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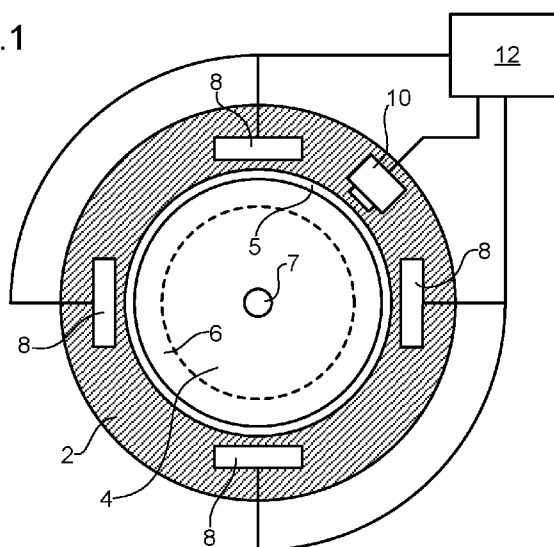
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(54) Title: TURBO-MACHINE ASSEMBLY

Fig.1



(57) Abstract: There is disclosed a turbo-machine assembly configured to facilitate improved blade clearance management. In a disclosed arrangement, there is provided a turbo-machine assembly comprising: a casing (2); a fan or turbine including a blade (6) and mounted rotatably within the casing; and a detector (10) for measuring the clearance between the blade and a portion of the inner surface of the casing, wherein: the detector is configured to generate an output by interacting with the blade; and the blade (6) and detector (10) are configured so that a portion of the output from the detector that can be used to generate a measure of the clearance is independent of the axial position of the blade over a predetermined range of axial positions.

TURBO-MACHINE ASSEMBLY

The present invention relates to a turbo-machine assembly, in particular a turbo-machine assembly that is adapted to facilitate effective measurement of the clearance between blade tips and a surrounding casing. The assembly may be part of a jet engine for an aircraft for example.

Leakage of gas between the blade tips and the surrounding casing will reduce the efficiency of the assembly. In many applications it is difficult to prevent such leakage completely. Forces, torques and heat loads applied to the assembly in use will tend to distort both the blade and the surrounding casing. These distortions will tend to change the clearance between the blades and casing. In many applications, the nominal clearance is set so that contact between the blades and casing will not occur to an excessive extent, or at all, even under the most unfavourable conceivable conditions (i.e. the conditions that would be most likely to cause such contact). This approach allows the assembly to operate safely but is relatively inefficient because the clearance will tend to be larger than necessary for most operating conditions.

For example, in an aircraft engine extreme events such as take-off, aborted landing or engine restarts during flight will involve heat loads and forces/torques on the engine that are very different to those experienced during the rest of the flight. Setting the nominal clearance so that the blades do not touch the casing excessively during such extreme events means the clearance will tend to be larger than necessary for the rest of the flight, significantly increasing fuel costs. In addition, the engine needs to work harder to achieve the same output power, which may affect engine longevity.

Prior art systems have been developed to mitigate the above problems by controlling the shape and/or size of the casing during use. This is sometimes referred to as clearance control. For example, in the context of an aircraft engine it is known to cool the casing during a cruising phase so that it contracts and reduces the clearance. This may be done “passively” (i.e. without reference to measurements of the actual clearance or detailed predictions of the clearance). In principle, active clearance control is also possible. Active clearance control might involve driving of actuators or temperature control systems in response to measurements of the clearance for example. However, it is challenging to provide a sensor that is sufficiently robust, reliable and accurate. This is particularly the case in the context of an aircraft engine, where operating temperatures are very high and a degree of axial movement can occur between the blades and casing. US 4,813,273 recognises that such axial movement may cause a sensor that is fixed relative to the casing to “look” at different portions of the blade when assessing the clearance, and that this may affect the output of the sensor. As a solution US 4, 813,273 proposes a capacitive sensor having an electrode that is axially larger than the blade tip, so that the sensor always interacts with the whole of the blade tip regardless of axial position. However, this approach will tend to limit the resolution that is achievable in the clearance measurement. Also, capacitive sensors tend to degrade quickly in use, particularly in the context of aircraft engines.

US 4,813,273 also mentions an alternative approach of calibrating for axial movement of the blade. This can be done for example by recording sensor measurements at various different axial positions and blade tip clearances (measured using independent sensors). However, use of such calibration generally requires a second sensor for measuring the axial position of the blade. Alternatively, the axial position of the blade can be predicted, but such prediction may be subject to significant errors.

It is also known in the art to provide shrouds at the radial tips of the blades. Such shrouds reduce flow over the tips of the blades but at the cost of increased blade mass. The increased blade mass has a negative impact on efficiency and may limit the speeds at which the assembly can be driven. Partially shrouded designs that can operate efficiently at higher speeds and which retain some control over clearance leakage are also being investigated.

It is an object of the present invention to provide a turbo-machine assembly in which the blade tip clearance can be measured accurately even when there is axial movement of the blade relative to the casing.

According to an aspect, there is provided a turbo-machine assembly comprising: a casing; a fan or turbine including a blade and mounted rotatably within the casing; and a detector for measuring the clearance between the blade and a portion of the inner surface of the casing, wherein: the detector is configured to generate an output by interacting with the blade; and the blade and detector are configured so that a portion of the output from the detector that can be used to generate a measure of the clearance is independent of the axial position of the blade over a predetermined range of axial positions.

According to an alternative aspect, there is provided a method of operating a turbo-machine assembly, wherein: the turbo-machine assembly comprises a casing and a fan or turbine including a blade and mounted rotatably within the casing; and the method comprises: using a detector to measure the clearance between the blade and a portion of the inner surface of the casing, wherein: the detector generates an output by interacting with the blade; and the blade and detector are configured so that a portion of the output from the detector that can be used to generate a measure of the clearance is independent of the axial position of the blade over a predetermined range of axial positions.

Thus, a detector output is provided that will not be affected by axial movement of the blade within a predetermined range. The accuracy of the measurement of clearance can therefore be improved. The improved accuracy is achieved without needing to measure the axial position of the blade relative to the casing. The improvement can therefore be implemented at minimum expense. Furthermore, it is not necessary to perform calibration measurements to determine a relationship between the axial position of the blade and the output from the detector.

In contrast to prior art blade modifications, such as shrouded blade designs, the present disclosure proposes blade geometry modifications that may be non-optimal when considering only thermal or fluid-dynamical properties. However, when the accuracy with which blade tip clearance measurements can be made is introduced as a parameter, the overall efficiency of the turbo-machine assembly can be improved.

The cost associated with non-optimal thermal-fluid properties is outweighed by the increases in efficiency that become possible due to the improved blade tip clearance measurement (e.g. improved blade tip clearance control).

