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Apparatus and method for active reduction of the noise
emission from jet engines and for their diagnosis

The present invention relates to an apparatus and a method for active reduction of the noise emission from jet engines and for their diagnosis.

The internal noise, as well as the external noise from jet aircraft, are nowadays governed primarily by the noise emissions from their jet engines. As air traffic increases, both the reduction of the internal noise in aircraft as well as, in particular, the reduction of the aircraft noise to which those living close to airfields are subjected are becoming more important.

Attempts are frequently made to achieve a reduction in the noise level in the interior of aircraft by further improvements to passive sound-proofing and silencing. The efforts to reduce noise also include measures relating to the decoupling of structure-borne sound. In this case, the aim is to prevent the sound emitted from a jet engine being transmitted to other parts of the aircraft, in particular to parts which are connected to the interior of the aircraft.

Furthermore, so-called DVAs (Dynamic Vibration Absorbers) are used which, within a defined, relatively narrow frequency spectrum, use resonance to absorb a portion of the vibration and oscillations transmitted through the aircraft fuselage structure.

Finally, in individual cases, noise compensation systems are also installed within the internal cladding of the passenger area of the aircraft fuselage. In this case, loudspeakers are used to emit compensation sound, in order to reduce penetrating engine noise.

The measures described for soundproofing, silencing, structure-borne sound decoupling etc. almost necessarily lead, however, to increased weight. In general, all the noise protection measures which increase weight reduce the efficiency of aircraft by reducing the payload and increasing the fuel consumption.

Furthermore, effective noise reduction is linked to high development costs for locating and combating the individual noise sources and the noise transmission paths. In the end, this cost is incurred with all new internal equipment for a jet aircraft. In order to design the noise reduction to be effective in the long term, the quality and the ageing of the materials used as well as the effectiveness of the processing techniques used must be investigated and approved using costly procedures. A general disadvantage of the systems mentioned above is that they do not result in any reduction in the noise emission in the area outside the aircraft.

In the past, various design measures were taken to reduce the external noise emission from jet engines. For example, the development of bypass engines led to a reduction in the noise emission. However, this noise reduction has still not reached a satisfactory level.

US Patent Specification 5,325,661 relates to a noise suppressor for jet flow mixers for high-speed jet aircraft. This suppressor mixes a high-speed air flow with a lower speed air flow. Acoustic waves which are produced by obstacles fitted in the jet nozzle are used to suppress noise.

US Patent Specification 5,758,488 describes a system for reducing the noise from aircraft turbines. This essentially comprises a noise reduction unit, a fan, an air flow diverter, a core flow expansion chamber device, a thrust-reverser and a tailpipe.

In these solutions, noise reduction is attempted by means of design, flow-mechanics improvements. Furthermore, apparatuses for active noise reduction have been proposed in the prior art, in order to reduce the external noise from jet engines.

PCT Application WO 96/12269 describes an electro-pneumatic apparatus. This operates with a reference signal. This reference signal is derived from the fan angular speed or blade passing frequency and from error signals which are sensed by acoustic transducers. The signals are used to actuate valves on the fan stage, from which valves an air flow whose pressure and temperature are regulated is directed for noise compensation.

PCT Application WO 96/11465 likewise describes an apparatus for actively reducing engine noise in the region of the engine inlet. The apparatus has sensors to measure the fan blade passage frequency and sensors to measure residual noise. Both sensors supply signals which are passed on to a control unit. The control unit is connected to loudspeakers which generate antiphased noise in order to reduce noise from the aircraft propulsion system. The sensors for measuring the blade passing frequency and the loudspeakers are fitted circumferentially in the wall of the engine inlet.

PCT Application WO 98/12420 also relates to an apparatus for the active reduction of the rotor machinery noise from rotor blades in aircraft engines. For this purpose, a fluid is passed at high pressure along the path of the source signal so that an inverted pressure wave is created relative to the pressure wave of the source signal.

US Patent Specification 3,936,606 describes an apparatus for reducing acoustic noise among other things in connection with a gas turbine engine. Here, the acoustic transducers are arranged at the outside of the engine or are spread over the complete outlet opening.

The object of the present invention is to provide an apparatus and a method for active reduction of the noise emission from jet engines, in which case a high level of noise reduction is intended to be achieved in a way which is as simple as possible and is effective in the long time, in particular in controlled acoustic conditions and avoiding major changes to the engine. In this case, the solution is intended to be applicable in both the inlet and outlet region of the engine.

