(12) UK Patent Application (19) GB (11) 2 067 677 A

(21) Application No **8101267**
(22) Date of filing **15 Jan 1981**
(30) Priority data
(31) **112446**
(32) **16 Jan 1980**
(33) **United States of America (US)**
(43) Application published
30 Jul 1981
(51) **INT CL^3**
F01D 5/04
(52) Domestic classification
F1V 102 106 200 CF
(56) Documents cited
GB 1064399
GB 795249
GB 770004
GB 705387
GB 608476
(58) Field of search
F1T
F1V
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(54) Stress-resistant composite radial turbine or compressor rotor

(57) The rotor comprises a cast metal shell 10 having a plurality of integral radially extending airfoils 30, joined to an annular periphery 38 with a constant diameter axially extending portion 12 and a radially outwardly flared skirt portion 14, into which is fitted a preformed hub disc 18 of dense stress material which has an axially extending nose portion 20 thereon, and a conical end 22 with a surface congruent with the slope of the shell skirt 14 such that it is configured to optimize the hub material location for blade and hub stress.

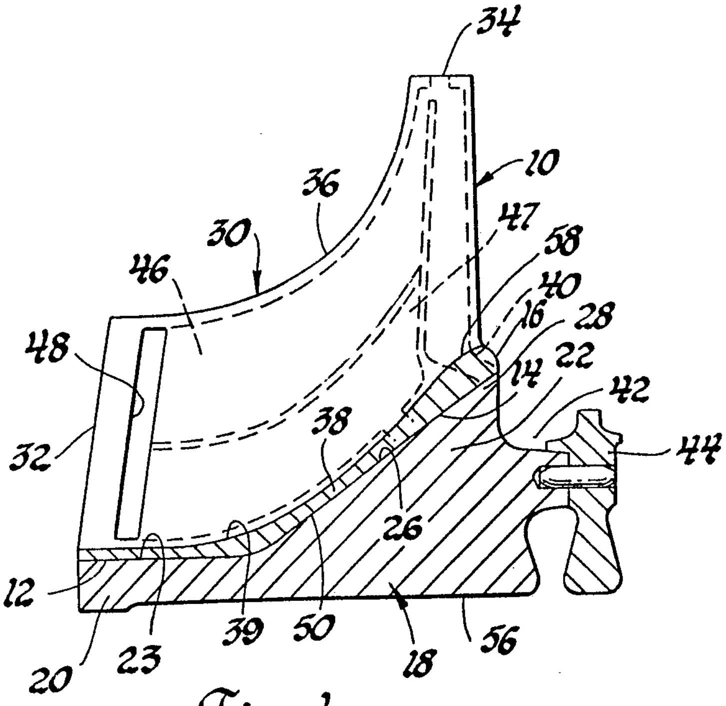

Fig.1

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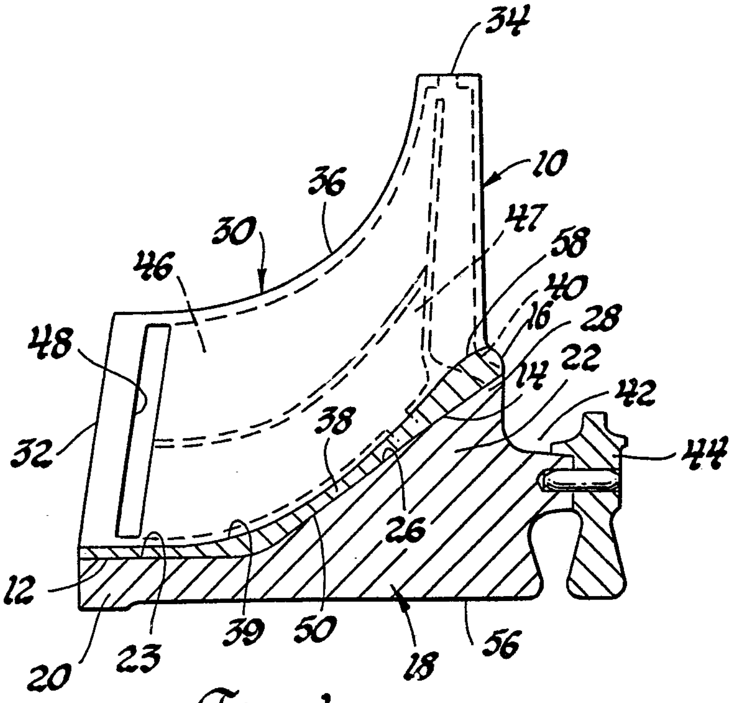
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Fig.1

