Oct. 20, 1970 **H. D. CONNORS** **3,534,548**

SEPARATOR APPARATUS FOR ENGINE AIR INLETS

Filed June 30, 1969 3 Sheets-Sheet 1

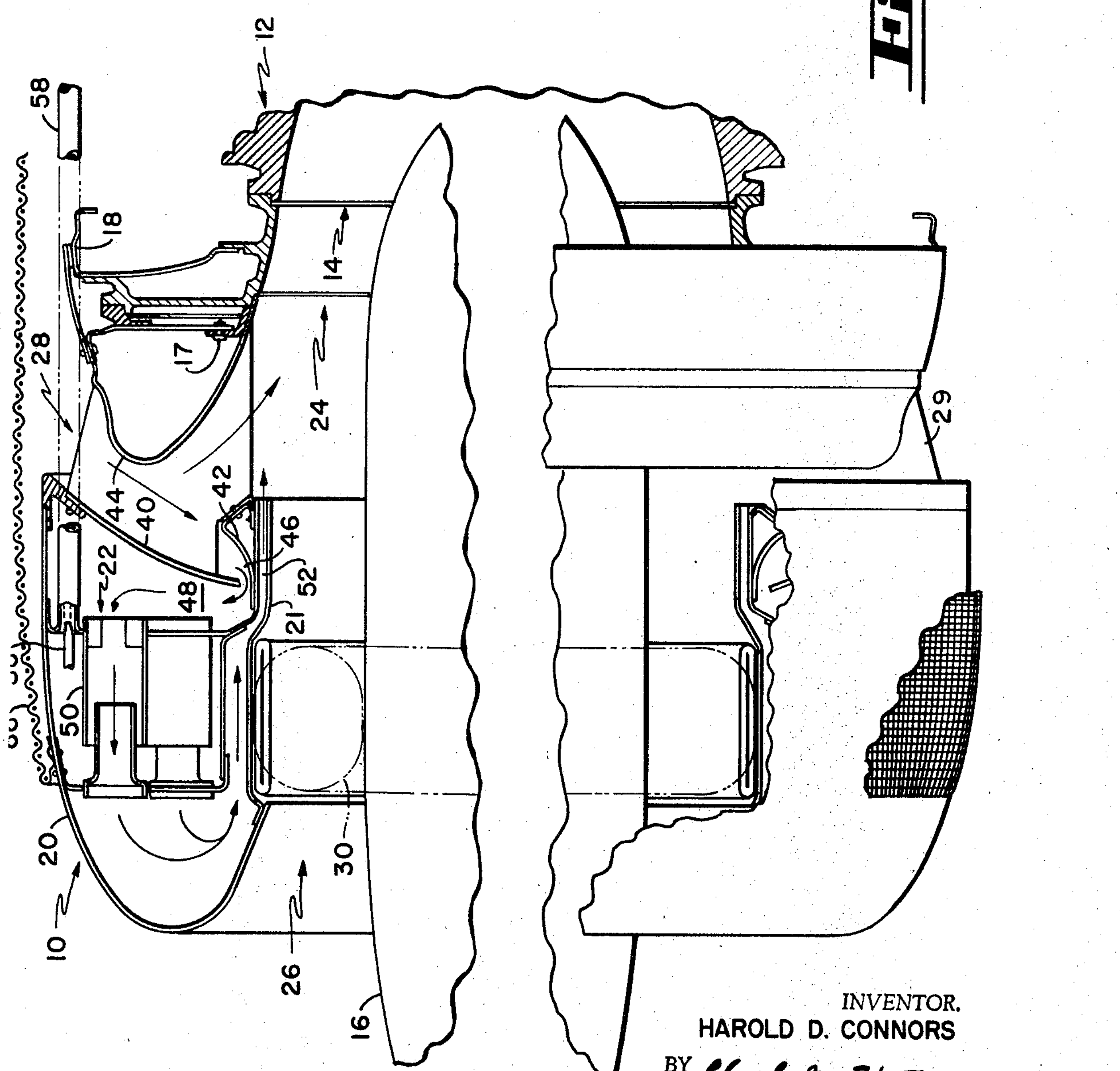

