Nov. 3, 1953

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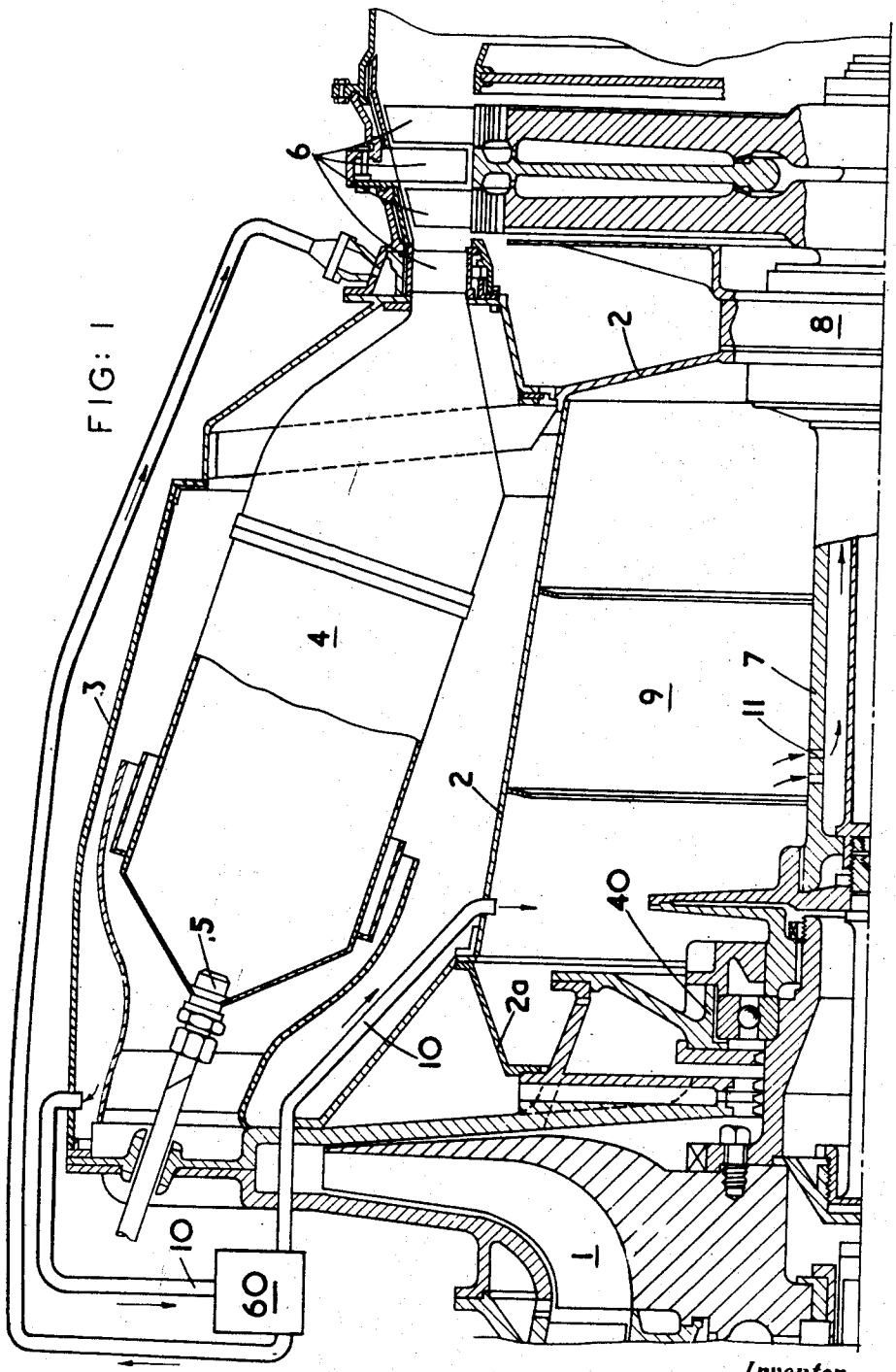
2,657,901

CONSTRUCTION OF TURBINE ROTORS

Filed June 4, 1946

4 Sheets-Sheet 1

FIG: 1



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CONSTRUCTION OF TURBINE ROTORS