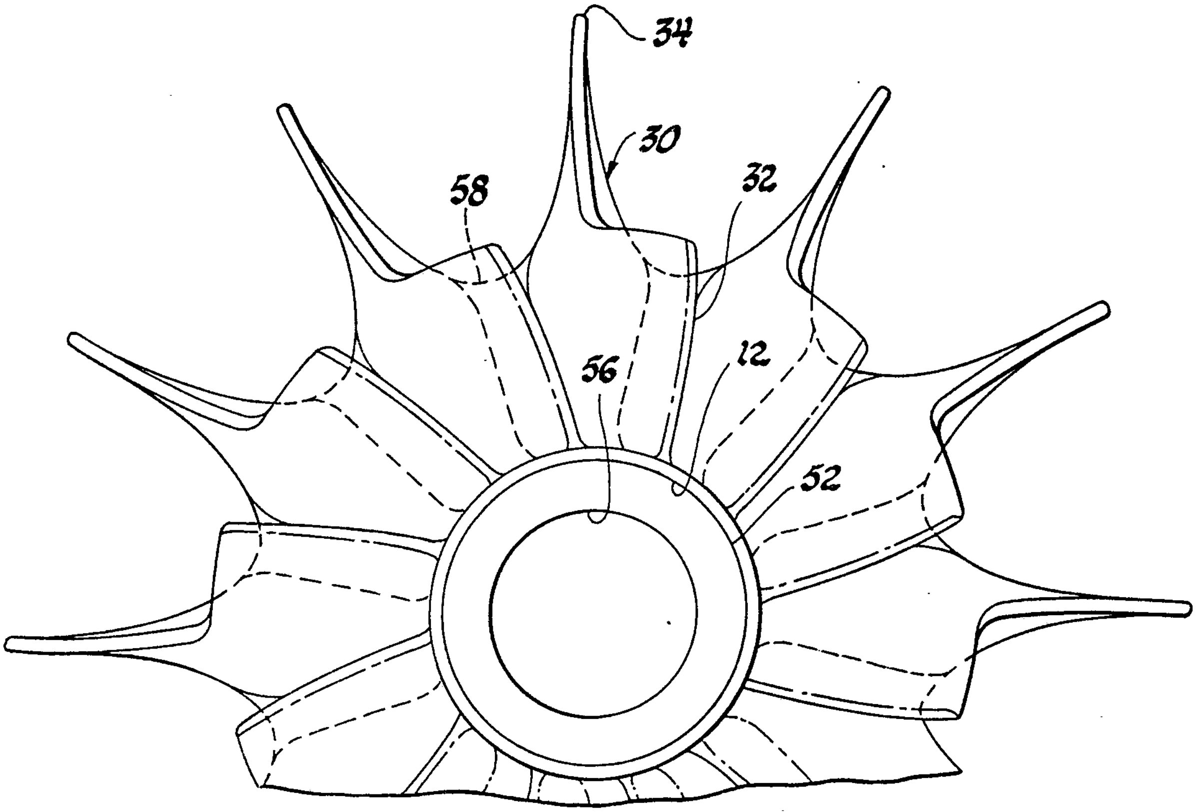
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Fig.2

