(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 013 894 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
28.06.2000 Bulletin 2000/26

(51) Int Cl.[7]: **F01D 21/04**, F01D 11/12, F01D 25/24

(21) Application number: **99310555.0**

(22) Date of filing: **23.12.1999**

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **23.12.1998 US 220544**

(71) Applicant: **UNITED TECHNOLOGIES CORPORATION**
Hartford, CT 06101 (US)

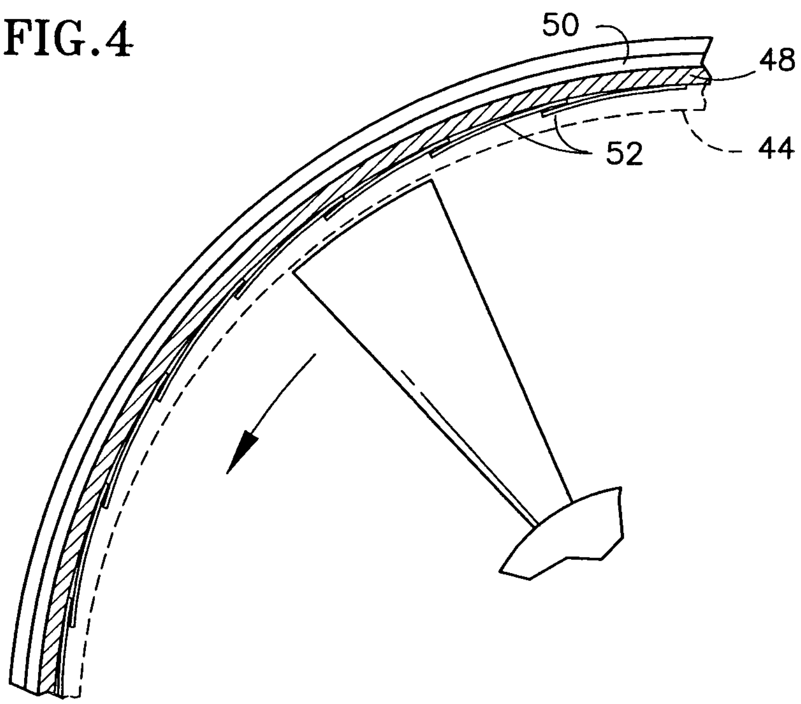
(72) Inventor: **Van Duyn, Keven G.**
Bloomfield, CT 06002 (US)

(74) Representative: **Leckey, David Herbert**
Frank B. Dehn & Co.,
European Patent Attorneys,
179 Queen Victoria Street
London EC4V 4EL (GB)

(54) Fan case liner

(57) A fan case 48 in a gas turbine engine has a radial zone of interaction 60 bounded outwardly by a fan case surface 53. Hardened structure 42 such as overlapping shingles is disposed in the zone 60. The zone 60 is less than one hundredth of the fan case diameter as measured from the blade tips 38 in a non-operative, zero speed engine condition and is such that during a high rotor imbalance condition, the blade tips 38 skid on the hardened structure 42 and reduce the destructive cutting away of the fan case, and reduce torque and imbalance loads transmitted to the interface of the engine and the aircraft.

FIG.4



EP 1 013 894 A2

Description

[0001] The present invention relates to gas turbine engines, and more particularly, to providing a hardened liner in the fan case of the engine to reduce damage to the fan case and support structure in the event of a high rotor imbalance condition, such as a fan blade loss.

[0002] A gas turbine engine, such as a turbofan engine for an aircraft, includes a fan section, a compression section, a combustion section, and a turbine section. An axis of the engine is centrally disposed within the engine, and extends longitudinally through these sections. A primary flow path for working medium gases extends axially through the engine. A secondary flow path for working medium gases extends parallel to and radially outward of the primary flow path.

[0003] During operation, the fan draws air into the engine. The fan raises the pressure of the air drawn along the secondary flow path, thus producing useful thrust. The air drawn along the primary flow path into the compressor section is compressed. The compressed air is channeled to the combustor section, where fuel is added to the compressed air, and the air-fuel mixture is burned. The products of combustion are discharged to the turbine section. The turbine section extracts work from these products to power the fan and compressor. Any energy from the products of combustion not needed to drive the fan and compressor contributes to useful thrust.

[0004] The fan section includes a rotor assembly and a stator assembly. The rotor assembly of the fan includes a rotor disk and a plurality of outwardly extending rotor blades. Each rotor blade includes an airfoil portion, a root portion, and a tip portion. The airfoil portion extends through the flow path and interacts with the working medium gases to transfer energy between the rotor blade and working medium gases. The stator assembly includes a fan containment case assembly, which circumscribes the rotor assembly in close proximity to the tips of the rotor blades. The fan containment case assembly includes a fan case which provides a support structure, a plurality of fabric wraps disposed radially outwardly of the fan case, a plurality of circumferentially adjacent acoustic panels and a plurality of circumferentially adjacent rub strips disposed radially inwardly of the fan case. Conventional fan cases are typically a solid metal casing which forms a rigid structure to support the fabric wraps. The plurality of rub strips are formed from a relatively compliant material. In the event that the tip of a fan blade makes contact with the rub strips, the compliance of the rub strips minimizes the risks of damage to the fan blade.

[0005] There are two specific clearances between the fan blade tips and the fan containment case assembly which are of importance. The first one is characterized as a performance clearance and is defined as the clearance between the blade tips and the soft rub strip in the inner surface of the fan case. The performance clearance is measured for a fan blade during a steady state cruise condition with the rotor in an undisturbed position, i.e. with the axis of the fan rotor being concentric with the engine centerline. The second clearance is characterized as an effective structural clearance and is defined as the clearance between the blade tips and a hard metallic surface in the fan case. The structural clearance is measured for a fan blade in its non-operative condition. The present invention is concerned with this structural clearance, as opposed to the performance clearance.