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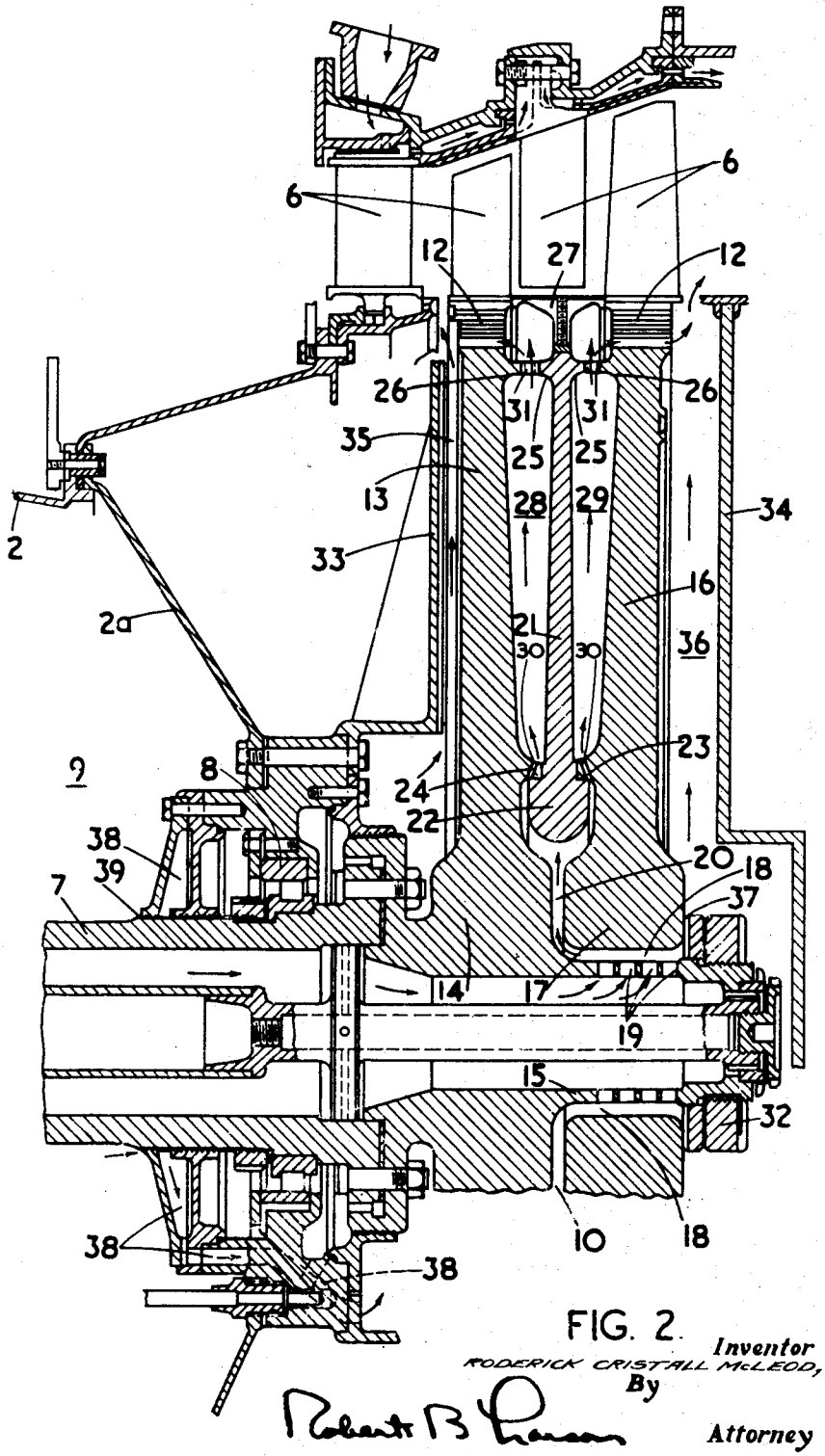


FIG. 2.

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CONSTRUCTION OF TURBINE ROTORS

