DEVICE FOR GROUND TESTING FORWARD FAN JET ENGINES

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7 Claims

ABSTRACT OF THE DISCLOSURE

An improved duct structure is disclosed for use in a jet engine that is being run on a test stand. The engine usually has a forward fan which is mounted on the compressor shaft and may take the place of the first stage of the compressor. It is usually larger than the compressor and therefore produces a certain amount of air which bypasses the compressor. This air would normally cause a loss over the engine during test and may cause injury to the test facility personnel as well as damage to the externally mounted engine accessories. The invention, instead of employing long slave ducts, each in one piece and attached to the discharge plate of the fan to conduct the bypassed air to a less harmful region, divides each slave duct into two separate portions, arranged end-to-end and to provide an air jet pumping action on the intermediate space and equips one of the portions with a bell-mouth entrance to enhance this aspirating effect. The presence of this air provides the beneficial effect of reducing the pressure within each aligned but separated duct pair to one not greatly in excess of the atmosphere. Thus, the same pressure differential is provided in each duct pair and the blades of the fan are caused to encounter the same resistance of flow as they move across each duct opening in the discharge plate, and the fan blade load variation is eliminated. This reduces the possibility of fan failure through metal fatigue.

BACKGROUND OF THE INVENTION

The present invention relates to the testing of jet engines, and more particularly, to engines that employ a forward fan. These fans are mounted on the compressor shaft, ahead of the compressor, or may constitute a part of the compressor structure as a substitute for the first stage.

The purpose of these fans is twofold: (1) they supply air directly to the compressor to increase the amount of compressed air flowing into the combustion chamber and (2) they provide a column of air which is guided past the front of the engine to cool its exterior and eventually, to join the jet stream to produce added thrust. This air-guiding function is obtained by the use of "short discharge ducts" which are secured to the discharge plate of the fan.

However, when the engine is removed from the plane for overhauling and later put on a test stand to determine its thrust, it is customary to provide long one-piece "slave ducts" connected to the discharge plate of the fan for directing the air along the sides of the engine to a position remote from the test personnel and also from the heat-sensitive instruments used during the testing operation. It has been found that when one-piece slave ducts are employed for this purpose, unless the ducts are carefully matched and symmetrically positioned with respect to the engine, considerable variation in the fan blade load might be encountered, and this variation would contribute to fan blade failure over a prolonged testing period. In addition, the long, single piece slave duct structure may require painstaking, time-consuming calculations in determining the overall thrust which must take into account any variation in the pressure drop in any one or more of the slave ducts. Moreover, the fact that the latter are long and in a single piece tends detrimentally to affect the engine performance parameters due to pressure variations within the respective ducts as well as the aerodynamic drag due to the passage of air through the duct system. On test stands where engine thrust is measured directly and the slave ducts are attached rigidly to the engine, the entire aerodynamic drag reduces the measured thrust and must be determined to attain the thrust actually being delivered by the engine.

SUMMARY OF THE INVENTION

An object of the invention is to provide a fan discharge slave system for determining the increase in thrust provided by a forward fan in a jet engine and which does not require calibration, but does eliminate the fan blast over the engine while providing maximum consistency to the engine during operation as well as safety to the test personnel. This object is carried out in brief by dividing each lengthy duct into two portions, arranging the portions end-to-end, and providing a space between them as well serve as an aspirator, or provide a jet pumping action to force discharge air into the duct system. The peripheral edge of one of the ducts at the said space is given a bell-mouth entrance to increase the rate at which the ambient air is admitted. Presence of the air at the separated duct edges assures that the pressure within the ducts is substantially atmospheric; thus each duct pair presents the same load pressure drop throughout its length which is greatly beneficial to the fan blades as they rotate across each duct opening at the fan discharge casing.