[0006] Severe rotor imbalance can occur in an engine, particularly after a fan blade breaks off from the rotor assembly. One cause of fan blade loss is impact with foreign objects, such as birds, hailstones or other objects which, on occasion, are ingested into the engine. The detached fan blade is thrown outwardly and passes through the fan case, but is typically caught by the fabric wraps in the fan containment case assembly. Blade loss produces an imbalance in the rotor and causes the rotor shaft to deflect radially outwardly. Deflection of the rotor away from its longitudinal axis may also lead to additional damage to the rotor assembly. The more the rotor deflects, the greater is the radial load on the rotor bearing supports.

[0007] The fan case structure stops the deflection of the rotor assembly. The damage to the rotor assembly is reduced by decreasing the fan tip-to-case clearance as the shaft deflection is limited by the proximal portion of the fan case assembly. Minimizing the amount of radial deflection of the shaft minimizes the likelihood of damage occurring in the shaft, the rotor bearings and the bearing support structures.

[0008] Heretofore, the deflection of the shaft was restrained by the fan blades embedding themselves in the fan case. In doing so, the fan blades rapidly cut away and destroy the fan case because the blades are usually of a harder material than the fan case. As the fan blades continue to rotate, they couple with the static fan case structure and transmit the kinetic energy of the rotor shaft to the case, causing twisting of and damage to the case. Due to the coupling of the rotor shaft with the fan case, high torque loads are transmitted to the fan case. This torque loading of the fan case during a fan blade loss event, results in tremendous loads being imposed upon the related engine mounts and engine case structure.

[0009] Thus, the challenge for modern gas turbine engines, during high rotor imbalance conditions, such as fan blade loss events, is the limiting of the rotor shaft deflection while reducing the torque loading of the fan case from the rotor shaft kinetics.

[0010] This invention is in part predicated on the recognition that by constraining the interaction of fan blade tips and the fan case to a predetermined radial zone in which is disposed hardened structure, there is a decrease of the loads transmitted to the interfaces of the engine by approximately the same percentage of the loads transmitted to the interfaces of the aircraft, and will allow an additional factor of safety during an abnormal imbalance condition of the rotor assembly.

[0011] According to the present invention, a fan case in a gas turbine engine has a radial zone of interaction bounded outwardly by an inwardly facing surface, preferably a hardened metallic surface, of the fan case, the zone being a clearance which is less than one hundredth of the fan case diameter measured from the blade tips in a non-operative, zero speed engine condition with the rotor centered, a hardened structure disposed in the zone, such that during a high rotor imbalance condition, the blade tips skid on the hardened structure and reduce the destructive cutting away of the fan case, and reduce torque and imbalance loads transmitted to the interface of the engine and the aircraft.

[0012] In accordance with one particular embodiment of the invention, the optimal radial zone of clearance is defined as a constant approximately five thousandths (0.005) of the fan case diameter.

[0013] In accordance with one particular embodiment of the invention, the lower limit of the radial zone of clearance is defined as a constant approximately two and one half thousandths (0.0025) of the fan case diameter, below which fan blades would destroy themselves due to high interaction loads between the fan blades and the fan case.

[0014] In accordance with another embodiment of the invention, the structural clearance lies in a range of 0.20 inches to 1.25 inches (5 mm to 32 mm) for corresponding jet engine fan case diameters which lie in a range of 20 inches to 120 inches (0.5 m to 3.05 m).

[0015] The hardened structure or material is preferably a liner which provides a skid-surface for the blades to circumferentially glide on and thus minimizes torque loading of the fan case. Further, the fan case structure limits the deflection of the rotor shaft during a fan blade loss event. In one embodiment of the invention, the liner of the present invention comprises shingles of hardened material.

[0016] A primary advantage of the present invention is the minimization of damage to the fan case thus, resulting in a durable fan case in the event of a fan blade loss. The hardened fan case liner of the present invention reduces the destructive cutting away of the fan case by the fan blades. A further advantage of the fan case of the present invention is its ability to provide an appropriate restraining structure to the deflection of the rotor shaft during a fan blade loss event. In addition, the hardened liner reduces frictional forces and therefore, the torque transmitted from the rotor to the engine cases. Another advantage is the ease and cost of manufacturing and incorporating into the fan case the liner of the present invention. The simplicity of the structure of the liner and the use of economic materials, allows for cost effective manufacturing processes. Further, fan cases of the prior art can be retrofitted to include the present invention in a cost-effective manner.

[0017] Some preferred embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

[0018] FIG. 1 is a perspective view of a typical axial flow, turbofan gas turbine engine.

[0019] FIG. 2 is a perspective view of the rotor assembly of the prior art showing a released fan blade.

[0020] FIG. 3 is a cross-sectional schematic representation of the fan containment case assembly a fan case of the present invention taken along the lines 3-3 of FIG. 2.

[0021] FIG. 4 is a schematic representation of a fan case liner of the present invention under operating conditions.

[0022] FIG. 5 is a schematic representation of an alternate embodiment of the fan case liner of the present invention.

[0023] FIG. 6 is a schematic representation of the radial zone of interaction between the fan blade tips and the hardened inner surface of a fan case of the present invention.

[0024] FIG. 7 is a graphical representation of normalized engine interface loads versus the ratio of the structural clearance to the fan case diameter.