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which corresponding reference symbols indicate corresponding parts, and in which:

Figure 1 depicts a turbo-machine assembly comprising a detector for measuring the clearance between a blade and an inner surface of a casing, and a controller for controlling a size and/or shape of the casing based on the clearance detected by the detector;

Figure 2 is a schematic radial view depicting air flow over a blade of a turbo-machine assembly, a direction of motion of the blade, and a region of interaction between a detector and the blade;

Figure 3 is a schematic radial view depicting an example blade geometry in which the walls of a cavity have an axially independent thickness over a portion of the blade;

Figure 4 is a schematic axial view of the section defined by broken line 24 of the blade of Figure 3;

Figure 5 is a schematic radial view depicting an example blade geometry in which the thickness of a lip is axially independent over a portion of the blade;

Figure 6 is a schematic axial view of the section defined by broken line 24 of the blade of Figure 5;

Figure 7 is a schematic radial view depicting a first example blade geometry in which a cavity wall comprises an axially aligned planer region;

Figure 8 is a schematic radial view depicting a second example blade geometry in which a cavity wall comprises an axially aligned planer region;

Figure 9 is a schematic radial view depicting an example blade geometry in which an axially aligned reference feature is formed within a radially open cavity;

Figure 10 is a schematic axial view of the section defined by broken line 24A of the blade of Figure 9;

Figure 11 is a schematic axial view of the section defined by broken line 24B of the blade of Figure 9;

Figure 12 is a schematic radial view of an example blade geometry comprising two axially aligned, radially open cavities;

Figure 13 is a schematic axial view of the section defined by broken line 24 of the blade of Figure 12;

Figure 14 is a schematic radial view depicting an example blade geometry having a tip extension member, the tip extension member having two axially aligned edges on opposite circumferential sides;

Figure 15 is a schematic axial view of the section defined by broken line 24 of the blade of Figure 14;

Figure 16 is a schematic radial view depicting an example blade geometry having a tip extension member, the tip extension member having an axially aligned edge spanning from an axially downstream side of the blade to an axially upstream side of the blade;

Figure 17 is a schematic radial view depicting an example blade geometry having a tip extension member, the tip extension member having an axially aligned edge on the axially upstream side of the blade;

Figure 18 is a schematic radial view depicting an example blade geometry having a tip extension member, the tip extension member having an axially aligned edge spanning from an axially downstream side of the blade to an axially upstream side of the blade;

Figure 19 is a schematic radial view depicting an example blade geometry having a tip extension member extending to the circumferentially leading side of the blade.

The term “turbo-machine assembly” is intended to encompass any device in which energy is transferred either to or from a continuously flowing fluid by the dynamic action of one or more blades being driven through the fluid. Where energy is transferred to the fluid, the element on which the blades are mounted and rotated may be referred to as a fan. A fan may be used as a compressor for example. Where energy is transferred from the fluid, the element on which the blades are mounted and rotated may be referred to as a turbine. Generally, the blades will be provided in a circumferentially oriented row relative to the axis of rotation of the fan or turbine.

Figure 1 depicts an example of a turbo-machine assembly 1 (e.g. a fan assembly, a turbine assembly, a compressor assembly, or an assembly comprising fan, turbine and/or compressor and/or one or more elements configured to operate selectively as a fan or as a turbine or as a compressor). The depicted assembly 1 comprises a casing 2 and a fan or turbine 4 mounted within the casing 2. The fan or turbine 4 is mounted so as to be rotatable about axis 7. The fan or turbine 4 comprises a plurality of blades 6 that extend radially outwards relative to the axis 7. A gap 5 between the radial tips of the blades 6 and the inner surface of the casing 2 may be referred to as a “clearance” between the blades 6 and the casing 2.

As explained in the introductory part of the description, it is desirable to minimise the size of the clearance between the blades 6 and the casing 2 in order to favour high operating efficiency, subject to avoiding excessive contact between the blades 6 and the casing 2.

In an embodiment, a controller 12 is provided for controlling the size and/or shape of the casing 2 based on the clearance detected by the detector 10. In an embodiment, the controller 12 is connected to control elements 8, which may be heating or cooling systems and/or mechanical actuators, for example. A control signal for controlling these elements is transmitted to them by the controller 12 based on the output from the detector 10.

In the embodiment shown, only a single detector 10 is provided. In other embodiments one or more further detectors are provided. For example, in an embodiment two or more detectors are provided at

different circumferential positions to enable measurement of anisotropic (i.e. azimuthally varying rather than axially symmetric) clearance. In the context of turbo-machine assemblies for use in aircraft engines, such anisotropic clearance may occur due to loading on the assemblies during flight for example.

The inventors have realised that the axial position of the blades 6 as they pass the detector 10 will vary in normal use of the assembly 1. Such variations may be caused by changes in the temperature and/or load on the fan or turbine 4 for example. The axial variation in blade position can affect the accuracy of the clearance measurement made by the detector 10, for example by changing the extent to which the detector 10 interacts with the blades 6.

Figure 2 is a schematic radial view of a blade 6. Arrow 18 illustrates a circumferential direction of motion of the blade 6. Arrows 14 illustrate axial air flow onto the blade 6. In an embodiment, the detector 10 is configured to generate an output by interacting with the blade 6 over a finite interaction distance 22 parallel to the axis of rotation of the fan or turbine 4. Circled area 20 illustrates schematically a region of the blade 6 that could be detected by the detector 10 at a given instant in time. Broken lines 16 illustrate the region of the fan or turbine 4 with which the detector 10 can interact as the fan or turbine 4 rotates.

Axial movement of the blade 6 (relative to the casing 2 and detector 10) will tend to change the proportion of the blade 6 with which the detector 10 can interact. For example, the blade 6 tends to become thicker in an upstream direction relative to the incoming flow 14. Thus, axial movement of the blade 6 in the downstream direction will tend to increase the proportion of the blade 6 with which the detector 10 interacts. Movement of the blade 6 in the upstream direction will, conversely, tend to decrease the proportion of the blade with which the detector 10 interacts. Thus, the amplitude of the signal detected by the detector 10 may vary with changes in the axial position of the blade 6 without any change in the distance between the radial tip of the blade 6 and the detector 10. These variations in amplitude may be mistakenly interpreted as a change in the clearance between the blade 6 and the casing 2, thus reducing the accuracy of the detector 10.

In an embodiment, the blade 6 and detector 10 are configured so that a portion of the output from the detector 10 that can be used to generate a measure of the clearance is independent of the axial position of the blade 6 over a predetermined range of axial positions. In this way, the detector 10 can measure the clearance accurately even when the axial position of the blade 6 varies. This improvement in accuracy is obtained without the need for calibration measurements to model the variation in detector output with axial position of the blade 6. Furthermore, it is not necessary to provide means for measuring the axial position of the blade 6.

In an embodiment, the portion of the output from the detector that can be used to generate a measure of the clearance comprises all of the output of the detector 10 for a single pass of the blade 6 in front of the detector 10. In an alternative embodiment, the portion of the output from the detector 10 that can be used to generate a measure of the clearance comprises less than all of the output of the detector 10 for a single pass of the blade 6 in front of the detector 10. In an example embodiment only the output from the detector 10

during a predetermined window of time during interaction with the blade 6 is used for generating the clearance measurement. The window of time may be towards the start or end of the period of interaction, or at an intermediate range of points. Where a reference feature is provided in the blade 6, the window of time may be defined relative to the reference feature. Some specific examples are described below with reference to specific blade geometries.

In an embodiment, the axial independence of the detector 10 output is maintained over a predetermined range of axial positions that is larger than the interaction distance 22.

In an embodiment, the detector 10 is configured to interact with the blade 6 using one or more of the following: x-ray radiation, electric fields, magnetic fields, optical radiation, microwave radiation, pressure/acoustic waves. In an example embodiment, the detector 10 measures a capacitance established between the radial tip of the blade 6 and the detector 10. In such an embodiment, a decrease in the clearance will tend to correspond to an increase in the capacitance, and vice versa. In another example embodiment, the detector 10 generates a signal by magnetically inducing eddy currents in the blade 6.