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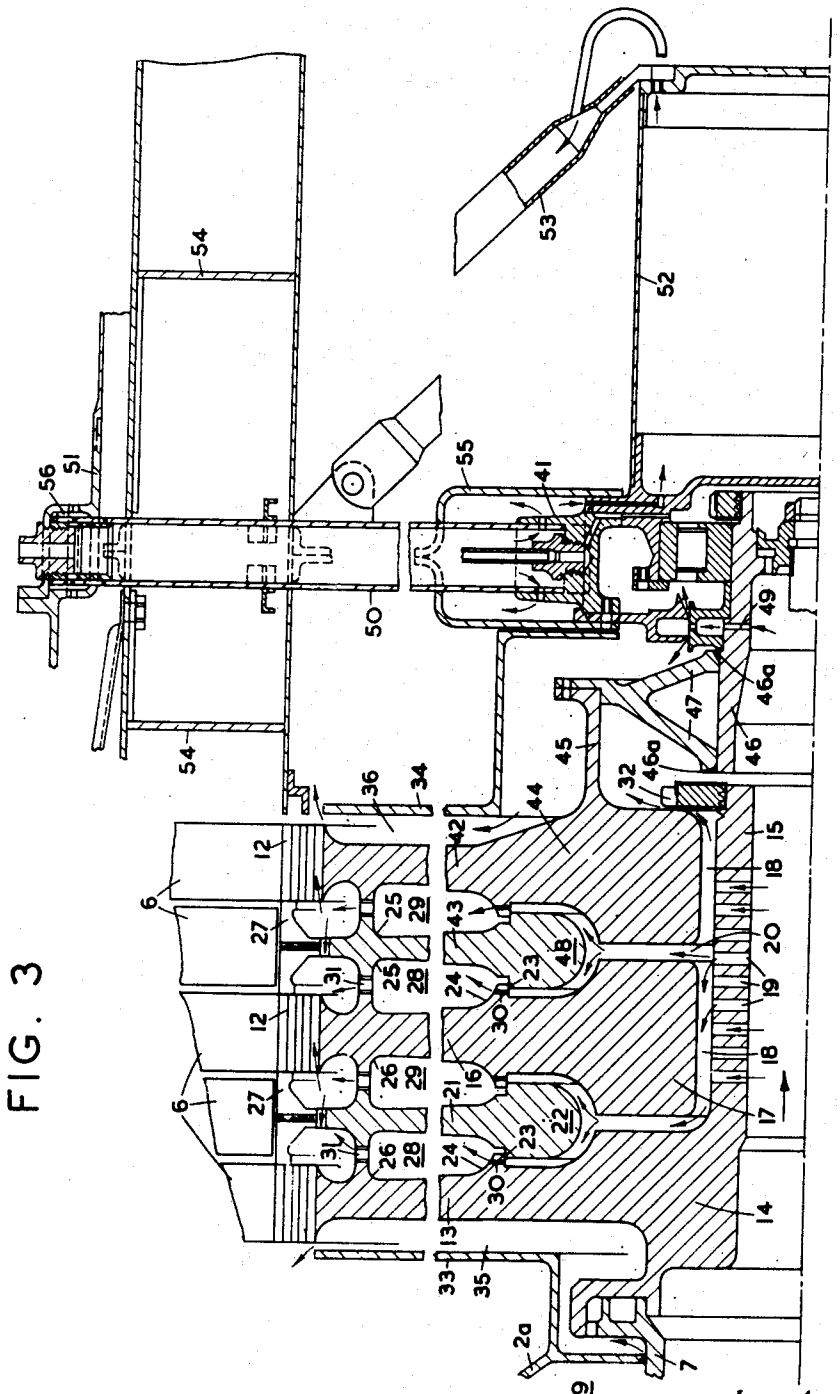


FIG. 3

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CONSTRUCTION OF TURBINE ROTORS

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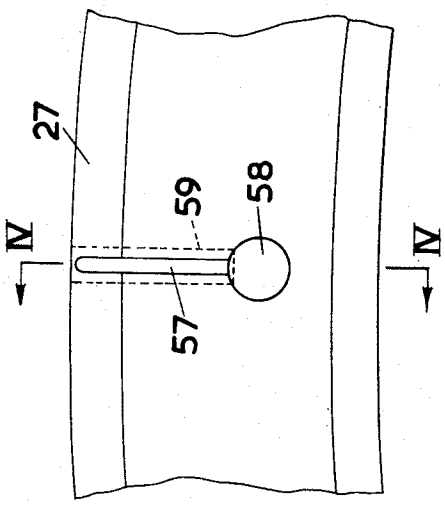


FIG. 5.

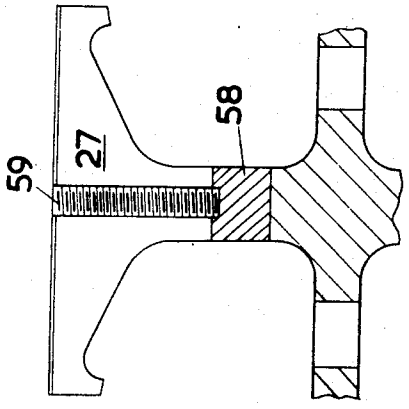


FIG. 4.