[0025] Referring to FIG. 1, an axial flow, turbofan gas turbine engine 10 comprises a fan section 14, a compressor section 16, a combustor section 18 and a turbine section 20. An axis of the engine Ar is centrally disposed within the engine and extends longitudinally through these sections. A primary flow path 22 for working medium gases extends longitudinally along the axis A_r. The secondary flow path 24 for working medium gases extends parallel to and radially outward of the primary flow path 22.

[0026] The fan section 14 includes a stator assembly 27 and a rotor assembly 28. The stator assembly has a fan containment case assembly 30 which forms the outer wall of the secondary flow path 24. The rotor assembly 28 includes a rotor disk 32 and a plurality of rotor blades 34. Each rotor blade 34 extends outwardly from the rotor disk 32 across the working medium flow paths 22 and 24 into proximity with the fan containment case assembly 30. Each rotor blade 34 has a root portion 36, an opposed tip 38, and a midspan portion 40 extending therebetween.

[0027] Referring to FIG. 3, a fan case liner 42 of the present invention is disposed in the fan containment case assembly 30. The fan containment case assembly circumscribes the rotor assembly 28 in close proximity to the tips 38 of the rotor blades 34. The containment case assembly 30 includes a liner 42, a plurality of circumferentially adjacent rub strips 44 and a plurality of circumferentially adjacent acoustic panels 46 disposed radially inwardly of a support structure or a fan case 48. A plurality of fabric wraps 50 are disposed radially outwardly of the fan case. The fan case is typically a solid metal casing which forms a rigid structure to support the fabric wraps. The term "fabric" 50 includes, but is not limited to, tape, woven material or the like, and restrains a fan blade in the event of a fan blade loss. The rub strips 44 are formed from a relatively compliant material. The rub strips 44 permit the fan blades 34 to be in close proximity to the fan case to minimize the amount of air that flows around the fan blades, thus reducing fluid flow leakage around the fan blades to improve fan performance. In the event that the tip 38 of a fan blade 34 makes contact with the rub strips 44, the compliance of the rub strips minimizes the risk of damage to the fan blade 34.

[0028] The fan case liner 42, is made from hardened material such as from alloys of stainless steel or nickel. The nickel alloy Inconel 718, or stainless steel alloys, such as AISI 321 or AISI 347, are examples of alloys that can be used to manufacture the liner. The liner is thus manufactured from material that is harder than the fan blade tip material which is typically titanium. For ease of installation, the liner could be manufactured as arced segments, which can then be bonded to the fan case.

[0029] Referring to FIG. 4, a segmented fan case liner of the present invention is disposed radially outwardly of the rub strip 44 in the fan containment case assembly 30. Each segment 52 or shingle is offset from its adjacent shingle, yet there is an overlap region 54, shown clearly in FIG. 5, between adjacent shingles. As shown in FIG. 5, the fan case liner 42 is attached to the fan case 48 by either rivets 56, or adhesives as shown in FIG. 4. The rivets 56 are located in the overlap region 54 between adjacent shingles.

[0030] Referring to FIG. 6, the radial zone of interaction 60 of the present invention is a clearance bounded inwardly by the blade tips 38 in a non-operative, zero speed engine condition with the rotor centered about the engine centerline and the blades in their engaged position with the rotor. The radial zone of interaction 60 is bounded outwardly by the hardened inner surface 53 of the fan case 48. The radial zone of interaction is referred to hereinafter as the structural clearance. The hardened liner 42 is disposed in the radial zone of interaction. The structural clearance 60 is less than one hundredth of the fan case diameter. The optimal structural clearance measured from the fan blade tips is about five thousandths (0.005) of the fan case diameter. The lower limit of the radial zone of clearance is defined as a constant approximately two and one half thousandths (0.0025) of the fan case diameter, below which fan blades would destroy themselves. The fan blade tips may be compromised by the bending or buckling of the tips if the interaction loads between the fan blade tips and the fan case are increased by reducing the structural clearance to a value of about zero.

[0031] Another clearance, referred to as the performance clearance 64 is defined as the clearance between the fan blade tips and the soft rubstrip 44 disposed in the inner surface of the fan case 48. The performance clearance is measured for a fan blade during a steady state cruise condition with the rotor in an undisturbed position, i.e. with the axis of the fan rotor being concentric with the engine centerline. The performance clearance is positioned within the structural clearance and is typically less than the optimal structural clearance. The soft rubstrip provides sealing during engine maneuver conditions. The rubstrip additionally provides for a level of mechanical isolation from vibrations between the fan blade tips and the fan case. Further, another reason why the structural clearance 60 cannot be reduced to a value of zero is the need to dispose some soft rubstrip material between the fan blade tips and the hard fan case.

[0032] Referring to FIG. 7, the normalized engine interface loads are plotted versus a ratio of the structural clearance to the fan case diameter for a typical modern gas turbine engine. The normalization of the engine interface loads is based on a typical structural clearance of one inch (1") (25 mm). The curve shown in FIG. 7 is representative of loads at different engine to aircraft interfaces and is dependent on several factors some of which are the weight of the fan case and related hardware attached to the fan case such as a nacelle, the fan case stiffness relative to the engine, the ratio of the weight of the combination of the fan and blades to the weight of the fan case, and the dynamics of the rotor such as the frequency of the rotor.