This problem is solved by an apparatus for the active reduction of the noise emission of a jet engine which has an air inlet, a gas outlet and the actual engine, in which case the actual engine is arranged between the air inlet and the gas outlet. The apparatus has at least one first acoustic transducer in the air inlet upstream of the engine and/or in the gas outlet downstream of the engine, for

conversion of sound waves into first signals, which are a measure of the frequency, amplitude and phase of the sound waves, an electronic control unit for converting the first signals in the second signals, and at least one second acoustic transducer for converting the second signals into compensation sound waves whose frequency, amplitude and phase are such that the sound waves and the compensation sound waves at least partially cancel one another out. According to the present invention, the second acoustic transducer is arranged centrally in the air inlet upstream of the engine and/or centrally in the gas outlet downstream of the engine.

In the context of the present invention, the term jet engine also covers turboprop jet engines and turbines for supplying an aircraft with electrical power when the propulsion turbines are not in use, so-called "Auxiliary Power Units (APU)".

The first acoustic transducer is typically a microphone for picking up the sound waves emitted by the jet engine, while the second acoustic transducer is typically a loudspeaker for emitting compensation sound waves. Other acoustic transducers to achieve the same purpose may, however, be used just as well in each case. For the purposes of the present invention, the term acoustic transducer may also cover a plurality of acoustic transducers. The plurality of acoustic transducers may be used operatively for covering the entire relevant sound propagation area, the relevant sound front planes and the required frequency range.

The first acoustic transducer converts the sound waves into electromagnetic or optical first signals, which represent a measure of the frequency, amplitude and phase angle of the incident sound waves. These first signals can be processed using a microprocessor. For example, a Fourier analysis can be carried out in

order to break the complex sound pattern down into individual oscillations. Furthermore, specific frequency components, for example those outside the spectrum that is audible to human beings, can be excluded from compensation, unless this is regarded as being necessary, for example, for reasons of physical noise perception. The noise compensation by the second acoustic transducer is intended to be as complete as possible, that is to say the remaining residual noise level is intended to be as low as possible.

According to the invention, the second acoustic transducer is arranged centrally in the air inlet upstream of the engine, and/or centrally in the gas outlet downstream of the engine. The central arrangement of the second acoustic transducer is chosen since the symmetrical acoustic conditions, limited at the sides, achieved in this way considerably enhance the effectiveness of the noise compensation and simplify the noise compensation system overall. In particular, inaccuracies in the noise compensation resulting from delay time differences for sound waves from a number of loudspeakers not located centrally are avoided, in the same way as disturbing interference which can occur if a plurality of loudspeakers are arranged other than centrally, in particular located opposite to each other.

The first acoustic transducer is preferably likewise arranged centrally in the air inlet upstream of the engine, and/or centrally in the gas outlet upstream of the engine.

In the context of the present invention, the term "centrally" also covers an acoustic transducer arranged essentially in the middle. Jet engines frequently do not have entirely circular cross-sectional areas in the engine inlet and in the gas

outlet. In this case, the acoustic transducers must then be arranged essentially centrally, in such a way that they ensure largely symmetrical acoustic conditions.

Generally, in jet engines, noise is propagated primarily both forwards out of the engine inlet and to the rear out of the gas outlet, in the direction of the longitudinal axis of the engine. The acoustic transducers are therefore preferably arranged and aligned so that the compensation sound is emitted in a plane which is oriented essentially at right angles to the longitudinal axis of the engine, and thus parallel to its main sound front plane. Secondary sound front planes which differ from this may be covered by inclining the emission angle of a second acoustic transducer (which may be split on a sector basis) or of a plurality of second acoustic transducers.

The arrangement and alignment of the acoustic transducers in the jet engine, particularly if they are retrofitted to an already existing jet engine, also have to take account of aerodynamic aspects. This is because, with the given high airspeeds in jet engines, the transducers must never create excessive drag and must not reduce the performance of the engine beyond a negligible extent. It is therefore advantageous to arrange the acoustic transducers upstream of the front cone on the hub of the engine low-pressure compressor, in the region of the air inlet of the engine. In the rear exhaust area of the engine, the acoustic transducers are preferably fitted downstream of the tail cone of the engine, that is to say in its wind shadow. This not only reduces the drag but also improves the mechanical robustness of the arrangement with regard to the forces acting on it from the flowing air masses.

One preferred embodiment of the apparatus according to the invention has a first acoustic transducer and a second acoustic transducer both in the air inlet upstream of the engine and in the gas outlet downstream of the engine. This allows not only the noise emitted forwards from the jet engine but also the noise emitted to the rear to be combated. In this case, the noise compensation systems can operate completely independently of one another.