Fig 1

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SEPARATOR APPARATUS FOR ENGINE AIR INLETS

Filed June 30, 1969 3 Sheets-Sheet 2

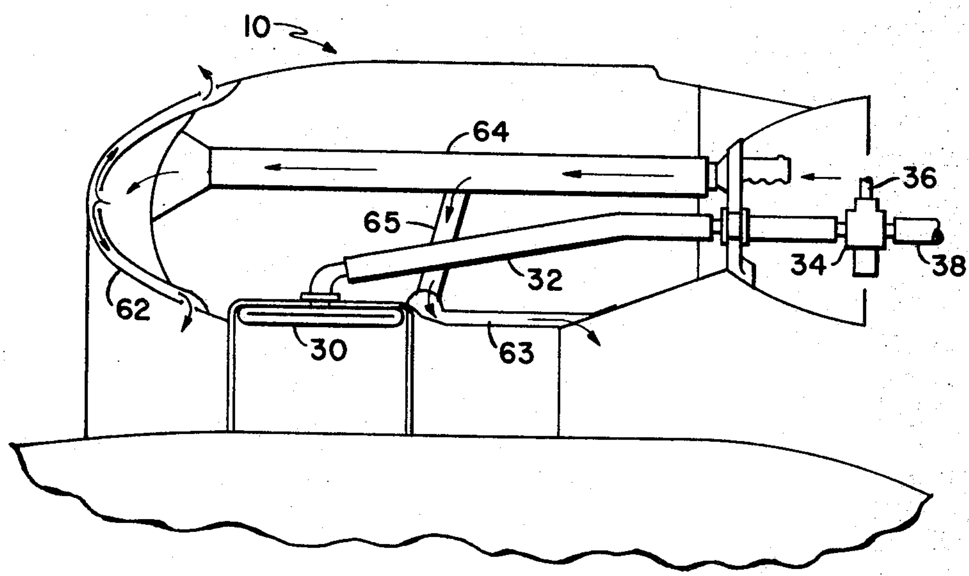