In an embodiment, the geometry of the blade is configured so that the surface area of the radial tip of the blade 6 facing the casing 2 is independent of axial position over a predetermined range of axial positions. In an embodiment this surface area determines the size of the output from a detector that uses a capacitance measurement. In an embodiment, the geometry of the blade 6 is configured so that the volume of blade material with which the detector 10 interacts is independent of axial position over predetermined range of axial positions of the blade 6 relative to the detector 10. In an embodiment, this volume determines the size of the output from a detector that uses an eddy current-based measurement.

In an embodiment, the above functionality is provided by forming radial projections in the radial tip of the blade 6. The radial projections may be formed by making a cavity in the radial tip of the blade. The walls defining the cavity may be considered radial projections (relative to the base of the cavity). The radial projections are defined as elements that extend radially further than other radially facing surfaces in the radial tip of the blade 6.

In the following embodiments reference is made to a predetermined axial range 15. This axial range 15 represents an upper limit on the range of axial movement of the blade 6 for which the blade 6 and detector 10 are configured to provide a measurement of the clearance that is not significantly affected by the axial movement. In embodiments of the invention, the range represents an upper limit on the expected range of movement of the blades 6 relative to the casing 2 during normal operation of the assembly.

In an embodiment, the predetermined range of axial positions is longer than the maximum range of axial positions over which the detector can interact with the blade at any given moment in time. In an embodiment, the predetermined range of axial positions is longer than 5% of the axial length of the blade, preferably longer than 10%, more preferably longer than 25%.

Figure 3 is a schematic radial view of an example blade 6 which achieves the abovementioned

functionality by means of a cavity 26 formed in the radial tip of the blade. The cavity 26 is formed by radial projections 28, which may also be referred to as walls 28. Figure 4 is an axial view of the section defined by broken line 24 of the blade 6 of Figure 3.

The uppermost part of the blade 6 in Figure 4 corresponds to the radial tip of the blade. The radial tip of the blade 6 is the portion of the blade 6 that is closest to the casing 2. In this embodiment, the cavity 26 is open in the radial direction. In other embodiments, the cavity 26 may be open in one or both of the circumferential directions instead or additionally, and/or may be closed.

In the embodiment shown, the walls 28 defining the cavity 26 are configured so that the volume and/or surface area of blade material with which the detector 10 interacts is independent of axial position over a predetermined range 15 of axial positions. In the embodiment shown, this is achieved by ensuring that the thickness of the walls 28 is constant over the range 15 of axial positions. In such an embodiment, the detector 10 may be configured to interact with the blade 6 to a radial depth that encompasses only the walls 28 and not any of the blade material that is radially deeper than the walls 28 (i.e. further away from the casing 2) and/or with the radially upper surface of the walls 28. In a capacitance measurement, for example, the radially facing surface area of the walls 28 will tend to contribute much more to the capacitance than the surface area of the bottom of the cavity 26 because the radial tips of the walls 28 are much closer to the detector 10.

In other embodiments, the detector 10 is configured to interact partly with the walls 28 and partly with blade material that is radially beneath the walls. In such an embodiment, the thickness of the walls 28 is adapted to compensate for the change in circumferential thickness of the blade 6 in the axial direction. For example, one or both of the walls 28 may be configured to become thinner in the upstream axial direction to compensate for an increase in thickness of the rest of the blade 6.

Figures 5 and 6 depict an alternative blade geometry in which the blade 6 comprises a radial projection forming a lip 29 that extends along a circumferentially leading side of the blade 6. The lip 29 operates in an analogous manner to the walls 28 of the blade geometry shown in Figures 3 and 4. In the embodiment shown, the lip 29 is flush with the side face of the blade 6. In other embodiments, the lip 29 is set back from the side face of the blade 6. In the embodiment shown, the thickness of the lip 29 within the predetermined range 15 of axial positions is configured to be constant to provide an axially independent detector output. The detector 10 in this embodiment is configured to interact predominantly or entirely with the lip 29 (minimally or not at all with material of the blade that is radially below the lip 29). In this way, by ensuring that the detector 10 interacts only with an element that does not change thickness as a function of axial position, the output from the detector 10 is made independent of axial position. In other embodiments, the detector 10 is configured to interact both with the lip 29 and with blade material that is radially below the lip 29. In embodiments of this type, the thickness of the lip 29 may be made to vary as a function of axial position within the predetermined range 15 of axial positions to compensate for the change in thickness of

the blade 6 as a function of axial position.

Figure 7 depicts an alternative blade geometry in which a reference feature 35 is provided. In this embodiment, the reference feature 35 comprises an interface that is aligned perpendicular to the circumferential direction. In the embodiment shown, the interface divides a cavity 26 from blade material defining the wall 28 of the cavity 26. In this embodiment, the detector 10 is configured to interact with the blade 6 over an axial range lying within the predetermined range 15 defined by the axial limits of the reference feature 35. In an embodiment of this type, the detector 10 will first start to interact with the reference feature 35 at the same angular position of the fan or turbine independently of the axial position of the blade 6. Furthermore, the output from the detector 10 during a predetermined time period between a point at which the detector 10 is radially above a portion of the blade 6 and the detector 10 crossing the reference feature 35 will involve the same volume of blade material regardless of the axial position of the blade 6. Using this portion of output from the detector 10 to derive a clearance measurement ensures that the accuracy of the clearance measurement is not affected by axial movement of the blade 6 relative to the detector 10.

In Figure 7, the reference feature 35 is an interface formed on an inner surface of the wall 28 that is on the circumferentially leading face of the blade 6. Figure 8 depicts an alternative arrangement in which the reference feature 35 comprises an interface formed in a portion of the wall 28 that is on the circumferentially trailing side of the blade 6. In the arrangement of Figure 7, the output from the detector 10 in a predetermined time period prior to encountering the reference feature 35 may be used for the clearance measurement. In the arrangement of Figure 8, in contrast, the output from the detector 10 during a predetermined time period after the reference feature 35 is encountered may be used for the clearance measurement.

Figure 9 to 11 illustrate an alternative blade configuration in which a reference feature 34 that is formed from a radial projection is provided within a radially open cavity 26. Figure 9 is a schematic radial view of the blade 6. Figures 10 and 11 are axial views of the section represented by broken lines 24A and 24B. In embodiments of this type, the detector 10 is configured to interact with the blade 6 in a manner which allows the signal arising due to the reference feature 34 to be distinguished from the signal arising due to interaction with other portions of the blade 6. The reference feature 34 is aligned with the axial direction at least over the predetermined range 15 of axial positions. In this way, the interaction with the reference feature 34 will not depend on axial position over the range 15 of axial positions. Any axial movement of the blade 6 within this range 15 will not therefore reduce the accuracy of the clearance measurement provided by the detector 10.

Figures 12 and 13 depict an alternative blade configuration in which two reference features 38 and 40 are provided in the radial tip of the blade 6. In this embodiment, each of the two reference features 38 and 40 comprise cavities that are open in the radial direction. In the embodiments shown, both of the

reference features 38 and 40 are aligned axially. In an example embodiment of this type, the region 39 that is circumferentially delimited by the two reference features 38 and 40 and by the predetermined range 15 of axial positions is used as the basis for the clearance measurement. The circumferential thickness of this region 39 does not vary as a function of axial position within the predetermined range 15. The detector 10 is configured to interact with a portion of the region 39 that is axially shorter than the threshold range 15 and is contained within the threshold region 15 for all expected axial positions of the blade 6 in use. Thus, the volume and/or surface area of blade material with which the detector 10 interacts in use will not vary as a function of axial position of the blade 6, thus ensuring optimal accuracy in the clearance measurement.