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Patented Nov. 3, 1953

2,657,901

UNITED STATES PATENT OFFICE

2,657,901

CONSTRUCTION OF TURBINE ROTORS

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Application June 4, 1946, Serial No. 674,229
Claims priority, application Great Britain June 8, 1945

7 Claims. (Cl. 253—39.15)

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This invention relates to the construction of multistage turbine rotors and whilst it is deemed to be especially applicable to gas turbines in which certain special problems of design may arise it is capable of being applied to other turbines also.

In turbines generally and in gas turbines in particular there are difficulties of design in relation to the appropriate disposition of stress-carrying structure in a multistage rotor, particularly if the rotor is required to operate at high speeds and is subject to marked temperature gradients and high temperatures at least locally. These design problems are particularly acute if it be required to minimize the weight of the turbine rotor as for example in the case of a gas turbine for aircraft use.

The invention accordingly has two main objects in view; firstly, to provide a multistage rotor whose stress-carrying structure is designed and arranged to afford adequate mechanical strength with economy in total mass; secondly, to provide adequate cooling to enable the temperature gradients as between different parts of the rotor to be kept within acceptable limits.

The invention is based upon an appreciation of the fact that the attainment of these objects can be facilitated by the use of a composite rotor built up from a plurality of individual blade-carrying discs or wheels, and has a number of aspects concerned with giving practical form to this basic conception.

Considered from one aspect, the invention provides a multistage turbine rotor consisting of or comprising two coaxial bladed wheel-type rotor elements axially abutting with a non-bladed intermediate wheel-type rotor element, whose rim preferably forms the rotor surface between said bladed elements, said intermediate and bladed elements having between them radially inter-engaging connecting means by which they are mutually located and supported in the radial sense relatively to one another.

In a further aspect of the invention, the two coaxial bladed rotor elements have between them an annular space which is divided by the intermediate rotor element against which they abut to define separate annular cavities, these cavities being associated with ducting at an inner radius for the entry of cooling air and with ducting at a greater radius, preferably in the region of the blade roots, for the egress of such air.

According to a further feature of the last-mentioned aspect of the invention, the internal cooling of the rotor is associated with cooling of

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its external faces and bearing, for which purpose the upstream and downstream external faces have adjacent thereto stationary structure defining with each face a narrow annular cavity having a supply of cooling air entering at a radially inner diameter and leaving at a greater diameter, preferably in the region of the blade roots.

It is necessary that provision should be made for holding all the elements together in the axial sense and this, according to a further feature of the invention, is achieved by providing an axial extension on the hub of the bladed element at one end of the rotor which passes through the hub of the bladed element or each further bladed element and the spacing element or each spacing element and has a nut or other retaining means at its free end.

According to a further feature of the invention, some, but not all the elements of the rotor are self-supporting in relation to centrifugal load, and such self-supporting elements are used to give centrifugal support to those which are not self-supporting.

The invention in its various aspects may be applied either to an overhung multistage turbine rotor (that is, one which has a bearing support at one end only), or to one having a bearing support at each end, and a number of further features of the invention arising from these two applications thereof will appear from the following description of the two examples of construction, one an overhung rotor and the other not, illustrated in the accompanying drawings in which:

Figure 1 is a longitudinal half section of part of an aircraft gas turbine power unit embodying an overhung two stage rotor constructed according to the invention, sufficient parts of the unit being shown to illustrate the relation of the turbine rotor to the other elements of the unit;

Figure 2 is a section on a larger scale of the rotor illustrated in Figure 1, and its bearing support;

Figure 3 is a view generally similar to Figure 2, but illustrates the inveniton applied to a three stage rotor supported at both ends and suitable for inclusion in a power unit of the general form illustrated in Figure 1;

Figure 4 is a detail view of the rotors shown in Figures 2 and 3; and

Figure 5 is an end view of the arrangement shown in Figure 4.

The small arrows throughout the drawings represent the direction of flow of cooling air.

Referring first to Figure 1, the power unit to which the rotor according to the invention is shown as being applied comprises a compressor 1 (of which only thet last stage is shown) supplying air to an annular air casing afforded by inner and outer annuli 2, 3, and containing an annularly disposed set of flame tubes 4 into which fuel is injected by burners 5. The products of combustion are discharged through blading 6 of a two stage axial flow turbine whose rotor is mounted on and drives the compressor 1 through a shaft 7. It will be noted that the turbine rotor is overhung, that is to say, it is supported only at one end, in this case by the shaft bearing 8 at its upstream end.