[0033] The interface loads cannot be reduced beyond the normalized value of about 0.5 due to the structural characteristics of the fan case, i.e., a heavier fan case would be required to increase the transmission of loads to the fan case thereby reducing rotor deflections. As the structural clearance is reduced, the fan case interacts more closely with the fan blade tips and as such the fan case constrains the deflection of the imbalanced rotor by inertial resistance. As a result, there is a decrease in the amplitude of the rotor deflections which results in the decrease of the forces or loads transmitted through the bearing support structure. Thus, the kinetic energy associated with the imbalance of the rotor is transmitted through the fan blade tips into the fan case and is largely dissipated by the translational (radial) movement of the fan case. A portion of the kinetic energy associated with the imbalance of the rotor is dissipated by the movement of the fan blades relative to the fan case. The associated heat generated due to the frictional forces between the fan blade tips and the fan case is dissipated in the materials of the fan case and blade structure.

[0034] In the event of a fan blade loss during engine operation, the detached blade is thrown radially outwardly. It typically will pass through the fan case 48 and will be caught by the fabric wraps 50 in the fan containment case assembly 30.

[0035] The blade loss produces an imbalance in the rotor and causes the rotor to deflect radially outwardly in close proximity to the fan case. The separation between the fan blades and the inner surface of the fan case is minimized in modern engines to decrease the radial deflection of the rotor assembly. Due to the rotor deflection and the reduced clearance between the fan blades and the fan case, the fan blade tips rapidly cut away the compliant rub strip 44 in the innermost surface of the fan containment case assembly. The thin, fan case liner, made from hardened materials such as steel or nickel alloys, provides a skid surface for the relatively softer blades. The fan blades move circumferentially along on the skid-surface of the liner. The embedding of the blades in the fan case is eliminated or reduced; and as a result, the unwanted torque loading of the case is reduced. Without the hardened liner, the fan blades would continue to cut away and firmly embed in the fan case. The present invention, thus provides for a system that allows for limiting rotor deflection during a fan blade loss event and provides a skid-plate function which eliminates or reduces the generation of additional torque loading on the case.

[0036] As described hereinabove, the shingled embodiment, also provides a skid-surface for the fan blades to circumferentially rotate upon. However, by being segmented, the damage to the liner after a fan blade loss event is limited to the loss of one or more adjacent shingles 52. The remaining shingles continue to provide an effective skid-surface for the fan blades to glide on.

[0037] The diameter of the fan case can be an inner, outer or mean diameter of the fan case in the region of the fan blades.

[0038] A primary advantage of the present invention fan case liner is the minimization of damage to the fan case thus, resulting in a durable fan case in the event of a fan blade loss. The liner reduces the destructive cutting away of the fan case by the fan blades. A further advantage of the present invention fan case is its ability to provide an appropriate restraining structure to the deflection of the rotor shaft during a fan blade loss event. In addition, the liner reduces frictional forces, and as a result, reduces torque loads transmitted from the fan rotor to the case. Another advantage is the ease and cost of manufacturing and incorporating the hardened fan case liner of the present invention. The simplicity of the structure of the liner and the use of economical materials, allows for cost effective manufacturing processes. Further, current, prior art fan cases can be retrofitted to include the fan case liner in a cost effective manner. By incorporating the present invention liner, current engines limit damage to the fan containment case assembly and to the rotor shaft.

[0039] Although the invention has been shown and described with respect to detailed embodiments thereof, it should be understood by those skilled in the art that various changes in form and detail thereof may be made without departing from the the scope of the claimed invention.

Claims

1. A gas turbine engine (10) having a centerline (Ar), a rotor (28) having a centerline of rotation coincident with said engine centerline, the rotor including a fan (14), the fan (14) having a disk (33), blades (34) with tips (38), a stator including a fan case (48) having a characteristic diameter, disposed radially outward of the fan (14), and comprising

   a hardened structure (42) disposed in the fan case (48), in a radial zone of interaction (60) which extends for a distance less than one hundredth of the fan case diameter, said radial zone of interaction (60) being bounded outwardly by an inner surface (53) of the fan case, the zone (60) being measured from the fan blade tips (38) in a non-operative condition of the engine, the arrangement being such that during a high rotor imbalance condition the fan blades (34) skid along the interior surface of the hardened structure as opposed to embedding in the fan case (48) thereby reducing torque and imbalance loads.

2. The gas turbine engine of claim 1, wherein said radial zone of interaction (60) has a value of about five thousandths (0.005) of the fan case diameter as measured from the fan blade tips (38) in a non-operative condition.

3. The gas turbine engine of claim 1, wherein said radial zone of interaction (60) has a value of about two and one half thousandths (0.0025) of the fan case diameter as measured from the fan blade tips (38) in a non-operative condition.

4. The gas turbine engine of claim 1, 2 or 3, wherein the hardened structure (42) is a thin skid-plate circumferentially disposed in the fan case (48).

5. The gas turbine engine of claim 1, 2 or 3, wherein the hardened structure (42) is a segmented liner disposed in the fan case (48) so as to circumscribe the fan blades (34).

6. The gas turbine engine of claim 5, wherein the segmented liner further includes thin, skid-plate shingles (52) circumferentially disposed in the fan case (48), said shingles (52) being offset from adjacent shingles and having an overlap region (54) between said adjacent shingles.

7. The gas turbine engine of any preceding claim wherein the inner surface (53) of the fan case (48) is hardened.

8. A gas turbine engine (10) having fan blades (34) and a fan case (48) positioned radially outwardly of the fan blades (34) and having an inwardly facing surface (53) wherein the distance from the blade tips (38) to the surface (53) in an inoperative condition of the engine is less than one hundredth of the

diameter of the fan case (48), and wherein a hardened structure (42) is disposed between the blade tips (38) and the surface (53).