In an embodiment, the reference feature is configured so as to be individually detectable by the detector 10. In other words, the reference feature is such that its contribution to the output from the detector 10 is readily distinguishable from other contributions to the output from the detector 10. In the examples discussed above the reference feature is formed by modifying the geometry of the main material of the blade. In other embodiments, the reference feature is formed using a material having a different composition to the material of the main body of the blade. In an embodiment, the reference feature is formed from a material that modifies the strength of interaction with the detector so as to make the part of the output from the detector 10 caused by the reference feature more distinct. In an embodiment, the reference feature comprises a material that reflects electromagnetic radiation within a predetermined frequency range to a greater extent (i.e. is more reflective) or a lesser extent (i.e. is less reflective/more absorptive) than the material of the main body of the blade 6. The reference feature may be configured in this manner when the detector is an optical detector. In an alternative embodiment, the reference feature comprises a material having a lower or a higher electrical resistivity than the material of the main body of the blade 6. The reference feature may be configured in this manner when the detector exploits the generation of eddy currents or changes in capacitance to measure the clearance. The reference feature may be formed or attached to the blade 6 in various different ways. In one embodiment, the reference feature is provided in a cavity. The cavity may be open in one or more directions, for example in the radial direction. In an example of such an embodiment, the reference feature is arranged to have a radially outer surface that is flush with a surrounding outer surface of the blade. In another example, the reference feature is set back from the surrounding outer surface of the blade or protrudes forwards from the surrounding outer surface of the blade. In another embodiment, the reference feature is formed as a coating on the surface of the blade, for example using a doped ceramic material. In another embodiment, the reference feature is formed by growing a material on the surface of the blade, for example epitaxially. In another embodiment, the reference feature is formed by modifying the surface properties of the blade material, for example by roughening the surface to reduce specular reflection. In another embodiment, the reference feature is completely encapsulated by the material of the main body of the blade 6.

Figures 14 to 18 depict alternative blade configurations in which a tip extension member 30 is

provided. The tip extension member 30 extends outwards from the radial tip of the blade 6 in directions lying parallel to the plane of the inner surface of the casing 2 facing the blade (i.e. perpendicular to the radial direction). In an embodiment, the detector 10 is configured to interact predominantly or exclusively with the tip extension member 30 (and to a lesser extent or not at all with the blade material that is radially beneath the tip extension member 30).

Figures 14 and 15 illustrates an example configuration in which the tip extension member 30 extends to both the circumferentially leading and trailing sides of the blade 6. Figure 14 is a schematic radial view. Figure 15 is a schematic axial view of the section defined by broken line 24 in Figure 14. In this embodiment, the tip extension member 30 comprises edges 35A and 35B that are axially aligned. In this way, when the detector 10 is configured to interact over an axial sub-range of positions that is within the predetermined range 15 of positions, the detector 10 will interact with the same volume and/or surface area of blade material regardless of axial position of the blade 5. In this way, axial movement of the blade 6 will not reduce the accuracy of the clearance measurement provided by the detector 10.

Figure 16 depicts an alternative configuration in which the tip extension member 30 comprises portions that extend to both the axially upstream and downstream positions of the blade 6 in the region of the circumferentially trailing tip of the blade 6. In this embodiment, the tip extension member 30 comprises an axially aligned edge 35. Interaction between the detector 10 and the axially aligned edge 35 removes axial dependence on the detector output in a manner that is analogous to the blade geometry depicted in Figure 7.

Figure 17 depicts an alternative geometry based on the same principle as the blade of Figure 16, except that the tip extension member 30 extends only to the axially upstream side of the blade 6.

Figure 18 depicts a further variation in which an axially aligned edge 35 is provided on a tip extension member 30 on the axially downstream side of the blade 6. Dotted line 32 illustrates an alternative geometry in which the tip extension member 30 extends further in the axially downstream direction, with an axially aligned edge 37 also positioned further downstream.

Figure 19 depicts a further variation in which an axially aligned edge 35 is provided on a tip extension member 30 on the circumferentially leading side of the blade 6.

CLAIMS

1. A turbo-machine assembly comprising:
a casing;
a fan or turbine including a blade and mounted rotatably within the casing; and
a detector for measuring the clearance between the blade and a portion of the inner surface of the casing, wherein:
the detector is configured to generate an output by interacting with the blade; and
the blade and detector are configured so that a portion of the output from the detector that can be used to generate a measure of the clearance is independent of the axial position of the blade over a predetermined range of axial positions.
2. An assembly according to claim 1, where the portion of the output from the detector that can be used to generate a measure of the clearance comprises all of the output of the detector for a single pass of the blade in front of the detector.
3. An assembly according to claim 1, wherein the portion of the output from the detector that can be used to generate a measure of the clearance comprises less than all of the output of the detector for a single pass of the blade in front of the detector.
4. An assembly according to any of the preceding claims, comprising a plurality of the detectors, at least two of the detectors being configured to measure the clearance between the blade and the inner surface of the casing at different circumferential positions on the casing.
5. An assembly according to any of the preceding claims, wherein the detector is configured to interact with the blade using one or more of the following: x-ray radiation, electric fields, magnetic fields, optical radiation, microwave radiation, pressure/acoustic waves.
6. An assembly according to any of the preceding claims, wherein the geometry of the blade is configured so that the volume and/or surface area of blade material with which the detector interacts is independent of axial position over the predetermined range of axial positions.
7. An assembly according to any of the preceding claims, wherein the blade comprises one or more radial projections.

8. An assembly according to claim 7, wherein the one or more radial projections define a cavity that is open in the radial direction.
9. An assembly according to claim 7 or 8, wherein the one or more radial projections define a lip extending along an edge of the blade.
10. An assembly according to any of claims 7-9, wherein the detector is configured to interact with the blade over a radial distance from the radial tip of the blade that is shorter than the smallest radial depth of the one or more radial projections, measured from the radial tip of the blade.
11. An assembly according to claim 10, wherein the sum of the circumferential thicknesses of the one or more radial projections is constant over a range of axial positions that is equal to or longer than the predetermined range of axial positions.
12. An assembly according to any of claims 7-9, wherein the detector is configured to interact with the blade over a radial distance from the radial tip of the blade that is equal to or longer than the smallest radial depth of the one or more radial projections, measured from the radial tip of the blade.
13. An assembly according to claim 12, wherein the sum of the circumferential thicknesses of the one or more radial projections varies over a range of axial positions in such a manner as to compensate for an axial variation in the circumferential thickness of the blade material radially beneath the radial projections over a range of axial positions that is equal to or longer than the predetermined range of axial positions.
14. An assembly according to any of the preceding claims, wherein the blade comprises a reference feature that is individually detectable by the detector.
15. An assembly according to claim 14, wherein the reference feature is aligned parallel to the axial direction.
16. An assembly according to claim 14 or 15, wherein the reference feature is of a different composition to the main body of the blade.
17. An assembly according to any of claims 14-16, wherein the reference feature is formed from a material that has a different strength of interaction with the detector than the material of the main body of the blade.