The apparatus for reducing noise emission preferably contains a cone which is fitted centrally in the air inlet of the jet engine and has at least one opening, in which case the first acoustic transducer and the second acoustic transducer are fitted in the cone in such a manner that they are acoustically connected to the air inlet via the opening. The noise compensation unit comprising the two acoustic transducers and, possibly, a microprocessor can thus be accommodated in the air inlet aerodynamically before the direct incident flow strikes it and so that it is protected against dirt, while at the same time acting optimally on the compensation area in the air inlet. Furthermore, the aerodynamic optimization of the cone ensures that the pressure conditions are comparable not only in the region of the acoustic transducers, but also in the compensation area, that is to say in the region in which the noise compensation takes place.

In order to avoid icing in appropriate weather conditions, the cone and the vanes of the noise compensation unit in the air inlet of the engine can be electrically heated.

In the rear gas outlet of the jet engine, the acoustic transducers are preferably fitted on a central holder which is matched, in terms of flow mechanics, to the tailpiece of the engine. Aerodynamic optimization is also desirable here in order

to produce similar pressure conditions in the region of the acoustic transducers and in the region of the compensation area. Aligning the acoustic transducers towards the rear avoids them being subject to direct incident flow and thus not only prevents a noise signal being produced by the incident flow, but also prevents the acoustic transducers from wear and dirt.

A further preferred embodiment of the apparatus according to the invention has a cooling device for cooling the second acoustic transducer and, possibly, the first acoustic transducer in the gas outlet. For this purpose, the acoustic transducer or transducers is or are screened, preferably by means of cladding, from being acted on directly by the gas flow. It is particularly preferable for the noise compensation unit to be installed in an outer cone at a distance. For cooling purposes, external air or, in the case of bypass engines, relatively cool air from the bypass flow, can be tapped off and introduced into this outer cone within one or more vanes. The cooling air can then flow away, enclosing the acoustic transducers, outwards into the gas outlet from the engine, and at the same time prevents the production of reverse-flow hot-gas turbulence, which could impinge on the acoustic transducers. In bypass engines, the cooling air continues to flow automatically as a result of its pressure drop, provided there is sufficient pressure difference between the bypass flow and the gas flow. This is reinforced by the dynamic pressure produced upstream of the acoustic transducers by the gas flow in the gas outlet from the engine. If the aircraft speed is sufficient, particularly in the case of plain jet engines, the cooling air may also originate from the environment. During flight, the subsequent flow of external air can be provided by the ram-air pressure at a point which is suitable for use as an air inlet. This allows the rear noise compensation unit to be thermally well controlled.

If operating states occur, for example during engine start up or shutdown or when using thrust reversal, in which the natural subsequent flow of the air is not sufficient for cooling and to compensate for turbulence, the cooling air can be assisted by a fan.

The effectiveness of the cooling for the noise compensation unit can be assisted by choosing suitable materials with low thermal conductivity for the outer cone and for the vanes which carry the air and, where necessary, by means of surface treatments which reflect thermal radiation.

The apparatus according to the invention can also be used for diagnosis of the condition and of the operation of the jet engine. For this purpose, the apparatus according to the invention has a comparison unit for comparing the first signals from the first acoustic transducer with nominal signals. The frequency of the sound waves being considered need not necessarily be determined accurately in this case. If a very narrow sound frequency spectrum is present, it is possible in some circumstances even to dispense with frequency analysis, and all the frequencies which occur within a range can be regarded as a representative frequency. It is sufficient to have the capability to distinguish in a worthwhile manner between sound waves at a different frequency in order to break down the sound pattern as far as the level required in practice. This level may vary depending on the application and depending on the requirements for the accuracy of the sound analysis.

An actual sound pattern is thus compared with a nominal sound pattern. This comparison allows diagnosis of the jet engine, since jet engines have a characteristic sound pattern for each of the various operating states. Disturbances,

for example caused by damage to the propulsion system, disturb this sound pattern. If the first acoustic transducer is arranged in the inlet cone of the engine or its exhaust area, further conclusions can be drawn with regard to wear, combustion-chamber deposits, dirty combustion due to poor fuel quality or mechanical damage, for example due to a birdstrike. In this case, it is often possible to deduce the nature of the defect from the nature of the disturbance to the sound pattern. In many cases, this conclusion about the condition – the long-term state - or the operation or operating state - the temporary state - of the jet engine requires further processing steps, in particular further comparison steps. However, at least the presence of a defect can normally be detected even without this further signal processing.