9. A gas turbine engine (10) having a centerline (Ar), a rotor (28) having a centerline of rotation coincident with said engine centerline, the rotor including a fan (14), the fan having a disk (33), blades (34) and tips (38) at one end thereof, a stator including a fan case (48) having a characteristic diameter, disposed radially outward of the fan, the engine further comprising:

a hardened structure (42) having an interior surface, disposed in the fan case, and
a radial zone of interaction (60) which extends for a distance less than one hundredth of the fan case diameter, said radial zone of interaction bounded outwardly by the hardened structure (42), the zone being measured from the fan blade tips in a non-operative condition and fully engaged with the fan disk, wherein said rotor is centered about the engine, such that during a high rotor imbalance condition the fan blades skid along the interior surface of the hardened structure as opposed to embedding in the fan case thereby reducing torque and imbalance loads.

10. A gas turbine engine (10) having a centerline (Ar), a rotor (28) having a centerline of rotation coincident with said engine centerline, the rotor including a fan (14), the fan (14) having a disk (33), blades (34) with tips (38), a stator including a fan case (48) having a nominal diameter, disposed radially outward of the fan (14), and comprising

a hardened structure (42) disposed in the fan case (48);
a radial zone of interaction (60) which extends for a distance less than one hundredth of the fan case diameter, said radial zone of interaction (60) being bounded outwardly by an inner surface (53) of the fan case, the zone (60) being measured from the fan blade tips (38) in a non-operative condition of the engine, the arrangement being such that during a high rotor imbalance condition the fan blades (34) skid along the interior surface of the hardened structure as opposed to embedding in the fan case (48) thereby reducing torque and imbalance loads.

FIG.1

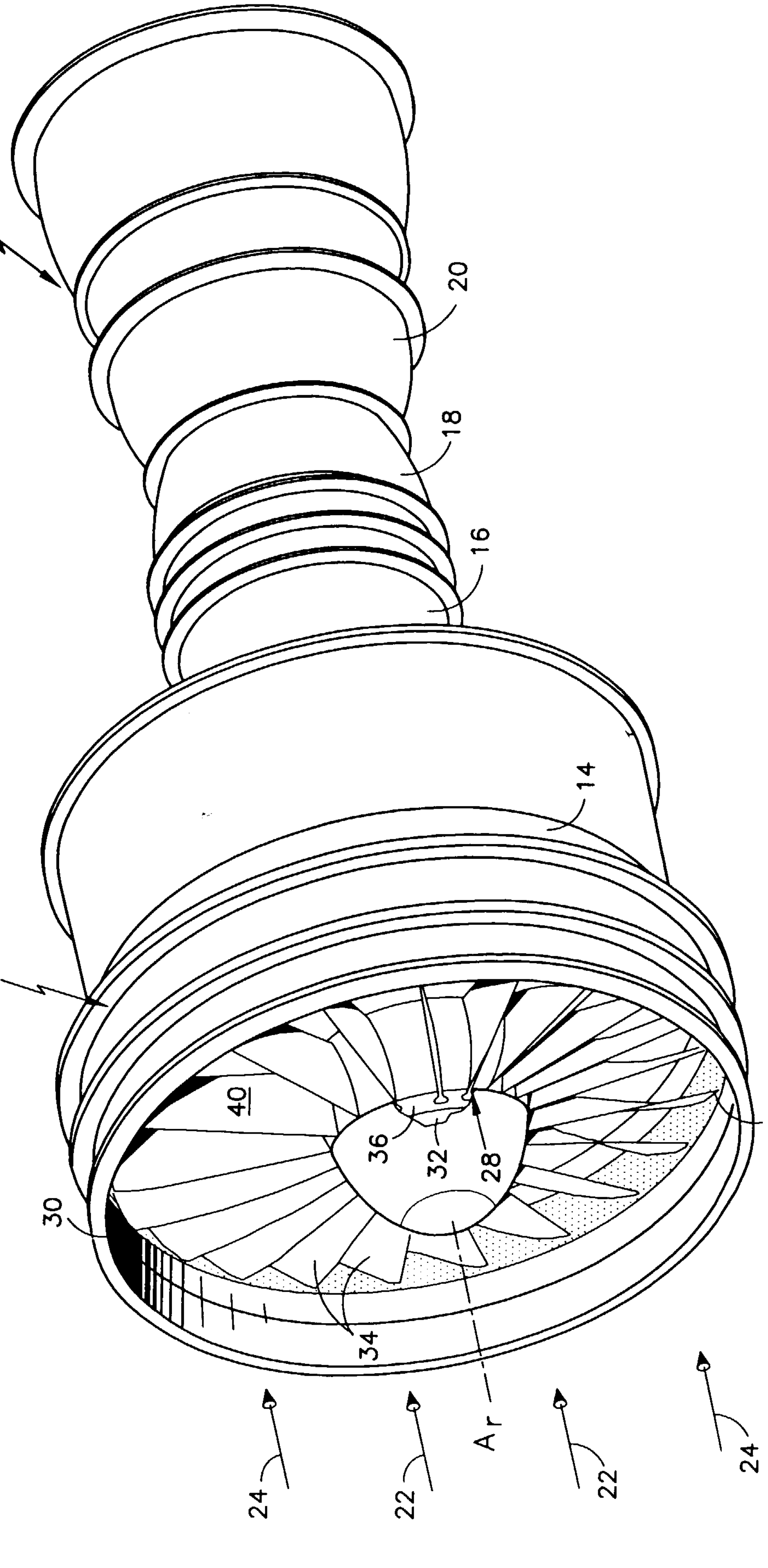
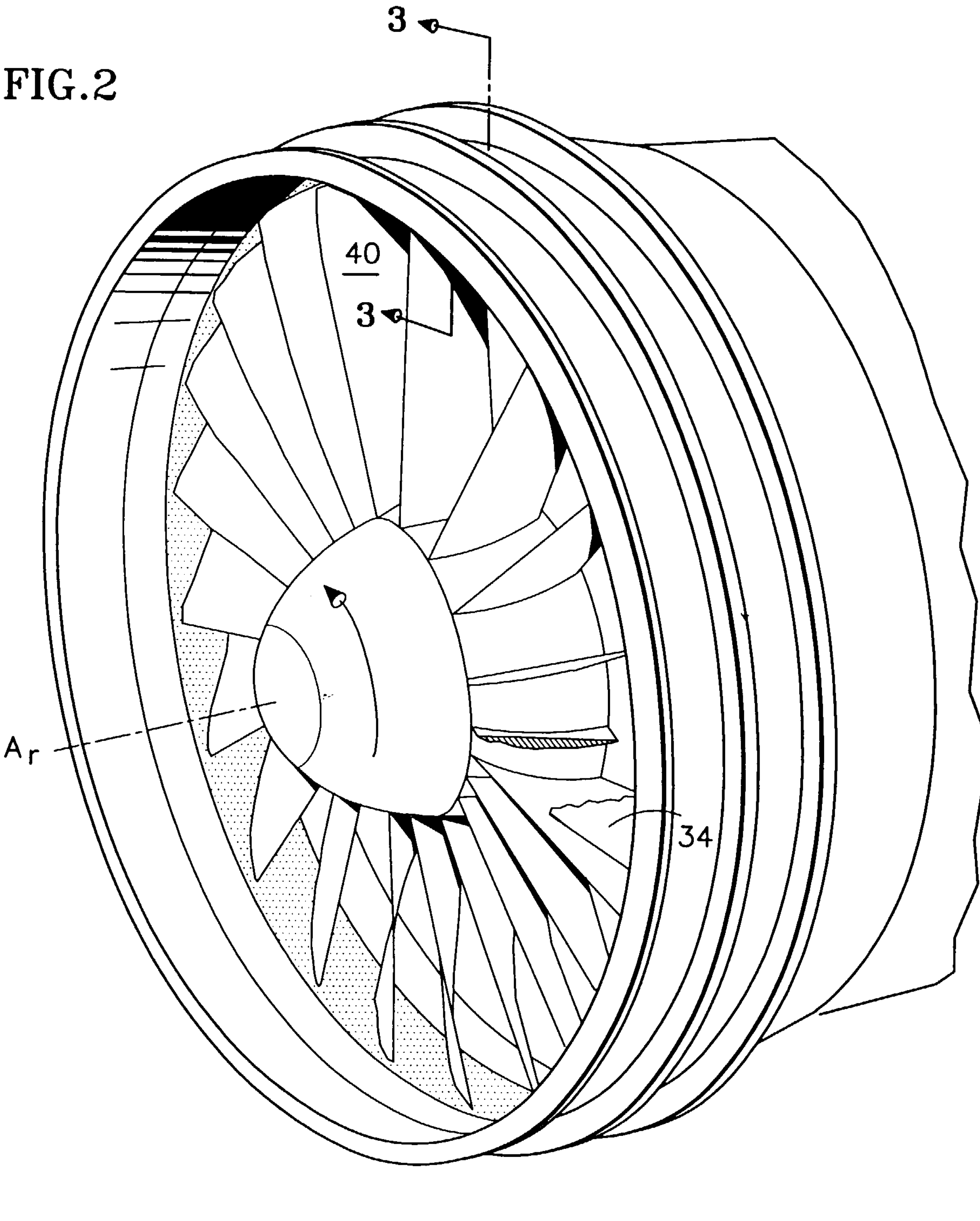