18. An assembly according to any of claims 14-17, wherein the reference feature comprises a material that reflects electromagnetic radiation within a predetermined frequency range to a greater extent or a lesser extent than the material of the main body of the blade.
19. An assembly according to any of claims 14-18, wherein the reference feature comprises a material having a lower or a higher electrical resistivity relative to the material of the main body of the blade.
20. An assembly according to any of claims 14-19, wherein the reference feature is located within an open or closed cavity, or encapsulated by the material of the main body of the blade, .
21. An assembly according to any of claims 14-20, wherein the reference feature is a coating, a surface layer having modified compositional or structural characteristics relative to other regions at the surface of the blade, or an embedded element having a surface that is flush with a surrounding surface of the blade.
22. An assembly according to any of claims 14-21, wherein:
the reference feature comprises a planar surface perpendicular to the circumferential direction.
23. An assembly according to any of claims 14-22, comprising two reference features and wherein the portion of the output from the detector that can be used to generate a measure of the clearance is derived from interaction with blade material lying circumferentially in between the two reference features.
24. An assembly according to claim 23, wherein both of the reference features are axially aligned.
25. An assembly according to claim 23 or 24, wherein both of the reference features comprise a radially open or closed cavity.
26. An assembly according to any of the preceding claims, wherein the blade comprises a tip extension member extending away from the tip of the blade in one or more directions perpendicular to the radial direction.
27. An assembly according to claim 26, wherein the detector is configured to interact predominantly or exclusively with the tip extension member.
28. An assembly according to claim 26 or 27, wherein the tip extension member comprises a first edge

that is aligned with the axial direction over a distance that is equal to or greater than the predetermined range of axial positions.

29. An assembly according to any of claims 26-28, wherein the tip extension member comprises a second edge that is aligned with the axial direction over a distance that is equal to or greater than the predetermined range of axial positions.

30. An assembly according to claim 29, wherein the first edge overlaps partially or completely with the second edge in the circumferential direction.

31. An assembly according to any of the preceding claims, further comprising:
a controller for controlling the size and/or shape of the casing based on the clearance detected by the detector.

32. An assembly according to claim 31, further comprising a heating system, cooling system, or mechanical actuator, the controller being configured to control operation of the heating system, of the cooling system, or of the mechanical actuator in order to control the size and/or shape of the casing based on the clearance detected by the detector.

33. An assembly according to any of the preceding claims, wherein the predetermined range of axial positions is longer than the maximum range of axial positions over which the detector can interact with the blade at any given moment in time.

34. An assembly according to any of the preceding claims, wherein the predetermined range of axial positions is longer than 5% of the axial length of the blade.

35. A jet engine comprising a turbo-machine assembly according to any of the preceding claims.

36. A method of operating a turbo-machine assembly, wherein:
the turbo-machine assembly comprises a casing and a fan or turbine including a blade and mounted rotatably within the casing; and
the method comprises:
using a detector to measure the clearance between the blade and a portion of the inner surface of the casing, wherein:
the detector generates an output by interacting with the blade; and

the blade and detector are configured so that a portion of the output from the detector that can be used to generate a measure of the clearance is independent of the axial position of the blade over a predetermined range of axial positions.