The first signals obtained in the first acoustic transducer, parts of these first signals or secondary signals derived from these first signals are used for the diagnosis process on the jet engine. The first signals obtained generally contain information about the frequency, the amplitude and the phase of a plurality of sound waves. However, in some cases, diagnosis of the jet engine can be carried out just on the basis of the frequency spectrum, without considering the amplitude and phase. In these cases, the amplitude need only exceed a specific limit value for the first acoustic transducer to indicate a consequence of the frequency occurring. This limit value may also be determined simply by the response threshold of the first acoustic transducer. If, for example, discrepancies occur in a predetermined variable or meaning of the actual spectrum from the nominal spectrum, these can be used to draw the above mentioned conclusions on the condition or operation of the jet engine. The nominal values are determined in advance for various typical operating states, for example different engine speeds, various load ranges or operating temperatures, and these are stored in the comparison unit, so that it is possible to compare the nominal values with the actual values in daily operation for a number, or a large number, of operating

states. In this case, it is not necessary to use all the information of the noise compensation unit such that, for example, a full frequency spectrum of actual values is compared with the corresponding nominal values. Selective comparison may be sufficient in all cases. The comparison itself is carried out regularly in a microchip or microcomputer, which is a part of the comparison unit.

The apparatus according to the invention preferably also has an output unit for outputting a warning signal when at least one previously defined discrepancy occurs between the first signals from the first acoustic transducer and the nominal signals. Such a warning signal may comprise a straightforward warning by means of a warning lamp or the demand to change the operating conditions, for example to reduce the thrust. For the purposes of this disclosure, such a warning signal is, however, also a signal which automatically results in a specific consequence, for example load matching, a change in the ignition timing, emergency disconnection or information to a control centre by radio that a specific malfunction has occurred.

The apparatus according to the invention preferably also comprises a selection unit for selecting first signals from the first acoustic transducer which correspond to one or more specific frequency ranges, in order to carry out the signal comparison. This allows selective comparison of frequencies, which requires less computer capacity and can therefore be carried out more quickly.

A further advantageous embodiment of the apparatus according to the invention has a service monitoring unit for calculating and indicating the date when the next servicing for the jet engine is due on the basis of the time behaviour of signals from the first acoustic transducer in comparison to the nominal signals for the

respective operating state. The service monitoring unit monitors the time behaviour of the actual values of first signals or parts of them, for example the frequency, and uses them to draw conclusions on when the next inspection of the engine is required. This is feasible since certain frequencies in the sound spectrum of the exhaust gases from an engine occur increasingly frequently when the engine is ready for inspection or overhaul. The present embodiment of the invention can thus be used to define individual inspection intervals which can not only result in considerable cost savings as a result of the average inspection intervals becoming longer, but can also result in an improvement in operating safety by inspection intervals actually being shortened. Particular advantages are feasible in this case, for example if the fact that an inspection is due on the aircraft engine is reported directly to an administration centre, which directly assigns the aircraft to inspection when it next arrives at a servicing airport or support-base airport.

In another advantageous embodiment of the apparatus according to the invention, at least one structure-borne sound sensor is arranged in or on the jet engine, preferably on its casing, and is used to associate the source of malfunctions with a specific section of the jet engine. If, as described above, a malfunction is found in the propulsion system, it is advantageous to determine the nature and location of the malfunction's source. The nature of the malfunction can frequently be deduced just from the actual signals, that is to say the frequency spectrum received. If certain malfunctions occur exclusively in certain parts of the jet engine, the nature of the malfunction also makes it possible to deduce the source of the malfunction, for example in the event of compressor instabilities. If this is not the case, it is, however, not possible to locate the origin of the malfunction. For these situations, the present embodiment of the apparatus according to the invention offers the capability to localize the origin of a malfunction by fitting one, or preferably a number of, structure-borne sound sensors to the casing of the

jet engine, whose results can be compared with one another so that the origin of a defect can be located. For example, such structure-borne sound sensors can be fitted to the casing of the jet engine, for example at the level of the first-stage compressor, another at the level of the main compressor and yet another at the turbines. If, for example, a malfunction occurs in the main compressor, the corresponding structure-borne sound sensor will normally exhibit the greatest change in the sound profile, from which the conclusion can be drawn that the malfunction source is located in the main compressor.

A further advantageous refinement of the apparatus according to the invention has a unit for synchronization of two or more engines, in which case this unit compares the first signals from the first acoustic transducer from the engines to be synchronized and then varies engine control parameters for the engines, for example the fuel supply, in such a manner that the first signals from the first acoustic transducers from the various engines become more consistent with one another. In the case of aircraft, the jet engines must run synchronously in order to avoid acoustic disturbances, such as beat frequencies or rumbling noises. These days, this engine synchronization is normally carried out by comparing the engine speeds. In practice, however, this engine speed comparison is subject to inaccuracy and a time delay, which hinders rapid and efficient synchronization. In the context of the described preferred embodiment of the invention, it is possible to compare the operating state of the engines with one another by comparing the first signals from the first acoustic transducers with one another and adapting the engine control parameters so that these first signals, for example the frequency spectra, become consistent with one another. This results in simple, effective and rapid engine synchronization.