The invention will be better understood when reference is made to the following description and the accompanying drawings:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows by way of diagram a jet engine on a test stand with the improved duct structure in place and connected to the discharge plate of the forward fan casing. The ducts are shown in side elevation by full line while the outline and pertinent interior parts of the engine, as well as the test stand, are indicated in light dot-dash lines;

FIG. 2 is a sectional view of the improved slave duct system taken at about line 2—2 in FIG. 1 to accommodate an engine having an opening in the fan discharge plate as will accommodate a horizontally disposed accurate duct at the top and a pair of accurate ducts of less length of opening near the bottom;

FIG. 3 is a view of the fan discharge plate taken at about the line 3—3 in FIG. 1 and looking in the direction of the arrows;

FIG. 4 is another sectional view of the improved duct system shown in FIGS. 1 and 2 but taken at about line 4—4 in FIG. 1 and looking in the direction of the arrows;

FIG. 5 represents a fragmentary view showing the improved spacing and bell-mouth air entrance between two adjacent lengths of duct portions in accordance with my invention when one-piece slave ducts are employed for this purpose, unless the ducts are carefully matched and symmetrically positioned with respect to the engine, considerable variation in the fan blade load might be encountered, and this variation would contribute to fan blade failure over a prolonged testing period. In addition, the long, single piece slave duct structure may require painstaking, time-consuming calculations in determining the overall thrust which must take into account any variation in the pressure drop in any one or more of the slave ducts. Moreover, the fact that the latter are long and in a single piece tends detrimentally to affect the engine performance parameters due to pressure variations within the respective ducts as well as the aerodynamic drag due to the passage of air through the duct system. On test stands where engine thrust is measured directly and the slave ducts are attached rigidly to the engine, the entire aerodynamic drag reduces the measured thrust and must be determined to attain the thrust actually being delivered by the engine.

FIG. 6 shows the outline of a jet engine on a test stand using a modified form of the improved duct structure and connected to a discharge plate of the forward fan casing. The ducts are shown in full lines and side elevation, while the engine and parts of the test stand are indicated by diagram using dot-dash lines;
FIG. 7 represents a sectional view of the modified form of the improved duct system, taken at about line 7-7 in FIG. 6 to accommodate an engine having side openings in the fan discharge plate which accommodate two vertically disposed arcuate shaped ducts having considerable length.

FIG. 8 is also a sectional view of the improved and modified duct system shown in FIGS. 6 and 7 but taken at about line 8-8 in FIG. 6 and looking in the direction of the arrows;

FIG. 9 represents a fragmentary view showing the spacing between two broken away portions including the two adjacent ends of the modified form of duct structure in accordance with the principles of my invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring more particularly to FIG. 1, there is shown an outline of a test stand indicated generally at 1 and constituted of the usual I-beams and other metal supporting columns bolted or otherwise secured together. The purpose of a test stand is to rigidly support a jet engine in the horizontal position and to permit the engine to be operated at normal speeds so that its thrust can be determined.

FIG. 2 is a fragmentary view showing the outline of the engine but the back of the jet engine is not shown. The jet engine is illustrated as a gas turbine of the axial-flow type having a two-stage and three-stage compressor, a combustion chamber, a turbine and exhaust system.

FIG. 3 is a sectional view of the engine showing the jet engine, the fan 3 and the main compressor 20 and impinge on a single or multistage turbine fan, indicated generally at 21, which is mounted on the same shaft 22 as the compressor 5.

As is well known, the turbine rotates the shaft at high speeds and transfers the motive power to the compressor. The gases, still traveling at high speed, pass through the turbine 21 and out through the tail cone, indicated at 22', as a fast-moving jet.

FIG. 4 is a sectional view showing the path of the air through the engine. FIG. 5 illustrates a sectional view of the improved duct system showing the path of the air through the engine.

FIG. 6 is a sectional view of the improved duct system showing the path of the air through the engine.

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As is well known, the turbine rotates the shaft at high speeds and transfers the motive power to the compressor. The gases, still traveling at high speed, pass through the turbine 21 and out through the tail cone, indicated at 22', as a fast-moving jet. A conically shaped member 23 may be attached to the end of the shaft 22 in order to streamline the flow of the exhaust gases through the tail cone and, if desired, a similarly shaped member 24 may also be employed next to the forward fan 23 to facilitate the flow of air to the fan.