Fig.1

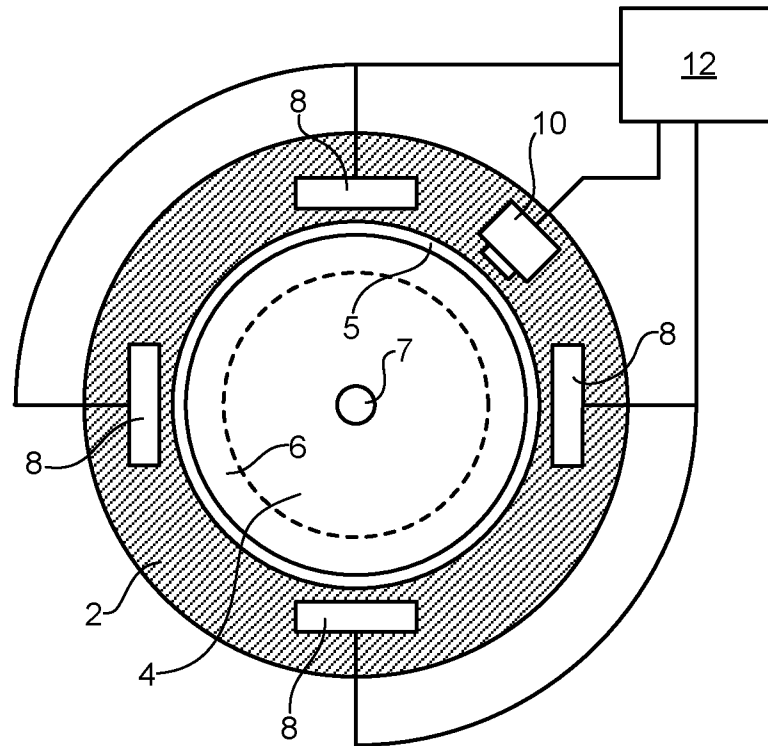


Fig.2

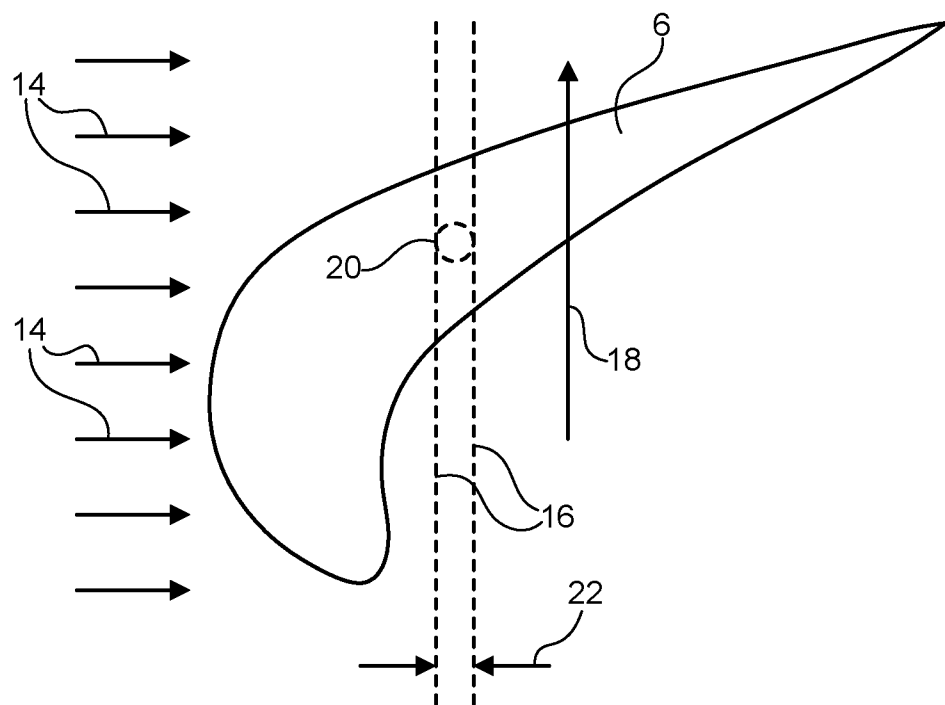


Fig.3

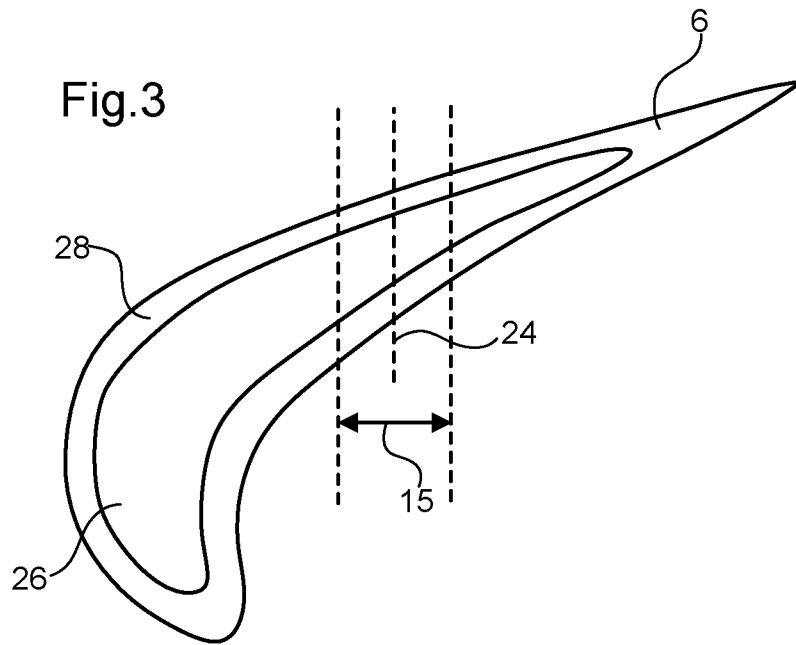


Fig.4

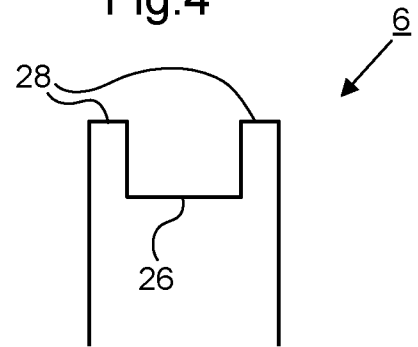


Fig.5

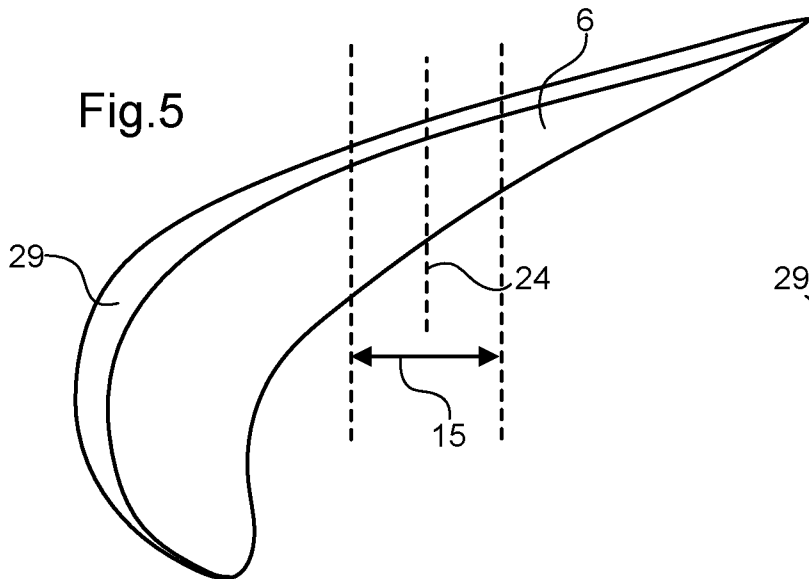


Fig.6

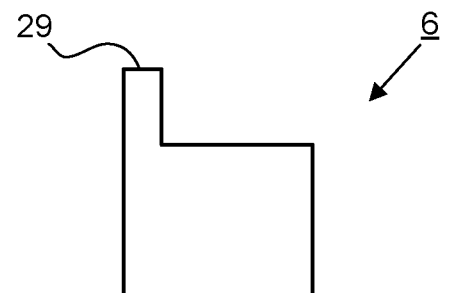
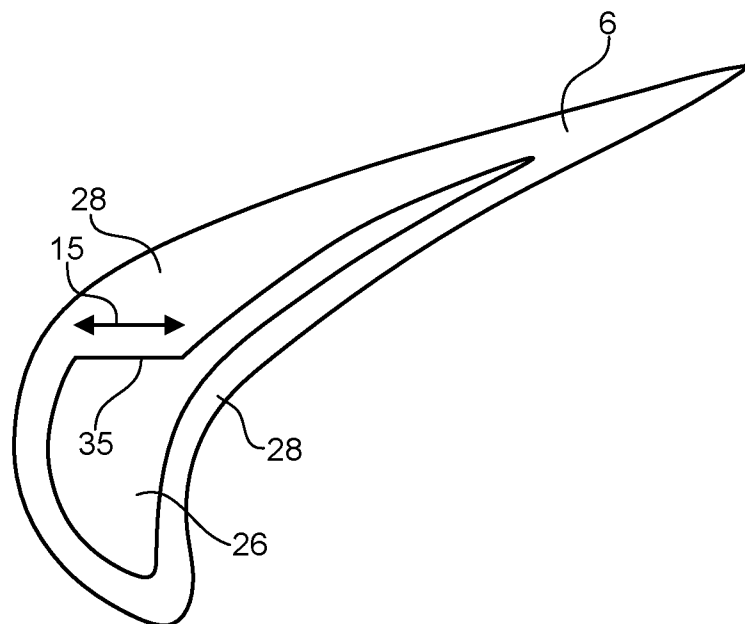