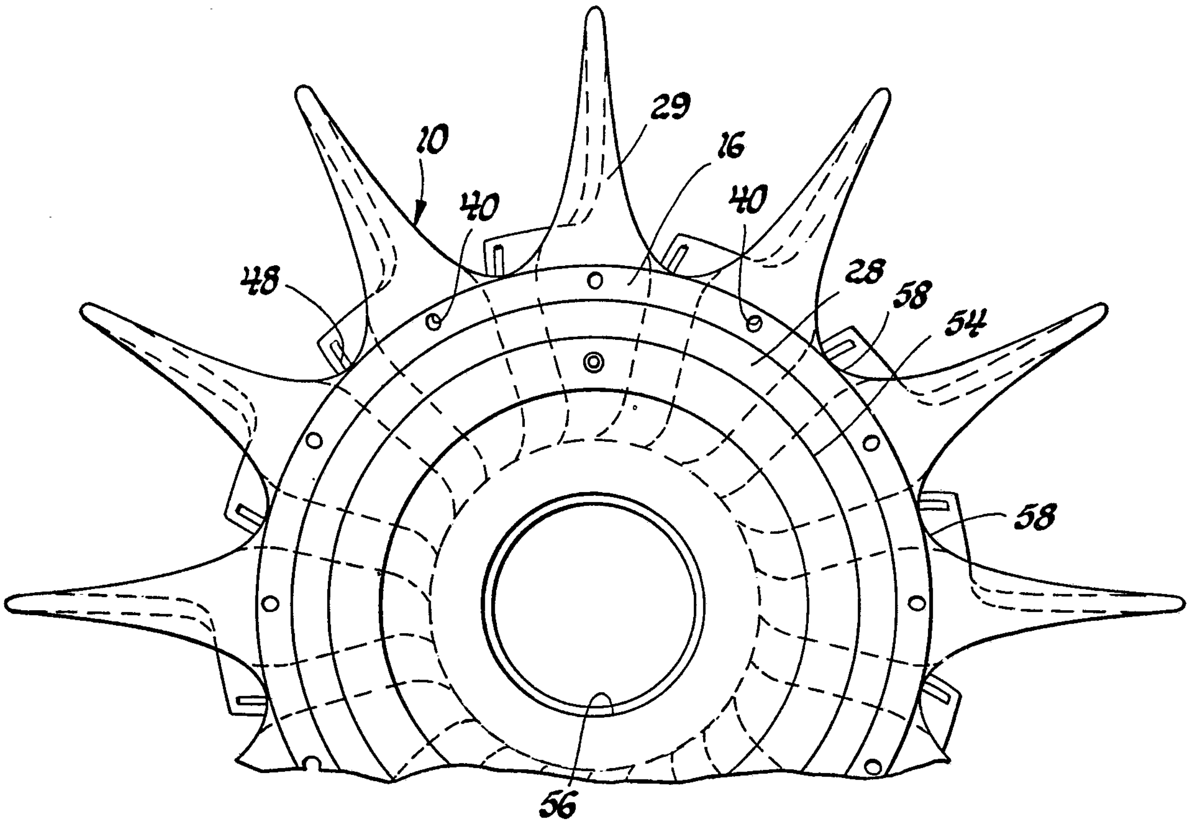

Fig.3

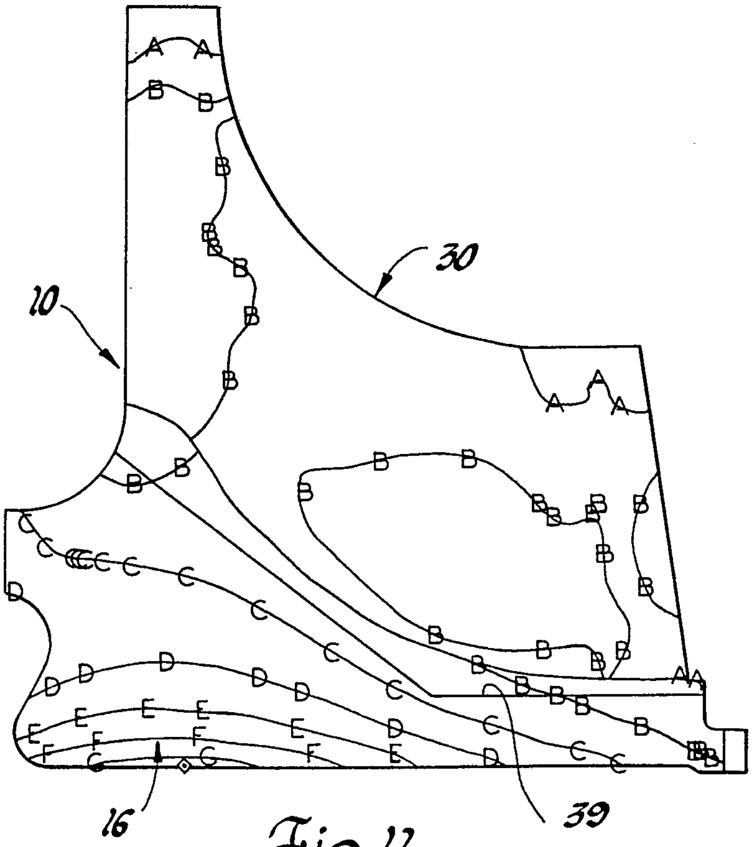

Fig.4

SPECIFICATION

Stress-resistant composite radial turbine rotor

This invention relates to composite turbine rotor assemblies and more particularly to composite radial flow type turbine engine rotors.

