaflet heart valve according to any of the preceding claims, in which  $x$  is in the range 0 to  $R_L$ ,  $y$ , when present, is in the range  $-R_L$  to  $+R_L$ , and  $z$  is in the range  $-1.8R_L$  to  $+0.2R_L$ .
6. A flexible leaflet heart valve according to any of the preceding claims, in which  $R_f$  and  $R_L$  are both between 5 mm and 20 mm, and  $g$  is in the range 0 to 3 mm.
7. A flexible leaflet heart valve according to any of the preceding claims including three flexible leaflets (2).

8. A flexible leaflet heart valve according to any of the preceding claims, in which the rigid frame (3) has a substantially circular cross section.

5 9. A flexible leaflet heart valve according to any of the preceding claims, in which the leaflets are made from polyurethane and have a variable thickness in the range 0.15 mm to 0.2 mm.

Fig. 1.

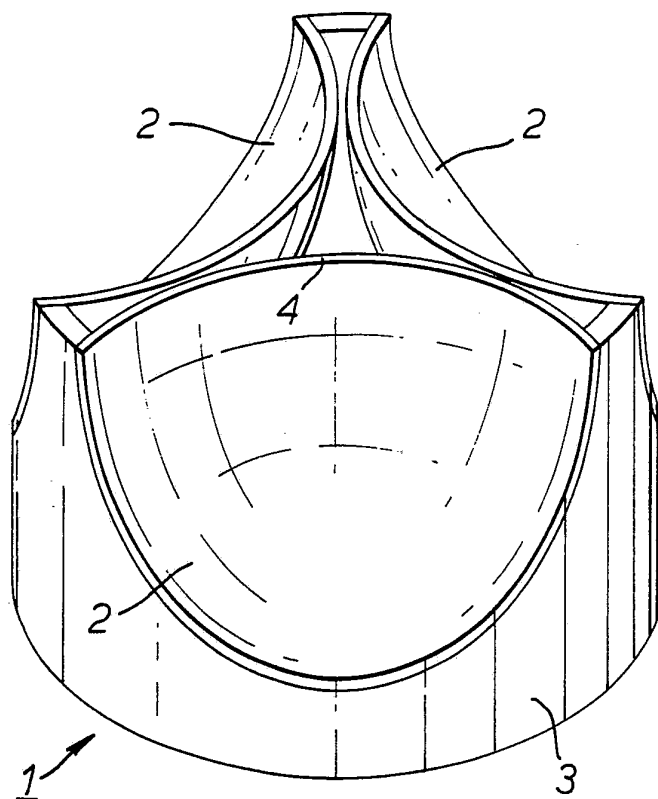
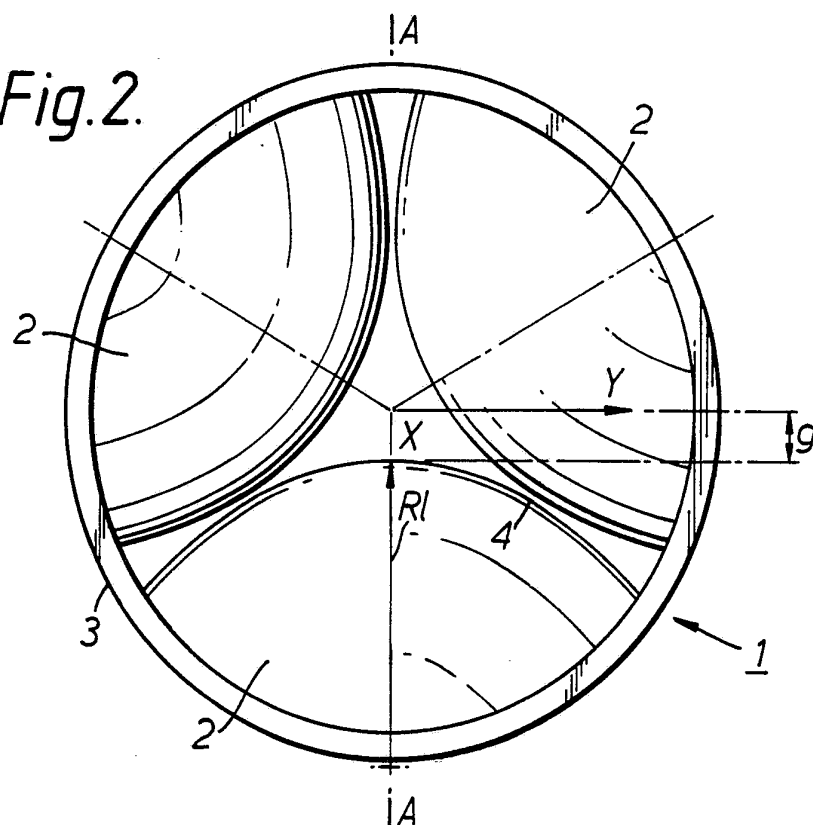
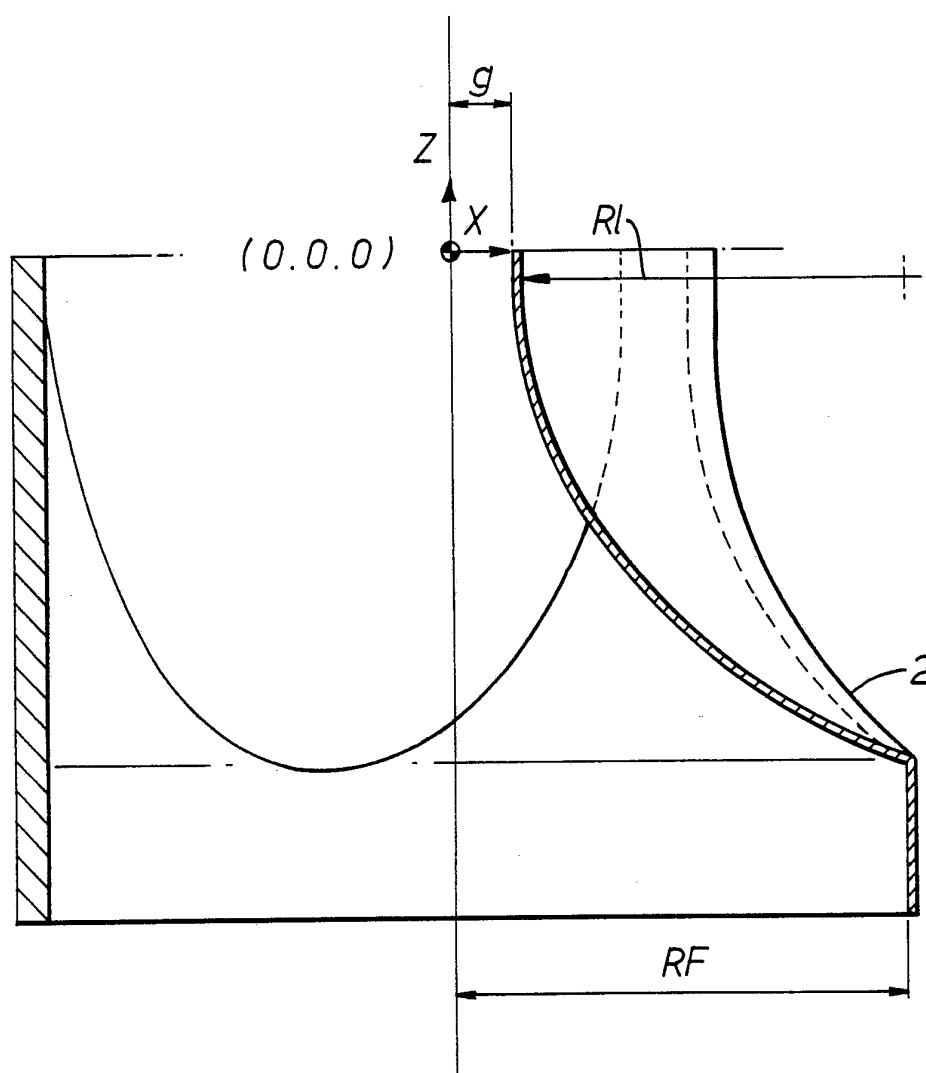