It is apparent that as the compressor is rotated, the fan 3 likewise rotates at high speed and serves to furnish additional air to the compressor as well as passing air between the peripheries of the compressor and the casing 7 and this air is normally used under flying conditions to add to the thrust of the jet stream. In order to obtain passage of this air from the fan 3 and carry it around to the exhaust system, the discharge plate 8 is provided with an opening 25, the boundary of which is defined by reference characters 26, 27 (FIG. 3). The line 27 corresponds with the periphery of the cone-shaped member 4. This opening is larger than necessary to permit sufficient air to flow to the combustion chamber. Part of the air issuing from this opening constitutes air under high pressure delivered by the compressor and the remaining part constitutes air which is delivered directly by the fan and is caused to bypass the compressor. The last-mentioned portion of air is collected by an improved duct system which will be described presently and is caused to flow past the engine to a position as to combine with the jet stream issuing from the tail cone 22. This additional air therefore serves to increase the thrust of the engine.

But when testing an engine of this character on an open test stand, the additional air must be conducted to a position where it will not interfere with the personnel operating the tests or with the heat-sensitive test instruments. It has been found in this connection that if two or more ducts are employed, each as long as the engine, and connected to the air discharge opening at the forward fan 3, unless these ducts are very carefully dimensioned and positioned with respect to the engine, which is almost impossible to do, unequal pressure drops, not only throughout the length of each duct of the system but also as between ducts are encountered. Consequently, as the forward fan rotates across each duct channel beyond the diffuser 9, severe load variations are reflected back to the fan blades and the latter exhibit a relatively early failure due to metal fatigue. Moreover, these long, single-piece ducts, when attached directly to the fan casing detrimentally affect engine performance parameters due to this variation in the air pressure drop as well as aerodynamic drag due to air passage through the duct system which is comprised of the long, one-piece elements. This aerodynamic drag reduces the measured thrust of the engine and must be taken into account to obtain the actual thrust produced by the engine.

Instead of using the long slave ducts connected directly to the discharge plate of the fan as employed heretofore, I employ, in accordance with my invention, the “short discharge ducts” referred to hereinafter and connect them directly to the discharge plate. The air expelled from these ducts is caused to pass into the bell-mouth entrance of long slave ducts which are spaced, end for end from the short discharge ducts. Thus, in FIG. 1, there is shown three slave ducts 24 made up of several different lengths, bolted together as indicated at 28 and each duct being formed of the combined lengths taking on an arcuate shape as seen by ducts 29, 30 and 31. These ducts, prior to my invention would have been connected directly to the discharge plate 8, but now, are separated from the fan discharge plate by a plurality of “short discharge ducts” generally indicated at 29, 30, 31. The latter are secured to the plate in any suitable manner. The openings in the center of the short discharge ducts 29, 30, 31 are shown more clearly in FIG. 3 wherein the openings are indicated at 25 as constituting an annular passageway through which the diverted air flows, The “short discharge ducts” designated 29, 30 and
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31 (FIG. 2) are of a partially circular configuration; the upper duct being of about twice the size of the two lower ducts 30, 31 as measured along the length of the respective openings. All ducts are symmetrically arranged within a circular configuration.

In order to clear the outline of the engine, the ducts 29, 30, 31 are directed outwardly in a smooth curve-like fashion until at the line 4—4 (FIG. 1) which represents the exit plane, the ducts take on a different shape than at the line 2—2 and become widely separated from one another as seen in FIG. 4. These ducts can be made of heavy sheet metal, rolled to the predetermined shape and the edges secured together to constitute a perfect circular closure. They may be supported as by bolts from any convenient part of the test stand shown in the background in FIG. 1.

As seen in FIG. 4, the two lower "short discharge ducts" 30, 31 cannot easily be supported from the test stand. For that reason, it may be desirable to provide or airpass FIG. 4) having duct system to fit snugly against the outside surface of the arcuate ducts. The outer edges of the ribs are formed as a right angle. Pivot holes 33 may be aligned through the ribs for receiving a relatively long stationary pin (not shown) about which the duct can swing outwardly and downwardly to allow the arcuate ducts to be placed in position. The lower inside corners of the two ducts may rest on a removable bar 34 after the engine is in place.

The right-hand end of each slave duct is shown as being spaced a short distance from the left-hand end of each "short discharge duct" and the inner edge of each slave duct is provided with a bell mouth entrance formed by a border plate 33 which extends angularly outwardly from the entire periphery of the edge of each duct.