Gas turbine rotors used in small gas turbine engines have discs and airfoil arrays that are dimensionally configured to make it difficult to mechanically connect blades of a first metallurgical composition to a disc of a second metallurgical composition. More specifically, it is recognised that the airfoil components of a turbine wheel are subjected to high temperature operation and are preferably of a creep-resistant superalloy material; while the material of the disc should have substantial strength and ductility to withstand high stresses produced by centrifugal loads and thermal gradients.

For example, one such composite turbine rotor is set forth in United States Patent No. 2,479,039, (Cronstedt). It is made by a multi-stage centrifugal casting method and applies to large turbine rotors. It is difficult to mechanically couple the turbine disc of small gas turbines by conventional joints and coupling components to a blade array. Accordingly, in United States Patent No. 3,940,268, (Catlin), a disc of powdered metal material is connected to a plurality of radially outwardly directed airfoil components by locating them in a mould and producing a metallurgical bond between the airfoil components and the disc during a hot isotatic formation of the disc element. While blades can be bonded to a disc of a differing material by the method set forth in the aforesaid Catlin patent, composite turbine rotor structures formed by such method lack precise dimensional control between adjacent airfoil components. Such dimensional imprecision is especially undesirable in the case of small, high speed gas turbine rotors.

In order to achieve accurate dimensional relationship between separate airfoil components in a turbine configuration, one method includes preforming blade components to exact dimensional shapes and thereafter assembling the individual blade components in a precisely shaped ring. Thereafter, the airfoil ring assembly is joined to a preformed hub of dissimilar material properties by hot isotatic pressure technology as is more specifically set forth in United States Patent No. 4,152,816, (Ewing, et al).

A composite turbine rotor according to the invention comprises a cast metal shell with an array of radial blades integrally formed thereon joined by a rim, said shell rim including a cylindrical bore at one end thereof and a conical cavity at the opposite end thereof, and a dense metal hub having its outer surface bonded to said rim, said hub including a radially flared back segment thereon congruent with the walls of said conical cavity and configured to optimize stress in said blades and in said hub during roation of the wheel.

One embodiment of the invention is an improved turbine rotor consisting of a cast airfoil shell of super alloy temperature-resistant material and a hot isostatically pressed powdered metal disc hub fitted in the cast airfoil shell by bonding and configured to combine desirable high temperature resistant properties of the airfoil materials and high strength of the disc hub as it is subjected to high stresses due to centrifugal loading and differential thermal expansion between the outer portions exposed to hot gas flow therethrough and cooler running center hub portions of the rotor.

In this embodiment of the present invention, a composite radial turbine rotor assembly includes a hub disc and a cast airfoil shell wherein the cast airfoil shell has an inner hub rim and a cascade of radial airfoils in an exact dimensional form to maintain desired aerodynamic flow paths therethrough and including a cavity therethrough of increasing diameter at the back plate surface of the shell into which is fitted a preformed accurately shaped hub disc having a conical skirt portion defining a stress resistant segment at the back of the hub, the slope of the flared skirt portion being configured to optimize the location of the high strength hub material and to achieve optimum blade and hub stress levels.

Another embodiment of the invention is a composite rotor including a forged titanium hub that is bonded to a cast titanium airfoil shell to combine desirable high temperature resistant properties of materials at the point of gas flow through the rotor and high stress resistance at the rim portion of the rotor hub when subjected to high stress levels because of centrifugal loading.

The invention and how it may be performed are hereinafter particularly described with reference to the accompanying drawings wherein a preferred embodiment of the present invention is clearly shown and in which:

Figure 1 is a longitudinal sectional view of a composite radial turbine rotor in accordance with the present invention;

Figure 2 is an elevational view of one end of the rotor wheel in Figure 1 looking in the direction of arrows 2—2;

Figure 3 is an end elevational view of the present invention from the opposite end thereof; and

Figure 4 is a plot of equivalent stress profiles in one embodiment of the invention.