Fig. 2.



2/2

Fig. 3.



## INTERNATIONAL SEARCH REPORT

PCT/GB 93/00568

International Application No

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>6</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC		
Int.Cl. 5 A61F2/24		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>7</sup>		
Classification System	Classification Symbols	
Int.Cl. 5	A61F	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>9</sup></b>		
Category <sup>10</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
A	MEDICAL AND BIOLOGICAL ENGINEERING vol. 14, no. 2, March 1976, LONDON U.K. pages 122 - 129 D. N. GHISTA 'TOWARD AN OPTIMUM PROSTHETIC TRILEAFLET AORTIC-VALVE DESIGN' see page 123, column 2, line 4 - line 22; figures 3,4 see page 128, column 1, line 19 see page 128, column 2, line 5 - line 14 ---	1,7-9
A	US,A,3 320 972 (R.F. HIGH ET AL.) 23 May 1967 see column 2, line 61 - line 72; figures 1-5 ---	1,7-9
A	EP,A,0 114 025 (E. HENNIG) 25 July 1984 see claim 4; figures ---	1,7-9
	-/--	
<p><sup>10</sup> Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&amp;" document member of the same patent family</p>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search		Date of Mailing of this International Search Report
02 JUNE 1993		08.06.93
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III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
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A	CA,A,1 232 407 (D. K. WALKER ET AL.) 9 February 1988 see claims 1,18,26; figures ---	1,8,9
A	GB,A,1 443 221 (MEDAC) 21 July 1976 see page 3, line 21 - line 53; figures ---	1,7
P,A	WO,A,9 212 690 (AUTOGENICS) 6 August 1992 see page 25, line 1 - page 27, line 14; figures 6F,6G -----	1,7,8

**ANNEX TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO.**

GB 9300568  
SA 71454

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GB-A-1443221	21-07-76	None	
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82