The inner annulus 2, together with its associated end structure 2a, forms an enclosed chamber 9 whose atmosphere is maintained under pressure by air taken from the aircasing by connections 10 through cooler 60, whilst the shaft 7 is hollow to form an air duct and is ported at 11 to communicate with the chamber 9.

The features so far described and illustrated are intended merely to give the general background or framework of a power unit to which the invention may be applied and do not in themselves form a part of the invention except in so far as they afford a means of supplying air for cooling purposes to the turbine rotor and its bearing, to which function further reference is made below.

Considering now in more detail the rotor and rotor mounting construction illustrated in Figure 2, the first stage blading is carried, preferably by serrated roots 12, in complementary axial slots by a first rotor element in the form of a wheel 13 which has a relatively massive hub 14 bolted to an end flange on the turbine shaft 7. This hub 14 has a coaxial extension 15 towards the downstream side, i. e. away from the shaft 7. The second stage blading is similarly carried on a second rotor element or wheel 16 which has a somewhat less massive hub 17 centrally bored so as to surround the extension 15 of the first hub and to leave an annular clearance at 18 forming a coolant duct. The axial extension 15 is radially ported at 19 for the passage of coolant air from within its hollow interior (to which compressed air is supplied from the chamber 9 by the ports 11) into the annular duct 18. The two hubs are spaced axially to form radial coolant ducting at 20 in continuation of the annular duct. Between the two blade-carrying wheels 13, 16, a third much lighter intermediate rotor element or wheel 21 is situated. This third wheel has at its inner margin a thickened hub or rim 22 provided with accurately machined radially facing steps or surfaces 23 which are fitted in engagement with complementary inwardly facing circular surfaces formed on flanges 24 projecting axially from the mutually facing sides of the first two wheels 13, 16. The fit between these respective surfaces is preferably a shrink fit and the object of the construction at this point is to afford radially locating engagement between the two blade carrying wheels 13, 16, whereby the wheel 16 is radially located relative to the wheel 13, whilst simultaneously the third wheel 21 is radially located relatively to both. The third wheel 21 extends outwardly and preferably with a tapered section to the region of the blade roots and at a radius just less than the minimum root radius has on each of its sides flanges 25 extending axially which are serrated to engage corresponding flanges 26 extending inwardly from the blade

carrying wheels 13, 16. This engagement is for the transmission of torque between the two blade-carrying wheels and does not take part in their radial location relatively to the wheel 21. Still further outwardly the third wheel extends to its periphery at which it has a T sectioned rim 27 to form a peripheral cylindrical surface which forms the inner fluid guiding surface of the turbine annulus between the two rotor blade stages. This rim may incidentally serve as the inward abutment of the turbine blade roots 12, preventing their shifting axially in that sense.

The third wheel 21 partitions the interior space enclosed by the first two wheels 13, 16, into upstream and downstream cavities 28, 29, of annular form, the air ducting at 20 previously referred to being thus split into two by the hub 22. Passages 30 are formed through the locating flanges 24 for the passage of air outwards through the two cavities 28, 29. These passages may be differently proportioned to act as restrictions controlling the pressure of the air in the cavities 28, 29. For example it may be arranged that the cavity 28 will be maintained at a pressure of approximately twice that of the cavity 29 for a reason mentioned later. The torque-transmitting flanges 26 are also provided with air passages 31 by appropriate clearances between their serrations, and still further passages are provided in or in the region of the fitting of the blade roots to the wheels, for example beneath the roots as shown. The coolant air is therefore passed from the cavities 28, 29, over the somewhat extensive areas of the structure formed by the serrations or dogs and thence through the root passages. The air from the upstream cavity 28 emerges on the upstream side of the first wheel 13 and escapes radially outwardly into the turbine annulus; the reason that the pressure at which this air is delivered is maintained high, is in order to avert any possibility of reversal of flow, i. e. from the turbine annulus into the turbine rotor chamber. The air pressure is of course selected to ensure airflow in the desired sense. The air from the cavity 29 emerges by a similar route to be discharged on the downstream side of the turbine where it leaks outwardly to join the exhaust from the turbine.

The wheels 13, 16, 21 are kept together axially by a lock nut arrangement 32 on the hub extension 15 of the wheel 13.