Fig.7



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Fig.8

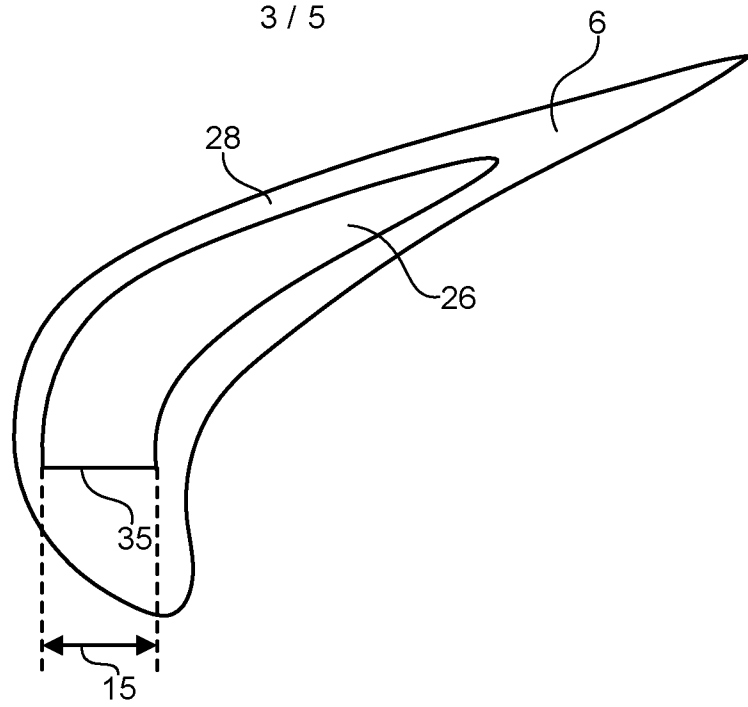


Fig.9

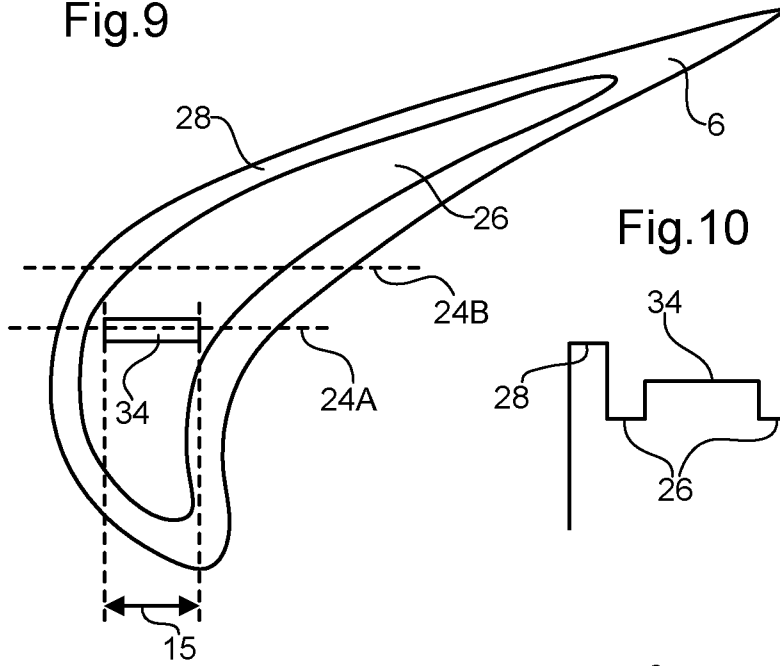


Fig.10

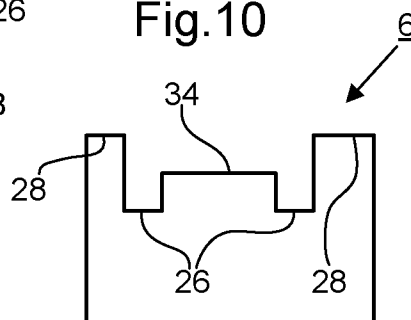


Fig.11

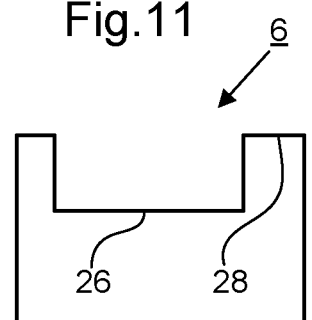


Fig.12

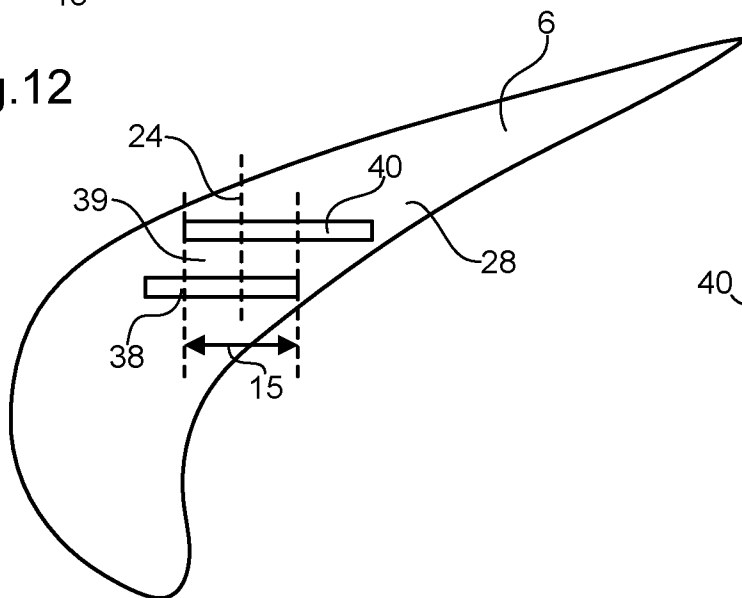


Fig.13

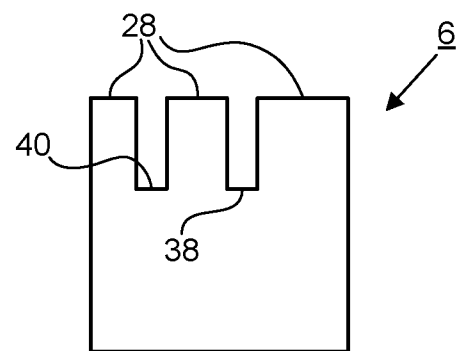


Fig.14

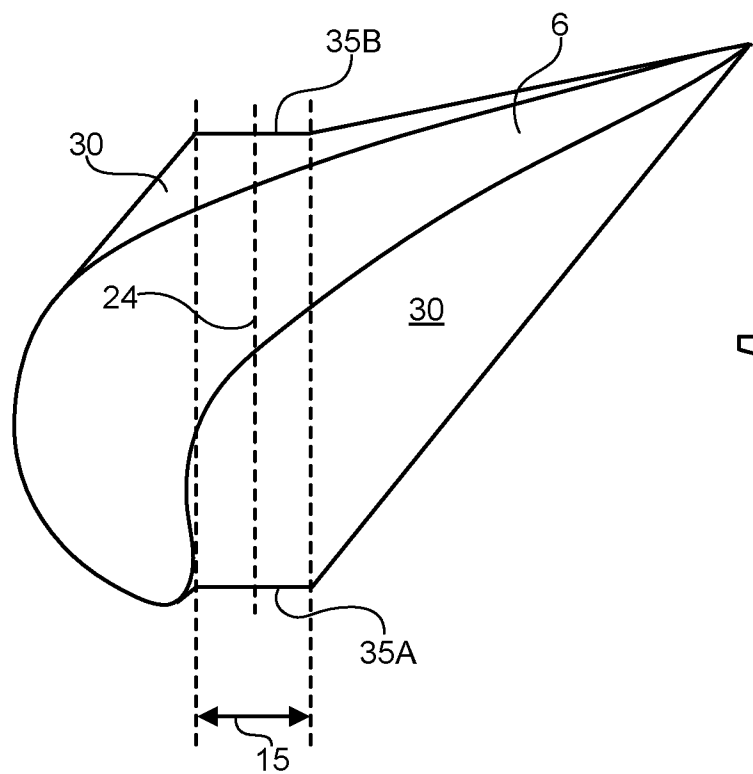


Fig.15

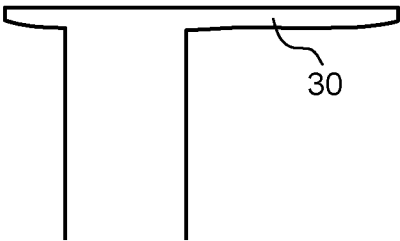


Fig.16

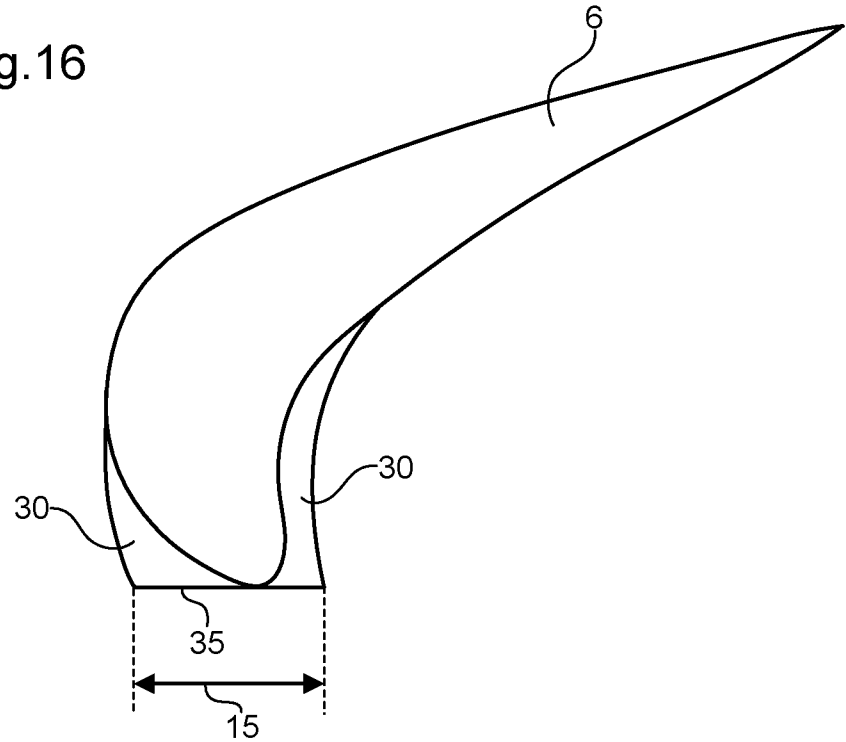


Fig.17

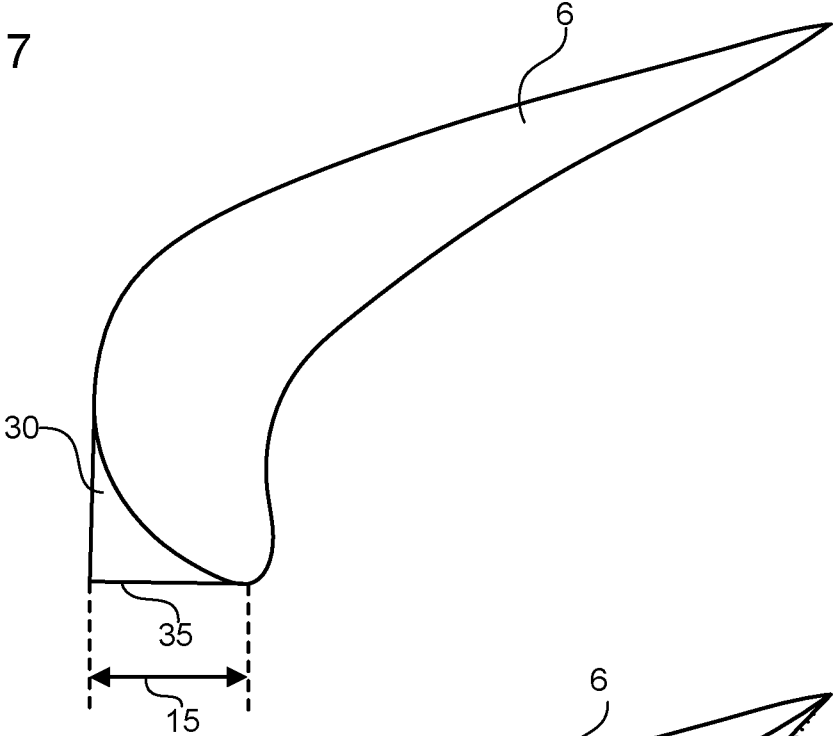


Fig.18

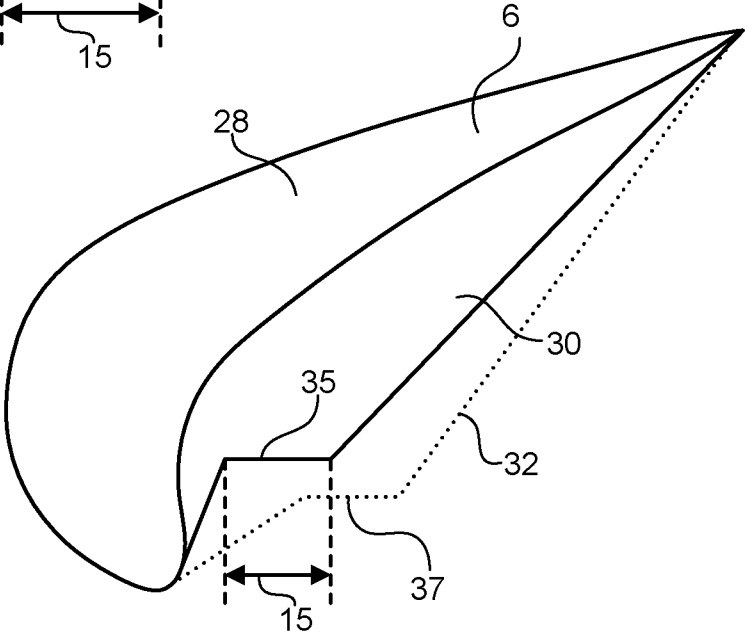
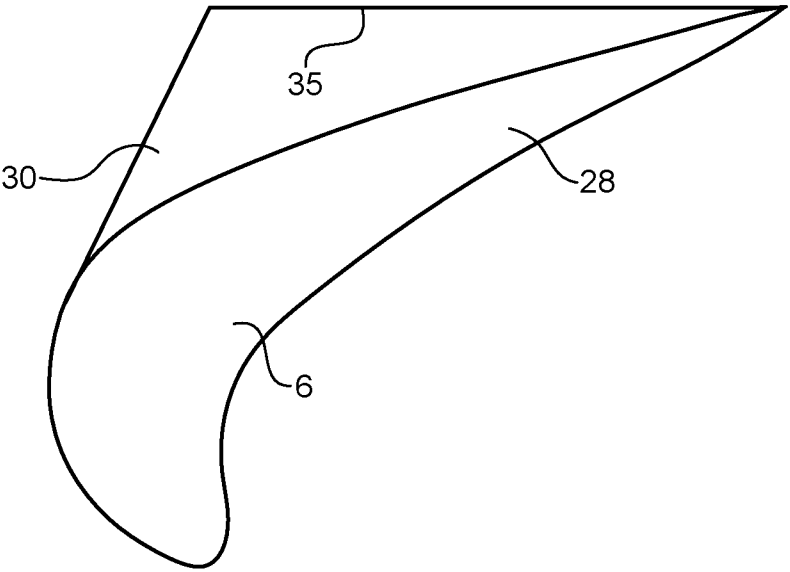


Fig.19



INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2013/051807

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01D17/20 F01D21/00 G01B7/14
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F01D G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 7 215 129 B1 (ANDARAWIS EMAD ANDARAWIS [US] ET AL) 8 May 2007 (2007-05-08)	1-5,35,36
Y	column 5, line 28 - column 6, line 22; figures 1-6	6-34
Y	----- US 2009/003991 A1 (ANDARAWIS EMAD ANDARAWIS [US] ET AL) 1 January 2009 (2009-01-01) paragraphs [0021] - [0027]; figures 1-11	6-34
X	----- WO 2008/031394 A2 (MTU AERO ENGINES GMBH [DE]; EBERL JOHANN [DE]; ZIELINSKI MICHAEL [DE];) 20 March 2008 (2008-03-20) page 8, paragraph 6 - page 9, paragraph 3; figures 1-2	1,2,4-7,14,15,18,22,35,36
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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"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

"&" document member of the same patent family

Date of the actual completion of the international search

20 September 2013

Date of mailing of the international search report

27/09/2013

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Oechsner de Coninck

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2013/051807

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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International application No

PCT/GB2013/051807

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			WO 2008031394 A2 20-03-2008

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			WO 9119963 A1 26-12-1991