The long ducts 24 which are usually called "slave" since they constitute an inseparable part of the test stand, extend practically over the entire length of the engine and their purpose is to carry or conduct the air given off by the "short discharge ducts" 29, 30 and 31 to a position remote from any position occupied by the test operators or their test equipment. The internal shape of the openings in the slave ducts conforms precisely to the arcuate openings of the short discharge ducts at the position indicated by the line 4—4 in FIG. 1. They can also be formed of sheet metal as in the case of the ducts 29, 30 and 31, rolled to form and the edges secured together. Their length can be changed by adding or subtracting one or more of the joined lengths. As stated hereinbefore, the "slave" ducts are usually permanently secured to the test stand.

It has been pointed out that it was customary to use only the single piece ducts regardless of their extreme lengths and to connect these ducts directly to the discharge plate 8 of the fan. However, it was found these systems detrimentally affect engine performance parameters due to the air passages (FIG. 1) having duct system. However, in accordance with my invention, by providing a space 39 between the discharge ducts 29, 30, 31 and the long ducts 24, and particularly, in providing a bell mouth rim 33 at the edge of each slave duct, I obtain a strong jet pumping action at the spacing 39 which causes air at ambient temperature to rush into the slave ducts as indicated by the arrow 40. This action is indicated in somewhat magnified fragmentary form in FIG. 5. This air tends to equalize the pressure variation throughout the entire length of each of the ducts since air at atmospheric temperature is introduced at the said opening and the fan will exert the same pressure as it rushes across each duct channel. Any fan blade load variation contributes to the early fan blade failure due to metal fatigue so that the fan has considerably longer life when using the spaced duct structure provided with the bell mouth entrance into each of the ducts that have been described hereinbefore. In view of the fact that the pressure variations throughout the entire length of the slave ducts are equalized by the admission of the ambient air, the improved duct structure eliminates the effect of aerodynamic drag in the slave ducts on the measured thrust, thereby permitting direct and correct reading of the thrust actually being produced by the test engine.

In FIGS. 6 and 7, I illustrate the application of the improved duct system as applied to the discharge plate of a forward fan which has side discharge openings rather than the top and the short lower openings. In this case, and as seen more particularly in FIG. 8, the ducts take on the form of a semicircular shape, spaced from one another at the top and bottom and are, as the case of the first modification, made of heavy sheet metal rolled to shape. In view of the extreme size as well as the length of these two ducts, it may be more convenient to make the ducts of several short lengths (FIG. 6) and to provide the outside edges with flanges indicated at 41 secured together by screws (not shown) located about the flanges. These flanges serve to maintain the arcuate configuration of the two ducts. The latter may be supported in any suitable manner from the test stand such as by screw bolts 42. The ducts may also be held in position, if desired, by furnishing triangularly shaped lugs 43 (FIG. 8) which are secured to extensions 44 provided under test stand.

The fan discharge plate is designated 45, and the part of the engine including the forward fan located to the right of the plate is indicated in phantom and may include the structure shown in FIG. 1. The discharge opening in the plate is of annular shape and contained between the boundaries 46 and 47 (FIG. 7). The opening accommodates that portion of the fan discharge, in the form of compressed air which moves through the annular passageway 48 on to the combustion chamber 49 as explained in connection with FIG. 1. The opening also receives the remaining portion of the fan discharge which flows through the modified form of "short discharge ducts" 51 and thence through the slave ducts 52 to a position remote from the test personnel to add to the thrust of the engine.

The ducts 51, of which there are two, as seen in FIG. 7, are secured in any suitable manner to the discharge plate 45. They are semicircular in shape, formed of thin walls and constituted of sheet metal rolled to shape. The ducts meet at the middle of the opening, top and bottom and the walls are spaced apart a distance such that when the outer wall is in coincidence with the outer boundary 47 of the discharge opening, the inner wall is approximately at a position about one third of the way between the boundaries 46, 47. Thus, the entire output of the forward fan, in passing through the openings 46, 47 will either have gone through the annular compartment 48 or through the two semicircular ducts 51 and into the slave ducts 52. As stated hereinbefore, the "short discharge ducts" 51 meet together at the top and bottom. But as the ducts extend upwardly and outwardly from the discharge plate, as shown in FIG. 6, the distance between the opposite sides of the duct is increased and the adjacent ends of the ducts become separated as shown in FIG. 8. However, the ducts retain the semicircular shape at their enlarged end. The interiors of the ducts 52 are shaped at their ends adjacent to the discharge ducts 51 similarly to the shape of the discharge ducts.