A further preferred embodiment of the apparatus according to the invention has a monitoring unit, preferably also for calibration of a tachometer for a jet engine. Conventionally, the output from tachometers is based on measuring the rotation frequency of a rotating part, for example the central drive shaft of the jet engine. By virtue of the principle, such measurements include a range of error sources, which can lead to incorrect measurements. These measurement errors can be identified and corrected by using a monitoring unit. The first signals from the first acoustic transducers in the engine are compared with the output from the tachometer and, if necessary, corrected. This comparison is possible since each jet engine speed corresponds to a specific engine sound pattern. In addition to monitoring correct operation, it is also possible to calibrate the tachometer in defined sound propagation conditions. This can be done at predetermined time intervals or else when required, that is to say if a considerable discrepancy is found between the output from the tachometer and the engine speed determined by evaluation of the sound pattern.

According to the invention, a method is also provided for active reduction of the noise emission from a jet engine which has an air inlet, a gas outlet and the actual engine which is arranged between the air inlet and the gas outlet, comprising the following steps: (a) conversion of sound waves into first signals which are a measure of the frequency, amplitude and phase of the sound waves, in at least one first acoustic transducer which is arranged in the air inlet upstream of the engine, and/or in the gas outlet downstream of the engine, (b) conversion of the first signals into second signals in an electronic control unit, and (c) conversion of the second signals into compensation sound waves whose frequency, amplitude and phase are such that the sound waves and the compensation sound waves at least partially cancel one another out, in a second acoustic transducer which is arranged centrally in the air inlet upstream of the engine, and/or centrally in the gas outlet downstream of the engine.

The present invention thus provides an apparatus and a method for active reduction of the noise emission from a jet engine, in which case compensation for the noise at the noise source results in reduction in noise emission from the aircraft both for the environment and for the occupants, in a simple and efficient manner. The apparatus according to the invention and the method according to the invention offer these advantages with minimal use of energy, little design complexity, and negligible loss of performance, while at the same time saving weight for design noise protection measures on the aircraft. In this case, at least the second acoustic transducer is arranged centrally in the engine, thus creating the best possible symmetrical, laterally limited, acoustic conditions. In this solution, the compensation sound waves can be emitted, and, if appropriate, the sound can be received, essentially parallel to the main noise oscillation plane, thus achieving high noise compensation efficiency. The apparatus according to the invention can be mounted in a simple manner on the engine without having to carry out any major design changes. The apparatus according to the invention is thus also suitable for retrofitting to engines which are already in use. The noise compensation apparatus may be used not only in the air inlet but also in the gas outlet. This allows noise compensation at both ends of the engine. With a comparison unit added to it, the apparatus according to the invention can also be used for diagnosis of jet engines. The precise condition of a jet engine can thus be determined at any time.

The invention will be described in the following text using the attached figures by way of example, in which:

Figure 1 shows an embodiment of the apparatus according to the invention for reducing the noise emission from jet engines, including a diagnostic function.

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Figure 2 shows a detail from the rear engine end of the apparatus shown in Fig. 1, with acoustic transducers cooled by an air flow.

Figure 3 shows a schematic diagram illustrating the operation of the apparatus according to the invention.

List of reference terms

1	Jet engine
2	Suspension
3	Air inlet
4	Gas outlet
5	Engine
6, 6'	Noise compensation unit (pair of first and second acoustic transducers)
7, 7'	First acoustic transducer (microphone)
8, 8'	Second acoustic transducer (loudspeaker)
9, 9'	Additional first acoustic transducer (microphone) within the retaining
vanes 11, 11'	
10, 10'	Correction microphones
11, 11'	Retaining vanes

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12	Cone
13	Opening in the cone 12
14	Outer cone
15	Tailpiece of the engine 5
16, 16'	Electronic control unit (with frequency analysis unit)
17, 17'	Comparison unit
18	Diagnosis terminal
19	Outer casing of the engine 5
20	Inner casing of the engine 5
21	Structure-borne sound sensor
22	Structure-borne sound sensor
23	Structure-borne sound sensor
30	Sound waves
31	Signals from the first acoustic transducers 7, 7'
32	Signals from the electronic control unit 16, 16'
33	Compensation sound waves from the second acoustic transducer 8, 8'

The reference numbers followed by an apostrophe in each case denote components in the rear part of the engine.