The present invention, as shown in Figure 1, includes a cast, bladed air-cooled arifoil shell 10 having a constant diameter bore 12 at one end thereof and a conical cavity 14 at the opposite end thereof having a variable diameter from the constant diameter bore 12 to a rear wall segment 16 of the shell 10.

The invention further includes a powdered metal hub disc 18, preferably a powdered metal preform of consolidated PA—101 alloy composition as hereinafter described. The hub disc 18 includes a cylindrical nose portion 20 thereon and a conical skirt 22.

The plug nose 20 has a constant diameter outer surface 23 thereon that is press fitted into the constant diameter bore 12 within the cast air-cooled airfoil shell 10 and the flared conical end 22 of the hub disc 18 has a precisely machined conical surface 26 formed thereon that is congruent with the surface of the cavity 14 that is machined in the airfoil shell 10.

The shell 10 and the hub disc 18 have an interference fit formed therebetween to position a backplate segment 28 of hub disc 18 in alignment with the aft edges 29 of each of the resultant radial airfoil blades 30 on the shell 10. Each of the cast metal blades 30 includes an educer edge 32 thereon and an inducer 34 thereon joined by a radially outwardly curved tip 36 and joined together by a radially inwardly formed hub rim 38 joining each of the cast blades 30 of the shell 10 and defining hub surfaces 39 between each of the blades 30. In the illustrated arrangement, an air cooling passage is formed in each blade including an inlet opening 40 that is in communication with a source of cooling air 42 as formed between the rotor and an associated rotary seal assembly 44. The inlet 40 is in communication with internal cavities 46, 47 in each of the blades 30 thereof for exhaust of cooling fluid through a side slot 48 formed in each of the blades immediately upstream of the educer edge 32.

A metallurgical butt-type joint 50, shown in Figure 1, is formed between shell 10 and hub disc 18. Joint 50 has an axial annular segment 52, Figure 2, spaced in parallel relationship to the axis of the rotor. Joint 50 also includes a conical segment 54, seen in Figure 3, which defines a joint angle divergent from segment 52. The joint has excellent metallurgical joint integrity that is of high strength in tensile, stress rupture and low cycle fatigue testing. Microscopic evaluation of the joint 50 shows that the bond is continuous across shell 10 and disc 18.

Parent metal PA101 mechanical properties at room temperature and 1200°F (649°C) show that the backplate segment 28 of the composite turbine rotor has a strength equivalent to some of the strongest materials that are presently commercially available in rotor designs machined from forgings or integral castings.

A material composition suitable for forming the cast shell is listed in the following table and a material composition for forming the powdered metal hub disc is also listed in a following table. All components of these compositions are given as percentages by weight of the respective composition.

CAST SHELL —— Mar—M247, Composition

Alloy	C	Cr	Mo	Al	Ti	Co	W
Mar—M247	0.15	9.0	0.5	5.5	1.5	10.0	10.0
(cont'd)	Hf	Zr	B	Ta	Ni		
	1.35	0.05	0.015	3.1	Bal		

HUB DISC —— PA 101 Alloy Composition (IN 792 + Hf)

C	Cr	Co	Mo	W	Ta	Ti	Al	B	Zr	Hf	Ni
.15	12.6	9.0	2.0	4.0	4.0	4.0	3.5	.015	.10	1.0	Bal

Alternatively, the hub disc 18 can be formed from a forged titanium alloy and hot isotatic pressure (HIP) bonded to a cast titanium alloy shell 10 to produce a centrifugal compressor wheel.

The forged titanium hub is thus a high strength wrought configuration and has its outer surface configuration similar to the previously described hub disc 18 so that it will fit into a cavity machined into the titanium airfoil shell. The wrought portion of the joint, because of its high strength capabilities, is preferentially exposed to the highly stressed areas in the backplate segment of the overall rotor assembly as was the backplate segment 28 of the powdered metal plug 18.