Fig 7

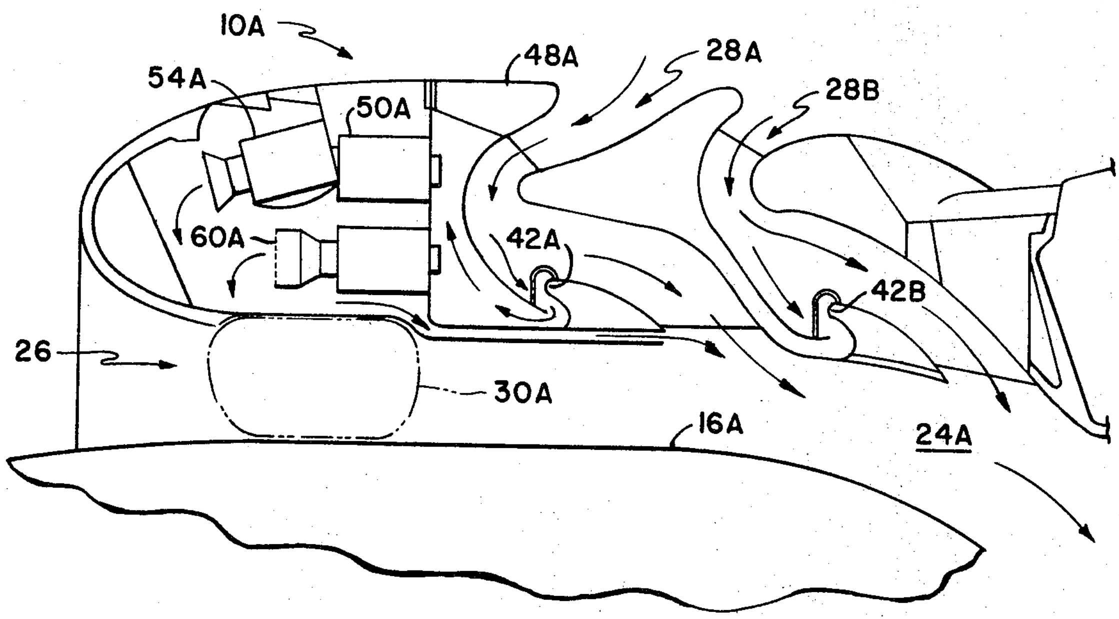

Fig 5

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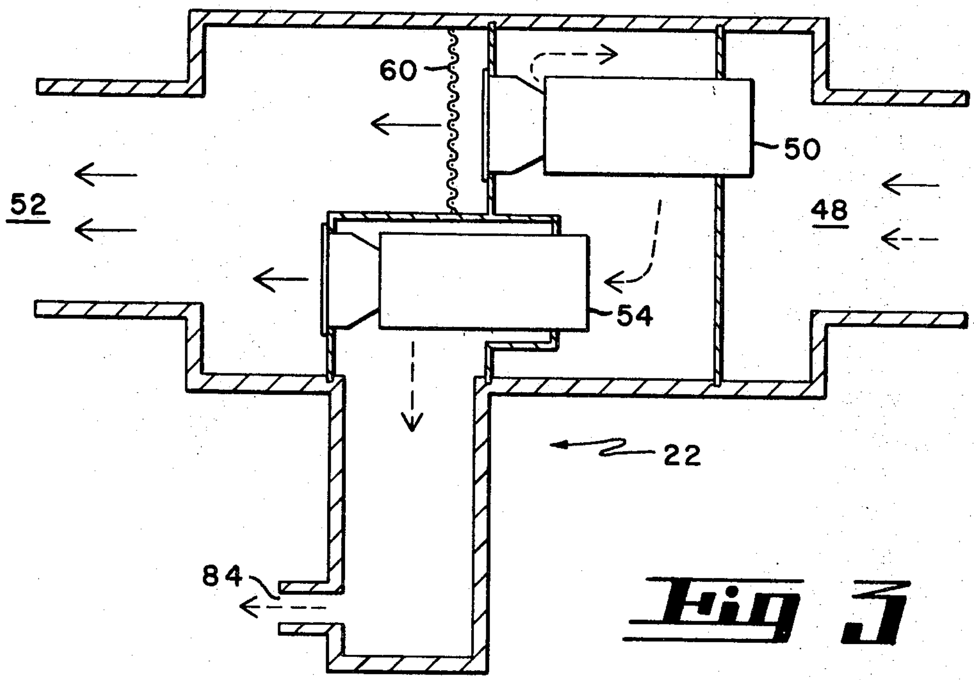