Figure 1 shows a jet engine 1, in this case a twin-spool bypass engine, which is arranged on a suspension device 2. The jet engine 1 is equipped with an apparatus according to the invention in order to reduce the noise emission. The jet engine 1 has a front air inlet 3 and a rear gas outlet 4. The actual engine 5 is fitted between the front air inlet 3 and the rear gas outlet 4. The jet engine 1 shown in Figure 1 has both in the air inlet 3 as well as in the gas outlet 4, a first acoustic transducer 7 and/or 7', that is to say, for example, a microphone, and a second acoustic transducer 8 and/or 8', for example a loudspeaker. The front noise compensation unit 6 is monitored by an electronic control unit 16, and the rear compensation unit 6' is monitored by an electronic control unit 16'.

The front noise compensation unit 6, comprising the acoustic transducers 7, 8, is fitted in a cone 12 in the air inlet 3, which has an opening 13 for the acoustic transducers 7, 8 to communicate acoustically with the compensation area in the air inlet 3. The noise compensation area, bounded by the inner surface of the air inlet 3, in this case has a conical, and thus symmetrical, shape, which leads to defined acoustic conditions. The opening 13 in the cone 12 continues this symmetry. The microphone 7 and the loudspeaker 8 (which is in this case configured in an annular shape) are therefore arranged centrally. Design characteristics, in particular aerodynamic characteristics, could, however, also necessitate a different arrangement, which is not completely but is nevertheless essentially central. Three retaining vanes, which are provided at uniform angular intervals from one another and of which only one can be seen completely in Figure 1 as the vane 11, are used for suspension of the cone 12. This is arranged a short distance in front of the front end of the low-pressure compressor, which likewise has a conical shape. This design leads to the noise compensation system causing only a small amount of additional drag. This drag can be further reduced by aerodynamically advantageous shaping of the vanes.

At the rear end of the engine, the microphone 7' and the loudspeaker 8' are fitted on a platform which is matched, in terms of flow mechanics, to the tailpiece 15 of the engine 5 in order to avoid the formation of turbulence which could lead on the one hand to increased drag, and on the other hand to poor acoustic conditions with regard to noise compensation. In this case, the noise compensation unit 6' is fitted, so to speak, in the wind shadow of the engine 5. This unit is held by three vanes, which are fitted at equal angular intervals from one another, only one of which is shown completely, as the vane 11'. The retaining vanes are preferably shaped aerodynamically. In this way, turbulence can be avoided, and the drag can be minimized.

The noise compensation units 6, 6' with the first acoustic transducers 7, 7' and the second acoustic transducers 8, 8' are supplied with electrical power via supply lines in the retaining vanes 11, 11'. The connections to the control units 16, 16' (which are fitted in the engine nacelle) also run in the retaining vanes 11, 11'. The vane 11' can also be used to pass cooling air to the holder, if it is necessary to cool the rear noise compensation unit 6' together with the acoustic transducers 7', 8'.

Fig. 1 also shows two further microphones 9, 9', which are arranged upstream of the noise compensation plane within the retaining vanes 11, 11'. The microphones 9, 9' are used for supplementary detection of the engine noise, for measurement purposes. The acoustic measurement is carried out facing away from the flow through an opening on the rear edge of the vanes 11, 11'. The rear microphone 9' is thermally protected in an equivalent manner to the noise compensation unit 6', as is also described in the following text.

Two correction microphones 10, 10' are also shown, which are arranged inside the jet engine 1, downstream of the noise compensation plane, in the wall of the air inlet 3 or of the gas outlet 4. The correction microphones 10, 10' record any residual noise from the jet engine 1 which has not been compensated for, and are thus used to monitor the noise compensation.

The present embodiment of the apparatus according to the invention furthermore comprises devices for diagnosis of the condition or operation of the jet engine 1. The first signals, which represent the noise in the air inlet 3 or gas outlet 4 of the jet engine, are supplied by the first acoustic transducers 7, 7' to the electronic control unit 16, 16', where they are processed for noise compensation. The comparison units 17, 17' will either receive the data required for the comparison of the nominal and actual values described above from the electronic control units 16, 16', or receive the first signals directly from the first acoustic transducers 7, 7'.

Figure 1 also shows a diagnosis terminal 18 for comparison of the output signals from the two comparison units 17 and 17'. Discrepancies between the actual value signals and nominal value signals which have been determined by the front comparison unit 17 are compared in the unit 18 with the corresponding discrepancies which have been found by the rear comparison unit 17' in order in this way to make a reliable and/or differentiated statement about any malfunction which may possibly have occurred. Both the nature of the malfunction as well as the location of the source of the malfunction can be analyzed better in this way. Interfaces for external use of the diagnosis data are accommodated in the diagnosis terminal 18, for example for a data line to the cockpit, for data radio, for a floppy disc drive or a screen.