As in the case of FIG. 1, there is provided a space between the discharge ducts 51 and the slave ducts 52, the said space being indicated at 53. At the discharge duct nearest the short space is provided with a bell mouth entrance formed by a plate 54 which extends angularly outward from the edge. This spacing and the bell mouth entrance is provided for the same purpose as is set forth in connection with FIG. 1. In short, the spacing gives rise to a jet pumping action of ambient air as indicated by the arrows 55 (FIG. 6) and this air serves to equalize the pressure variation not only throughout the
7 lengths of each of the slave ducts 52 but also as between the slave ducts as a whole. This jet pumping action is also shown in magnified fragmentary form in FIG. 9. By tending to equalize the pressure variation between each of the ducts, the fan blade overload incidence is eliminated when the blades rotate past each duct channel so that there are no deleterious effects as would be encountered if the ducts 51, 52 were all in one piece and secured directly to the apertured discharge plate of the fan casing. In addition to the advantages mentioned, the high velocity fan discharge air blast over the front of the engine is directed to a position that no injury to test facility personnel or damage to engine accessories can be sustained, and yet affording maximum access to the engine.

What is claimed is:
1. A duct structure adapted to convey air from the forward fan of a turbofan jet engine undergoing test, said fan having a discharge plate with a plurality of openings therein, ducts secured to said plate at the respective openings, said ducts extending to the exterior of the engine to a position as to carry air from the fan to a position remote from the test personnel and instruments, each of said ducts comprising two separate lengths, in line with one another but separated by a relatively short air space which results in ambient air being forced into the duct system thereby tending to equalize the pressure variations throughout each duct and as between ducts whereby any tendency for unsymmetrical changes of pressure to be reflected back to the fan as it moves across the discharge openings is eliminated.

2. A duct structure according to claim 1 and in which the separated duct farther removed from the fan is provided about its perimeter with a lip which extends angularly outward in order to enhance the entry of air at the space provided in each duct.

3. A duct structure carrying air from the forward fan of a jet engine undergoing test, comprising a casing about said fan and having a plate on the discharge side, said plate being provided with a plurality of discharge openings, some of which lead to the compressor of the jet engine and the remaining openings which provide additional air, and means for conducting the additional air to a position remote from the position occupied by the test personnel, said means including a plurality of duct structures secured to said plate at the air discharge openings, each of said structures being formed of at least two portions placed end-to-end, said portions being spaced from one another at a distance as to induce a jet pumping action of ambient air into each duct structure whereby the pressure variations in all of the duct structures are equalized.

4. A duct structure according to claim 3 and in which one of said two duct portions which are placed end-to-end but spaced from one another to include a jet pumping action, has a bell mouth entrance to enhance the flow of ambient air therein.

5. A duct structure according to claim 3 and in which one of said two duct portions is considerably shorter than the other of said two duct portions, the duct portions of lesser length being secured to said discharge plate, and the duct portions of greater length being provided with a bell mouth entrance to enhance the flow of ambient air with said duct structures.

6. A duct structure for carrying excess air from the forward fan of a jet engine undergoing test, said fan being provided with a plate having openings on the discharge side, short discharge ducts secured to said plate at said openings, and relatively long ducts arranged in line with said short ducts to convey the air past the major portion of the engine, the ends of the short ducts being spaced from the adjacent ends of the long ducts, in order to permit entrance of the atmosphere as a jet pumping action and thereby tending to equalize the pressure variations between all of the double unit duct structures.

7. A duct structure adapted to convey air from the forward fan of a jet engine undergoing test, said fan having a discharge plate with a plurality of openings therein, said duct structure being formed of a plurality of individual ducts respectively in communication with said openings whereby as the fan moves each of said openings and its associated duct, variations in pressure between the ducts are reflected back to the fan blades which lessen the life of the fan, and means for counteracting the variations in pressure, said means including a separation between said individual ducts, and the two separate duct portions placed end-to-end and leaving an air space therebetween which causes a jet pumping action at the air space which tends to equalize the pressure in the duct portions and thereby prevents any damaging pressure reaction on the fan blades as the blades pass across the path of one duct opening to another opening.

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