FIG.2



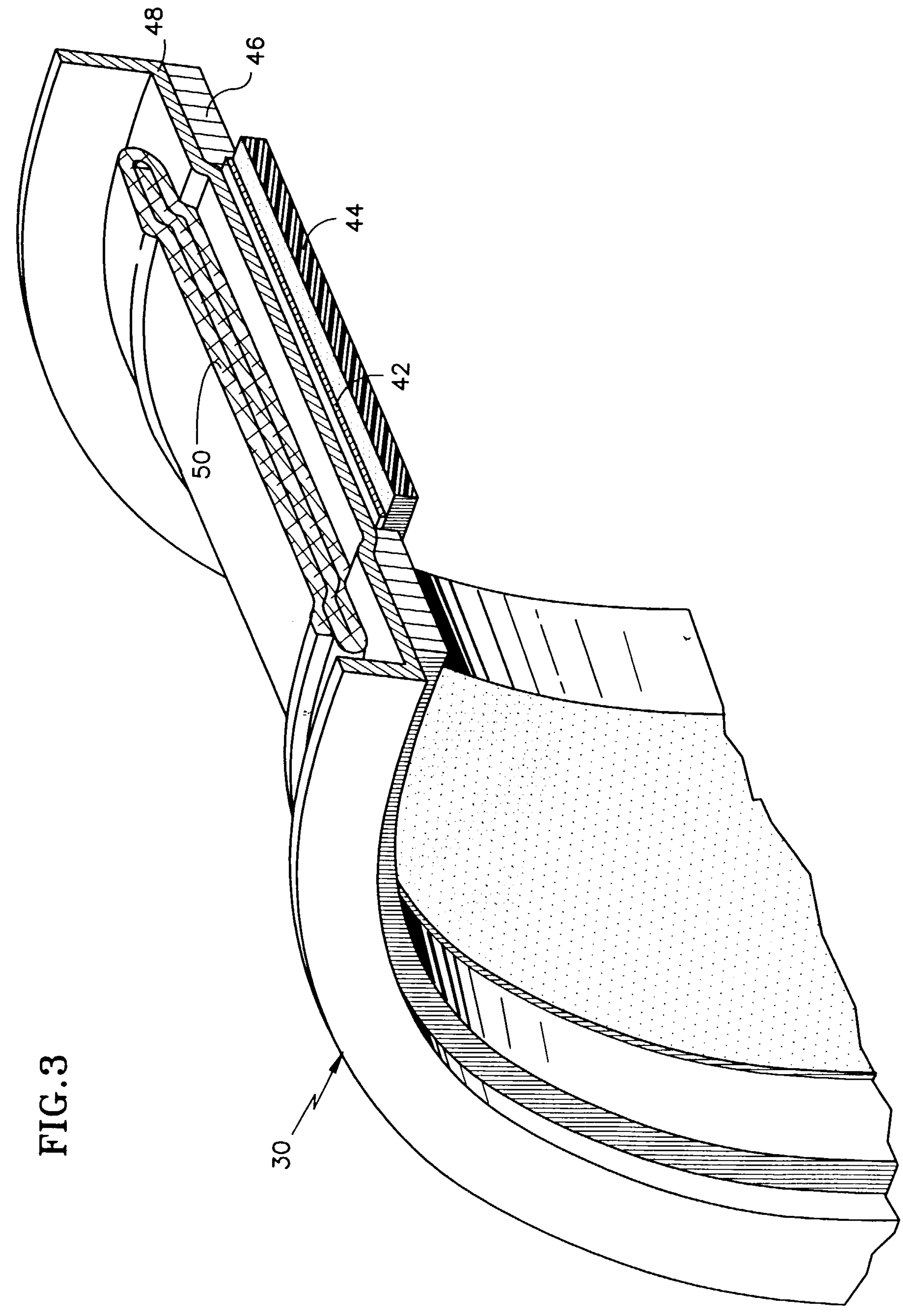
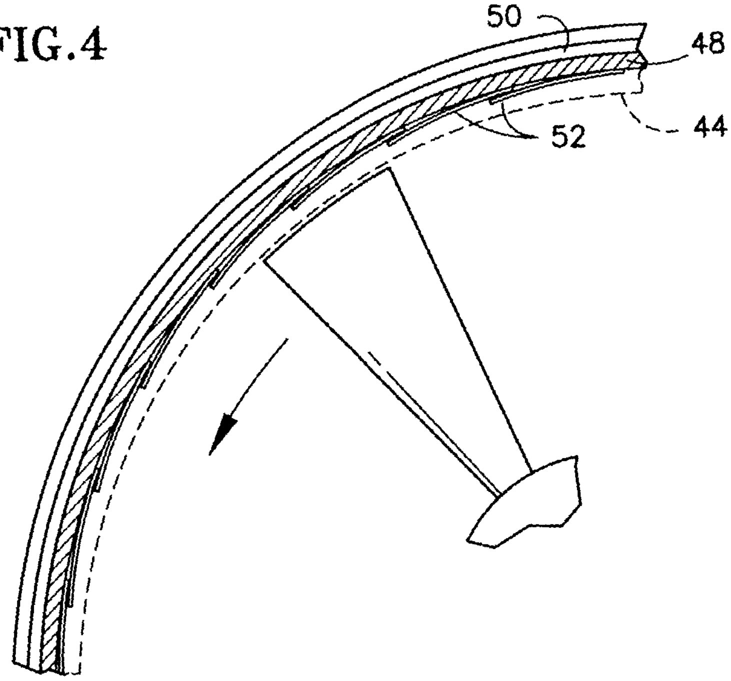