Figure 1 furthermore shows three structure-borne sound sensors 21, 22 and 23, of which the sensor 21 is fitted to the outer casing 19 of the engine 5, and the sensors 22 and 23 are fitted to the inner casing 20 of the engine 5. They are distributed and arranged in such a manner that the location of any malfunction which occurs and is diagnosed, for example, by the front comparison unit 17 or the rear comparison unit 17' can in many cases be localized better. This is because many defects cause structure-borne sound in addition to a differentiated airborne sound spectrum, which structure-borne sound is more or less characteristic, but in any case allows its local source to be identified. A defect can thus be localized more reliably and more quickly so that, for example, repair measures which have to be initiated can be determined in advance. The signals from the structure-borne sound sensors 21, 22, 23 are transmitted to the comparison units 17, 17' and/or to the diagnosis terminal 18.

The present embodiment of the apparatus according to the invention offers the capability for condition and operation diagnosis for a jet engine in a simple and cost-saving manner.

In order to prevent icing of the front acoustic transducer unit 6 in appropriate weather conditions, the inlet cone 12 and the vanes 11 may also be electrically heated. The electrical power for the heating elements is then preferably supplied through the vanes 11.

The apparatus shown in Figure 1 for reducing noise emissions from a jet engine can be arranged as an addition to an existing engine in a simple manner. In the case of new engine designs, integrated arrangements can in this case also be provided, which are even better matched aerodynamically.

Figure 2 shows a detail of the apparatus from Fig. 1. An outer cone 14, in which the compensation unit 6' is mounted at a distance, is provided in order to cool the rear noise compensation unit 6' together with the acoustic transducers 7' and 8'. In order to cool the noise compensation unit 6', cooling air is passed through the retaining vanes 11' into the outer cone 14. The cooling air passed through is introduced into the rear part of the outer cone 14 and then flows, enclosing the acoustic transducers 7', 8', away outwards into the gas outlet 4. At the same time, it prevents the production of reverse-flow hot-gas turbulence, which could impinge on the acoustic transducers 7', 8'. The outer cone 14 has appropriate openings for this purpose. External air, for example, or, in the case of the illustrated bypass engine, relatively cool air from the bypass flow, can be tapped off for cooling. If necessary, the cooling air is conveyed by means of a fan during the process of starting up or shutting down the engine. The rear noise compensation unit 7', 8' can be thermally well controlled in the described manner.

Figure 3 shows a schematic illustration of the method of operation of the present invention. Sound waves 30 arrive at the first acoustic transducer 7, 7', for example a microphone, and are converted into first signals 31 which are a measure of the frequency, amplitude and phase of the sound waves 30. The first signals 31 are processed in the electronic control unit 16, 16' and are converted into second signals 32 for noise compensation, these second signals 32 being phase-shifted through 180° with respect to the first signals 31. The sound waves 30 can in this case also be subjected, for example, to a Fourier analysis, in order to break the complex sound pattern down into elementary sine waves. Such a sine wave is shown in Figure 3.

The second acoustic transducer 8, 8', for example a loudspeaker, outputs compensation sound waves 33 corresponding to the second signals 32. If a Fourier analysis has been carried out one elementary compensation wave, for example, is emitted per elementary wave. Such an elementary compensation wave is likewise shown in Figure 3. This has the same frequency and amplitude, but the opposite phase, as the associated elementary wave which is likewise shown in Figure 3.

Claims

1. An apparatus for active reduction of the noise emissions from a jet engine (1) having an air inlet (3), a gas outlet (4) and an engine (5) which is arranged between the air inlet (3) and the gas outlet (4), having:
 - (a) at least one first acoustic transducer (7, 7') which is arranged in the air inlet (3) upstream of the engine (5), and/or in the gas outlet (4) downstream of the engine (5), for converting sound waves (30) into first signals (31) which are a measure of the frequency, the amplitude and the phase of the soundwaves(30),
 - (b) an electronic control unit (16, 16') for converting the first signals (31) into second signals (32),
 - (c) a second acoustic transducer (8) which is arranged centrally in the air inlet (3) upstream of the engine or in a centrally arranged cone upstream of the engine, for converting the second signals (32) into compensation sound waves (33) whose frequency, amplitude and phase are such that the sound waves (30) and the compensation sound waves (33) at least partially cancel one another out and /or
 - (d) a second acoustic transducer (8') which is arranged on a centrally arranged holder in the gas outlet (4) downstream of the engine (5), for converting the second signals (32) into compensation sound waves (33) whose frequency, amplitude and phase are such that the sound waves (30) and the compensation sound waves (33) at least partially cancel one another out.
2. Apparatus according to Claim 1, in which at least one first acoustic transducer (7, 7') is arranged centrally in the air inlet (3) upstream of the engine (5), and/or centrally in the gas outlet (4) downstream of the engine (5).