It will be appreciated from the foregoing that although the first wheel 13 is fixed in both the axial and the radial sense on the shaft 7, the relative positioning of all the wheels, 13, 16, 21, in the radial sense is determined solely by the complementary interengagement of the flanges 24 on the wheels 13, 16, with the surfaces 23 on the wheel 21, by means of which the wheels 16, 21, are mutually located in the radial sense relatively to one another and upon the wheel 13.

It is a further feature of the construction that the hubs 14, 17, are made self-supporting in relation to centrifugal load and are used to give centrifugal support through the flanges 24 and faces 23 to the hub 22 which, accordingly, is not made to be centrifugally self-supporting. By this means, use is made of the relatively large mass of the hubs 14, 17, to afford adequate anchorage for the hub 22. Further, as the interengaging parts 23, 24, are at a small radius there is an advantageous concentration of mass near the centre of rotation. With such an arrangement the hub 22 would be more highly stressed than the hubs 14, 17, so that under running conditions

the faces 23 tend to expand under centrifugal action against the flanges 24. Preferably, as shown, the support thus afforded to the wheel 21 is augmented by dishing the wheels 13, 16, to offset their centres of mass in a sense such as to produce, under running conditions, a centrifugally induced bending moment acting radially inwardly of the rotor at the flanges 24.

In addition to the internal air cooling afforded by the flow through the ducts and chambers 18, 28, 29, the rotor end faces are also cooled by providing adjacent to the upstream and downstream faces stationary partitions 33, 34, respectively which form parts of the general turbine structure and define with the rotor faces narrow annular cavities 35, 36, terminating peripherally at or near the outlets to the working fluid stream. Provision is made for a radially outward flow of air through each of these cavities, the supply to the cavity 36 being taken from the duct 18 surrounding the hollow hub extension 15 by way of ducts 37 in the lock nut assembly 32, and that to the cavity 35 from the chamber 9 by way of channels 38 in the bearing structure 8. In this latter connection, the bearing structure 8 has its channels 38, as far as practicable, distributed annularly around it to enclose the bearing parts proper and thus also cool these parts. The forward end of the bearing structure 8 is disposed and subjected to the pressure in the chamber 9 and restricted entry of air to the bearing structure is allowed by a pressure seal at 39 between the bearing structure and shaft 7; the channels 38, on the other hand, are of generous dimensions, thus eliminating any tendency for air to blow the lubricant out of the bearing parts proper.

The construction illustrated in Figure 3 differs from that illustrated in Figures 1 and 2 primarily in that the rotor is not overhung but is supported at each end, the forward support being by a bearing corresponding to the bearing 40 of Figure 1, and the rear support by a bearing structure 41 described more fully below, the bearing 8 of Figures 1 and 2 being omitted. The rotor is for three blade stages and so far as the first two stages are concerned follows closely the construction already described with reference to Figure 2 in that it again employs first and second bladed wheel elements 13, 16, and an intermediate element 21. The wheel 16 in this case, however, has its axial cross section symmetrical about a radial plane and is followed by a third bladed wheel 42 whose centre of mass is offset for the purpose already described and which is spaced from the wheel 16 by a further intermediate wheel element 43. The wheel 42 has a centrifugally self-supporting hub 44 which has an annular axial extension flange 45 which is supported from a hollow journal member 46 of smaller dameter by a stiff radially extending flange on the latter formed by annular frusto-conical walls 47 oppositely tapered to afford, in axial section, a triangular structure based on the bearer member 46 and secured thereto by welding at 46a. The hub 44 of the wheel 42 also has a clearance from the extension 15 of the wheel 13, which in this case passes through the wheel 42 as well as the wheel 16 and again has a retaining nut 32. The formation and mutual relationship of the individual wheels of the pairs 42, 43; and 13, 21, respectively, to each other and to the second wheel 16 is the same. The radial location of all the wheels relative to each other is thus determined solely by the interengagement of their parts 23, 24, whilst the intermediate wheel 43 is supported against centrifugal load by the wheels 16, 42, so that its hub 48 is not made centrifugally self-supporting.