Fig 3

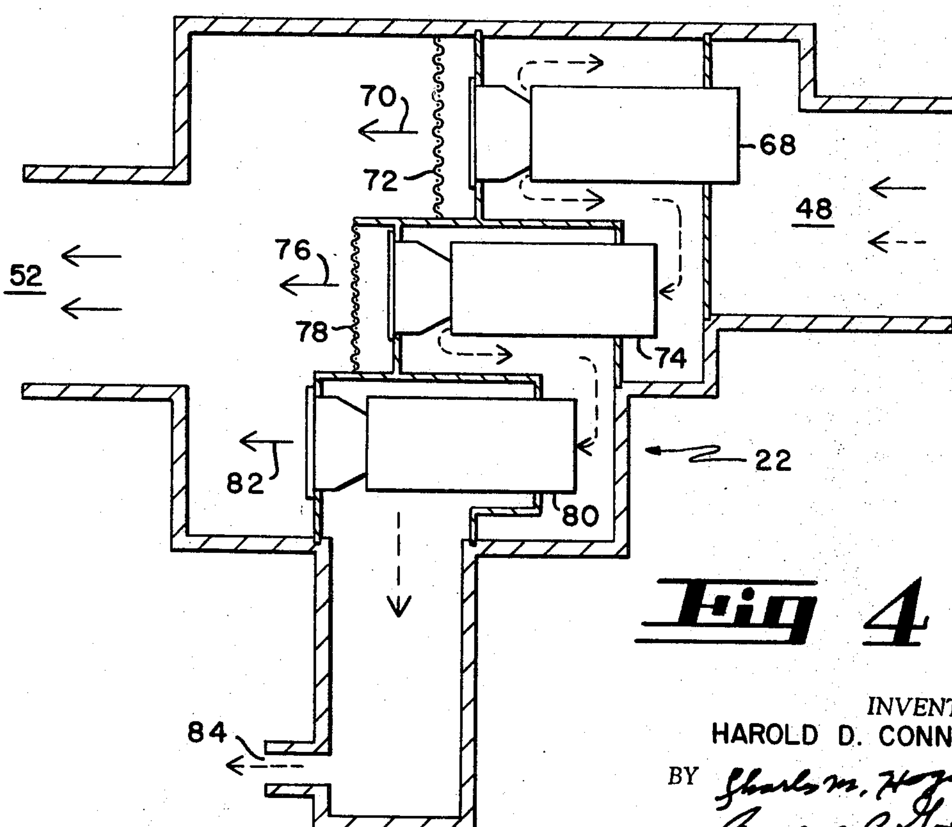

Fig 4

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3,534,548

SEPARATOR APPARATUS FOR ENGINE AIR INLETS

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Int. Cl. F02c *7/04*
U.S. Cl. 60—39.09 10 Claims

ABSTRACT OF THE DISCLOSURE

This disclosure describes an apparatus for attachment to a gas turbine engine for separating and removing foreign particles from the engine air supply. The separator provides separate primary and secondary airpaths which are combined in a main flow path upstream of the engine inlet. An expansible dam is positioned in the primary airpath for preventing flow in the primary path during periods of separator utilization. During periods of separator utilization, all engine air is drawn through the separator and cleaned air from the separator enters the engine inlet. Particle contaminants are removed from the airstream. Anti-icing means are also provided in the separator.

BACKGROUND OF THE INVENTION

This invention relates to a contaminant separator for use adjacent the air inlet to a gas turbine engine, and more patricularly to a separator apparatus for removing foreign matter such as sand and dust from the airstream.

Aircraft turbine engines are particularly susceptible to damage from foreign objects introduced into the air intake stream of the gas turbine engines. Stones, gravel and other foreign matter drawn into the airstream often rupture, distort, and damage blades and other component parts of the engine. These particles, which individually have little effect on the engine, can cause very substantial damage when introduced into the engine in large quantities. For example, it has been found that the engine of a helicopter operating at low altitude in a desert environment can lose performance due to erosion of engine blading by high velocity sand particles. In addition, the desired balanced condition of the compressor is often disrupted and the useful life of the engine shortened, if it is not completely destroyed.

The importance of removing small foreign particles, such as sand and dust, has long been recognized. Many mechanisms for accomplishing this purpose are known in the art. One example is the separator shown in U.S. Pat. 3,371,471 to H. D. Connors and assigned to Avco Corporation. However, the present invention provides certain improvements recognized as important. Some improvements and advantages of the present invention are the self-cleaning capability, minimal maintenance requirements, compact, lightweight, accessible, small volume of carrier air, low pressure loss, small amount of power required to eject contaminant and effectiveness over a broad range of particle size from full design flow to ½ flow.

Accordingly, it is an object of this invention to provide a lightweight and compact separator for effectively removing contaminant from the airstream supplied to a gas turbine engine.