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3. Apparatus according to one of the preceding claims, in which the air inlet (3) has, centrally, a cone (12) having at least one opening (13), in which case the first acoustic transducer (7) and the second acoustic transducer (8) are fitted in the cone (12) in such a manner that they are acoustically connected to the air inlet (3) via the opening (13).
5
4. Apparatus according to Claim 3, in which the central cone (12) in the air inlet (3) is matched, in terms of flow mechanics, to the front end of the engine.
10
5. Apparatus according to one of the preceding claims, in which the gas outlet (4) has a central holder (14) for accommodating the first acoustic transducer (7') and the second acoustic transducer (8').
- 15 6. Apparatus according to Claim 5, in which the central holder (14) is matched, in terms of flow mechanics, to the tailpiece (15) of the engine (5).
- 20 7. Apparatus according to one of the preceding claims, furthermore having a cooling device for cooling the second acoustic transducer (8') and/or the first acoustic transducer (7') in the gas outlet (4).
- 25 8. Apparatus according to one of the preceding claims, furthermore having a comparison unit (17, 17') for comparing the first signals (31) from the first acoustic transducer (7, 7') with nominal signals.
9. Apparatus according to Claim 8, furthermore having an output unit for outputting a warning signal when at least one predetermined discrepancy

occurs between the first signals (31) from the first acoustic transducer (7, 7') and the nominal signals.

10. Apparatus according to Claim 8 or 9, furthermore having a service monitoring unit for calculating and indicating the date when the next servicing for the jet engine (1) is due on the basis of the time behaviour of the first signals (31) from the first acoustic transducer (7, 7') in comparison to the nominal signals.
11. Apparatus according to one of the preceding claims, characterized by a unit for synchronizing at least two jet engines (1), in which case the unit compares the first signals (31) from the first acoustic transducers (7, 7') of the jet engines (1) with one another and, in the event of a discrepancy, varies control parameters for the jet engines (1) in such a manner that the first signals (31) from the first acoustic transducers (7, 7') of the jet engines (1) are matched to one another.
12. Method for active reduction of the noise emission from a jet engine (1) having an air inlet (3), a gas outlet (4) and an engine (5) which is arranged between the air inlet (3) and the gas outlet (4), comprising the following steps:
 - (a) conversion of sound waves (30) into first signals (31) which are a measure of the frequency, amplitude and phase of the sound waves (30), in at least one first acoustic transducer (7, 7') which is arranged in the air inlet (3) upstream of the engine (5), and/or in the gas outlet (4) downstream of the engine (5),
 - (b) conversion of the first signals (31) into second signals (32) in an electronic control unit (16, 16'),
 - (c) conversion of the second signals (32) into compensation sound waves (33) whose frequency, amplitude and phase are such that the sound waves (30) and the compensation sound waves (33) at least partially cancel one another out, in a second acoustic transducer (8) which is arranged centrally in the air inlet (3) upstream of the engine (5) or in a centrally arranged cone upstream of the engine (5)

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and/or

(d) conversion of the second signals (32) into compensation sound waves (33) whose frequency, amplitude and phase are such that the sound waves (30) and the compensation sound waves (33) at least partially cancel one another out, in a second acoustic transducer (8') which is arranged on a centrally arranged holder in the gas outlet (4) downstream of the engine (5).

13. Method according to Claim 12, in which the first acoustic transducer (7, 7') in method step (a) is arranged centrally in the air inlet (3) upstream of the engine (5), and/or centrally in the gas outlet (4) downstream of the engine (5).
14. Method according to Claim 12 or 13, in which the first signals (31) from the first acoustic transducer (7, 7') are compared, in a comparison unit (17, 17'), with nominal signals.
15. Method according to one of Claims 12 to 14, in which a warning signal is output by means of an output unit when at least one predetermined discrepancy occurs between the first signal (31) from the first acoustic transducer (7, 7') and the nominal signals.
16. Method according to one of Claims 12 to 15, in which the date when the next servicing of the jet engine (1) is due is calculated and indicated by a service monitoring unit on the basis of the time behaviour of the first signals (31) from the first acoustic transducer (7, 7') in comparison with nominal signals.

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17. Method according to one of Claims 12 to 16, in which the first signals (31) from the first acoustic transducers(7, 7') from two or more jet engines (1) are compared and, on the basis of this comparison, control parameters for the jet engines (1) are varied in such a manner that the first signals (31) from the first acoustic transducers (7, 7') of the jet engines are matched to one another, in order in this way to synchronize the jet engines (1) to one another.