The internal cooling of the rotor, except for additional cavities 28, 29, between the wheel 43 and the wheels 16, 42, and corresponding ducting 20 communicating therewith is identical with that illustrated in Figures 1 and 2. There is, however, in this case, the possibility of arranging different paths for the outlet of air from between the wheel 16 and the wheels 21, 43; either there may be no air passages through the blade root mountings of the wheel 16, and air on opposite sides thereof is allowed to pass through both the wheels 21, 43; or such passages may be provided and only one of the wheels 21, 43, allow air to pass. For cooling the end faces of the rotor, air guides are again formed by stationary partitions 33, 34; in this case, however, since the bearing 8 is absent, the partition 33 is suitably supported from the inner aircasing structure 2a and makes a seal with the shaft which permits controlled leakage from the chamber 9 to the channel 35. The partition 34 is supported on the bearing housing 41 and receives its cooling air supply by leakage from that housing as indicated by the arrows, the hollow interior of the housing being supplied with air through the shaft 7 and journal 46 by way of ports 49.

It is necessary, in order to avoid undue shaft vibration at the critical speed, that the shaft should have adequate stiffness and also that the shaft bearing should offer rigid support. The mounting of the wheel 42 by means of its extension 45 and the double-conical flange 47 on the journal 46 of less diameter enables the first of these requirements to be satisfied in an advantageous manner since it permits the effect to be obtained of a large-diameter shaft without involving a large diameter bearing. Rigidity of support is obtained by attaching the bearing housing 41 to a plurality (e. g. six) of radial spokes 50 whose outer ends are mounted in the main outer casing 51 of the power unit, and by providing on the housing 41 a tubular, axially rearward (downstream) extension 52, whose end is anchored by tie members 53 to radially outer points of the spokes 50, the whole thus forming an extremely rigid structure. The spokes 50, where they pass through the working fluid channel, are enclosed by walls forming a splitter 54 of more or less streamlined construction and the housing 41 is enclosed by a hollow shroud 55 which contributes to the stiffness of the structure.

By the use of hollow components for the spokes 50, housing 41, extension 52, and tie members 53, these parts are enabled to be air cooled, for which purpose the outer ends of the spokes 50 are, in the case illustrated, enclosed in a chamber 56 of the main casing 51 to which compressed air is supplied from a convenient point of the unit, the air then passing through the spokes 50 and to the other components, as indicated by the arrows, by way of suitably arranged ports and connections.

It will be appreciated that the constructions described and illustrated will have not only an excellent strength/weight ratio, with advantageous concentration of mass near the axis of rotation, but also lend themselves in a high degree to the elimination of undesirable temperature gradients in the various parts; it is, in fact, possible to reduce these gradients to acceptable values except at the extreme rim region

of the intermediate wheels 21, 43. Due to their direct exposure to the hot working gas stream, these rims are necessarily at the temperature of the latter, and since they are not interrupted, as are the rims of the wheels 13, 16, 42, by blade root mountings which will usually allow a sufficient degree of thermal expansion to avoid unacceptable thermal stresses, special provision is necessary to avoid such stresses therein. To this end the rims 27 of the wheels 21, 43, may have applied thereto the subject matter of our co-pending patent application number 665,106 filed April 26, 1946, now Patent No. 2,623,727 of December 30, 1952, in the name of the inventor in the present application, in accordance with which the rims 27 of the wheels 21, 43, have radially extending slits as at 57 which are peripherally closed by lips susceptible of crushing when expansion of the rims takes place. Where it is necessary, owing to the existence of differential air pressures on opposite sides of the wheels 21, 43, to limit leakage in an undesired direction through the slits 57, the latter are sealed as by loosely fitting plugs 58 and screws 59.

I claim:

1. A multistage turbine rotor designed for overhung mounting, comprising a rotary bearer member, a first bladed rotor element of substantially disc-form fixed in both the axial and the radial sense on said rotary bearer member, a further coaxial and substantially disc-form bladed rotary element, a non-bladed substantially disc-form intermediate rotor element arranged between said bladed elements, said intermediate element having a peripheral portion on either side thereof in axial abutment with the bladed elements to permit relative sliding movement in a radial direction due to thermal expansion and contraction, and said intermediate and further rotor elements each having an axial bore, means providing between said intermediate element and both the bladed elements complementary interengagment by which alone said intermediate element and the further bladed element are mutually located and supported in the radial sense relatively to one another and upon the first bladed element, and tensioning means extending from said first element through said axial bores with radial clearance therein to retain said intermediate and further elements against axial displacement.