FIG.3

FIG.4



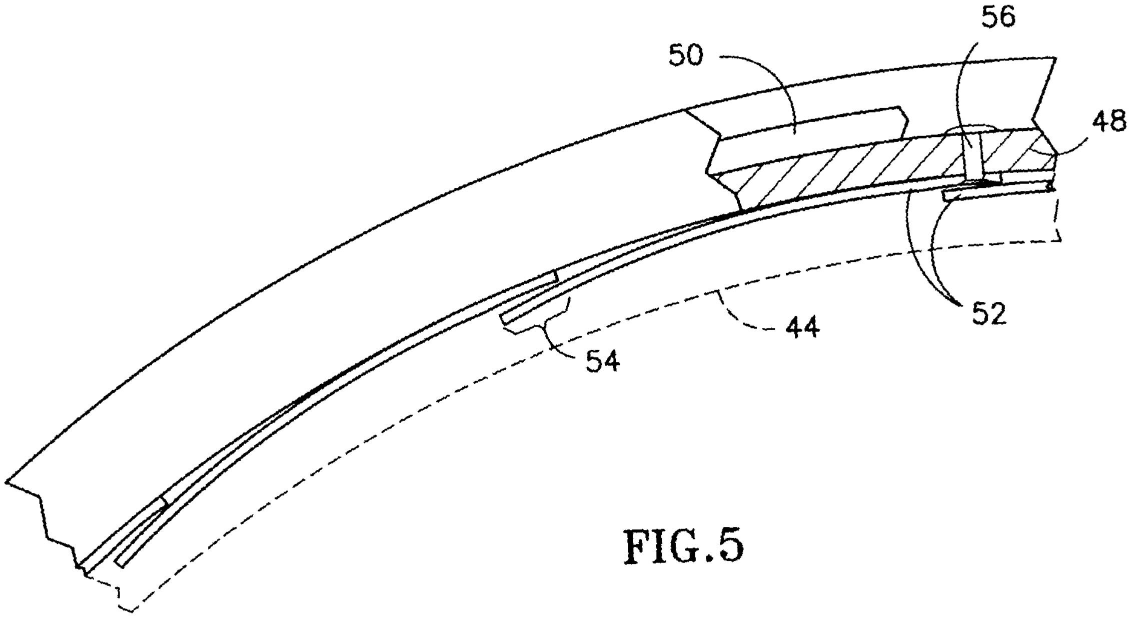


FIG.5

FIG.6

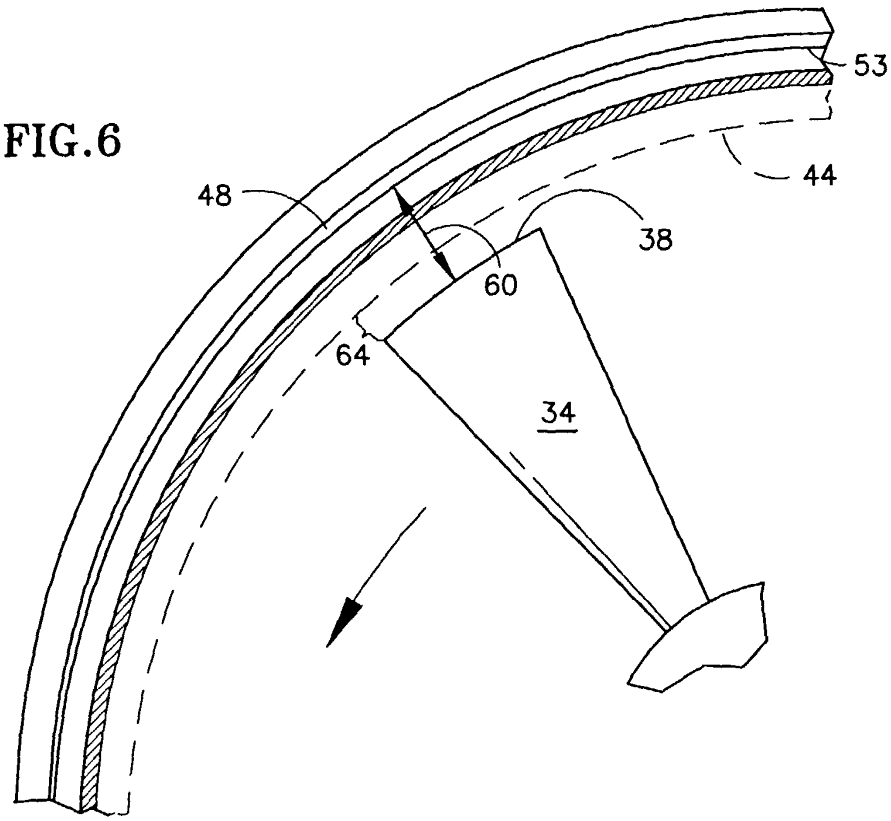
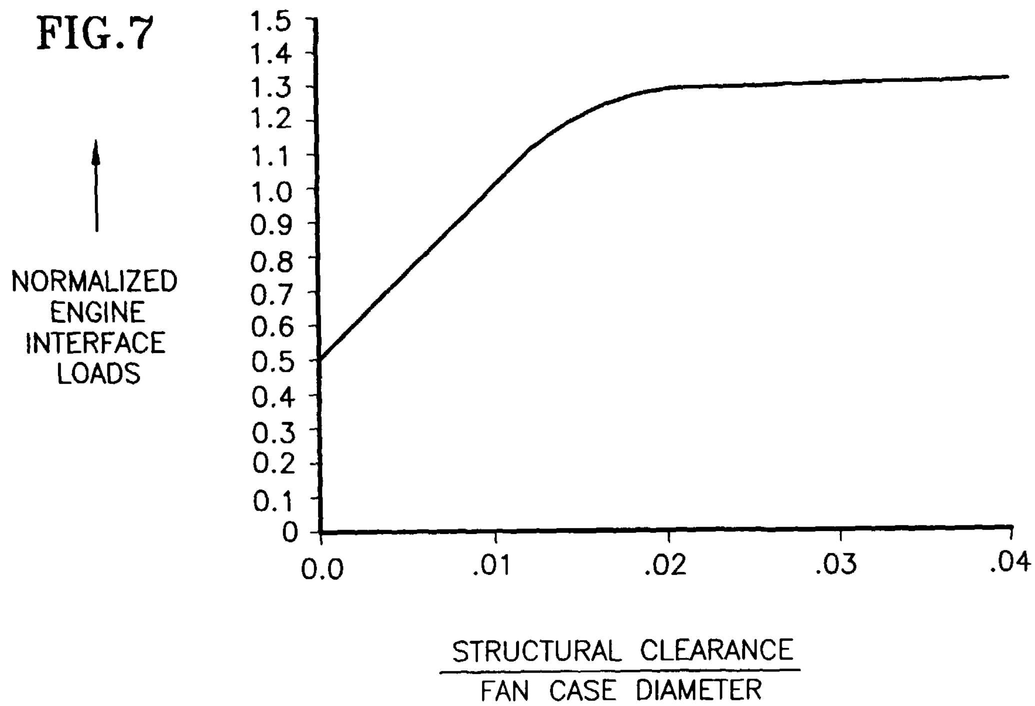

53
44
48
38
60
64
34

FIG.7


1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
NORMALIZED
ENGINE
INTERFACE
LOADS
0.0
.01
.02
.03
.04
STRUCTURAL CLEARANCE
FAN CASE DIAMETER