Performance of radial turbine rotors of the type described above is limited by stress distribution therein. The equivalent stress conditions in a rotor limit the achievable tip speeds primarily because of an excessive tangential bore stress level, particularly in cases where there is a front drive power turbine shafting system that requires sizeable bore holes in a rotor such as shown at bore 56 through the hub disc 18. In order to provide required connection details and a bore diameter at the bore 56 and retain proper fatigue life and burst requirements, in accordance with the present invention, the composite arrangement requires wrought properties at the bore 56 in order to achieve maximum tip speeds at the airfoil blades 30 during rotor operation.

In accordance with the present invention, as seen best in Figures 1 and 4, the angle of the resultant joint 50 at the conical surface 26 of the hub disc 18 is an optimum contour which reflects the contour of the hub surface 39. The contour is selected to achieve an optimum balance between stress levels in the blades 30 and the hub disc 18 within limits defined by aerodynamic requirements. In Figure 4, the stress levels are indicated by lines labelled with letters ranging from A to G, lines designated A representing lowest stress levels of the order of 20,000 p.s.i. (137,895.2 kPa) and lines G representing highest stress levels of the order of 140,000 p.s.i. (695,266.4 kPa) with the intermediate stress levels being evenly distributed therebetween. The contour of the hub surface 39 is dispersed generally between stress line C corresponding to about 60,000 p.s.i. (4.3,685.6 kPa) and stress line B corresponding to about 40,000 p.s.i. (275,790.4 kPa).

The illustrated arrangement includes fully scalloped openings 58 between each of the blades 30 as viewed from the end of the rotor shown in Figure 3. Elimination of a backplate to the blades serves to reduce dead load on the hub disc and thus reduces disc stresses. While there is some penalty in efficiency because of the cut-off in the gas flow passage associated with the fully scalloped openings 58, the penalty is not severe since clearance losses at the vicinity of the scalloped openings 58 represent an offsetting efficiency increase because of reduction of losses due to backplate friction.

In the illustrated arrangement the radial blade taper is logarithmic. This thickness distribution provides the lowest taper ratio to achieve desired stress levels in the construction while minimizing dead load on the disc. The logarithmic blade taper eases aerodynamic design by minimizing the blade thickness and thus providing lower trailing edge blockage and lower passage velocity levels during gas flow through the rotor.

The composite nature of the illustrated rotor enables variable material properties to be used in the rotor that will yield greater life than a monolithic rotor of wrought design. The cast Mar—247 shell 10 has superior stress rupture properties and is a low cost method of fabrication. The inner hub disc 18 of PA 101 powdered metal material has higher strength and greater ductility and superior fatigue properties than an integrally cast wheel. The bonding of the hub disc 18 to the shell 10 enables two materials to be used in a bladed rotor without requiring a mechanical fastener detail therebetween.

The hub 38 of the illustrated rotor has an average tangential stress of 50,300 PSI (346,806 kPa) and an average operating temperature of 1,203°F (650°C). The inner portion of the wheel represented by the hub disc 18 has an average tangential stress of 79,300 PSI (546,754 kPa) in an average temperature of 1104°F (595°C). The higher strength, ductility and superior fatigue material of the hub disc 18 is located to traverse greater regions of higher stress than in the case of a constant diameter smaller diameter hub of the type heretofore used in composite rotor configurations.

In the case of centrifugal compressor designs, the utilization of investment cast titanium shells bonded to wrought titanium hubs results in a more cost effective design than would be possible if an equivalent design were to be produced by machining a monolithic forging due to the inherently superior shape making capabilities of the investment casting process used to produce the airfoil shell. By comparison to a conventional monolithic titanium casting, the composite rotor design would exhibit superior life at a modest cost penalty due to the inherently superior low cycle fatigue capabilities unique to the wrought hub.

CLAIMS

1. A composite turbine rotor comprising a cast metal shell with an array of radial blades integrally formed thereon joined by a rim, said shell rim including a cylindrical bore at one end thereof an a conical cavity at the opposite end thereof, and a dense metal hub having its outer surface bonded to said rim, said hub including a radially flared back segment thereon congruent with the walls of said conical cavity and configured to optimize stress in said blades and in said hub during rotation of the rotor.

2. A composite turbine rotor according to claim 1, in which said shell has full scallop-shaped openings between each of said blades extending to said rim to reduce dead load on said rotor hub.

3. A composite turbine rotor substantially as hereinafter particularly described, and as shown in Figures 1 to 4 of the accompanying drawings.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1981. Published by the Patent Office,
25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.