2. A multistage turbine rotor designed for bearing support at each end, comprising a first rotary bearer member, a first bladed rotor element of substantially disc form fixed in both the axial and the radial sense on said rotary bearer member, at least one further coaxial and substantially disc-form bladed rotor element, a non-bladed and substantially disc-form intermediate spacing rotor element arranged between any one of said bladed elements and the one adjacent to it, said intermediate element having a peripheral portion on either side thereof in axial abutment with said bladed elements, and said intermediate and further elements each having an axial bore, means providing between such intermediate element and its abutting bladed elements complementary interengagement by which it and said elements are mutually located and supported in the radial sense relatively to one another, tensioning means extending from said first element through said axial bores with radial clearance therein to retain said intermediate and further elements against axial displacement, and a second rotary bearer member nominally coaxial with but separate from the bearer member of the first bladed element and from said tensioning means and upon which the last bladed element in the succession is fixed in both the axial and the radial sense.

3. A multistage turbine rotor as defined in claim 2, wherein said tensioning means comprises, for holding all the elements together in the axial sense, an axial extension from the hub of the bladed element at one end of the rotor which passes with a radial clearance through the hub of each further bladed element and each spacing element, and retaining means at the free end of said extension.

4. A multistage turbine rotor designed for bearing support at each end, comprising a first rotary bearer member, a first bladed rotor element of substantially disc-form fixed in both the axial and the radial sense on said rotary bearer member, at least one further coaxial and substantially disc-form bladed rotor element, a non-bladed and substantially disc-form intermediate spacing rotor element arranged between and in axially abutting relationship at both its central and peripheral regions with any one of said bladed elements and the one adjacent to it, said intermediate and further elements each having an axial bore, means providing between such intermediate element and its abutting bladed elements complementary interengagement by which it and said elements are mutually located and supported in the radial sense relatively to one another, tensioning means extending from said first element through said axial bores with radial clearance therein to retain said intermediate and further elements against axial displacement, said tensioning means comprising an axial extension from the hub of the bladed element at one end of the rotor and passing with a radial clearance through the hub of each further bladed element and each spacing element, and retaining means at the free end of said extension, a second rotary bearer member nominally coaxial with but separate from the bearer member of the first bladed element and from said tensioning means and upon which the last bladed element in the succession is fixed in both the axial and the radial sense, and means for passing coolant fluid through said axial extension into said radial clearance and thence into the space on either side of said intermediate elements.

5. A multistage turbine rotor designed for overhung mounting, comprising a rotary bearer member, a first bladed rotor element of substantially disc-form fixed in both the axial and the radial sense on said rotary bearer member, a further coaxial and substantially disc-form bladed rotor element, a non-bladed substantially disc-form intermediate rotor element arranged between and in axially abutting relationship at its peripheral regions with said bladed elements, said intermediate and further elements each having an axial bore, means providing between said intermediate element and both the bladed elements complementary interengagement by which alone said intermediate element and said further bladed element are mutually located and supported relative to one another and upon the first bladed element, an axial extension from the hub of said first-mentioned bladed element which passes with a radial clearance through the axial bores of said intermediate and further elements and retaining means at the free end of the extension to retain

said intermediate and further elements against axial displacement.

6. A multistage turbine rotor comprising a first and second bladed rotor element of substantially disc-form having between them an annular space, a non-bladed substantially disc-form intermediate rotor element lying between said bladed elements to divide said annular space into separate annular cavities and abutting with said bladed elements at both its central and peripheral regions, said second and intermediate elements each having an axial bore, a shaft extending from said first rotor element through said axial bores with radial clearance and retaining means at the end of said shaft to retain said intermediate and second rotor elements against axial displacement, and means for the entry of air to the cavities of said rotor, said last named means including ducting afforded in the shaft and by spaces between the hubs of the rotor elements.

7. A multistage turbine rotor designed for overhung mounting, comprising a rotary bearer member, a first bladed rotor element of substantially disc-form fixed in both the axial and the radial sense on said rotary bearer member, a further coaxial and substantially disc-form bladed rotary element, a non-bladed substantially disc-form intermediate rotor element arranged between said bladed elements, said intermediate element having a peripheral portion on either side thereof in axial abutment with the bladed elements, and said intermediate and further rotor elements each having an axial bore, means providing between said intermediate element and both the bladed elements complementary interengagement by which alone said intermediate element and the

further bladed element are mutually located and supported in the radial sense relatively to one another and upon the first bladed element, an axial extension from the hub of the first bladed element extending through said axial bores with radial clearance therein, retaining means at the free end of said extension to retain said intermediate and further elements against axial displacement, and means for passing coolant fluid through said axial extension into said radial clearance and thence in to the space on either side of said intermediate element.

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