A further object of this invention is to provide a separator with the above-mentioned advantages.

SUMMARY OF THE INVENTION

This invention provides an improved contaminant separator for removing contaminants from the stream of air supplied to the inlet of a gas turbine engine. The separator utilizes centrifugal forces acting on the contaminants in

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the separating stations to extract the contaminant from the stream of air. Cleaned air from the separating apparatus is in communication with the main airstream and reenters the airstream upstream of the engine air inlet. Means are provided for preventing airflow in the primary airpath during periods of separator utilization.

Other details, uses, and advantages of this invention will become apparent as the following description of the exemplary embodiments thereof presented in the accompanying drawings proceeds.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings show present exemplary embodiments of this invention in which:

FIG. 1 is a vertical section, partially in cross-section, through the separator assembly in a vertical plane and showing the engine transmission and drive shaft fairing extending forward of the annular air inlet to the engine;

FIG. 2 is a cross-sectional view showing the inflatable dam and anti-icing means;

FIG. 3 is a diagrammatic representation of a dual-stage cyclonic separating station used in the present invention;

FIG. 4 is a diagrammatic representation of another embodiment of the present invention utilizing a three-stage cyclonic separating station; and

FIG. 5 is a diagrammatic view of another exemplary embodiment showing multiple inlet channels.

DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENT

Reference is now made to FIG. 1 which illustrates one exemplary embodiment of the improved contaminant separator of this invention, which is designated generally by the reference numeral **10**. The separator assembly **10** is designed for mounting on the front of a gas turbine engine **12**, having an annular air inlet **14** and a forwardly extending engine transmission and drive shaft fairing **16**. The forwardly extending fairing **16** may have varying configurations depending on whether the engine is a turboprop, geared helicopter, high speed helicopter, or turbofan version and the present showing is only an exemplary embodiment.

The specific structure illustrated in FIG. 1 is a cross-section of an annular separator assembly **10** with the longitudinal axis of the fairing **16** or the axis of the engine as a centerline. The separator assembly **10** is cantileverly mounted to the inlet fairing **18** by suitable means such as bolts **17** which provide for easy attachment and removal of the separator **10**. The separator assembly **10** comprises an annular outer housing member **20** and an inner housing member **21** within which is mounted means **22** for removing contaminant from the airstream as will be explained herebelow.

The separator assembly **10** defines two separate flow paths which combine into a main flow path **24** upstream of the engine inlet **14**. The two airpaths are defined as a primary axial flow path **26** and a secondary flow path **28**. During normal operation of the engine, the majority of the airflow is through the primary airpath **26** to the main flow path **24** and then to inlet **14** with a small portion of secondary air being drawn through the secondary airpath **28**.

An inflatable boot or dam member **30** is mounted to the inner housing **21** adjacent the primary airpath **26**. The expansible boot **30** has an unexpanded position shown in solid line and an expanded position shown in phantom line. When the boot **30** is in the unexpanded or retracted position, the primary airpath **26** is not obstructed and air can flow therethrough to the main airpath **24** and engine inlet **14**. However, when the inflatable boot **30** is in the expanded position, it forms a dam or complete obstruction in path **26** since the boot inflates until it touches or engages fairing **16**, thus preventing any airflow through the primary airpath **26**. In the boot expanded condition, all air supplied to the engine inlet **14** is drawn through the secondary airpath **28** and will be cleaned by the separator assembly **10**.

As best seen in FIG. 2, the inflatable boot **30** is in communication with a compressor inlet vacuum source (not shown) and a compressor pressure source (not shown). Suitable means such as tubing or conduit **32** connects the boot **30** with a valve **34**. Conduits **36** and **38** connect the valve **34** with the compressor inlet vacuum source and the compressor pressure source, respectively. Thus, to inflate the boot **30**, valve **34** is energized such that the vacuum source conduit **36** is cut off and the boot **30** is directly in communication with the pressure source conduit **38**. To deflate or retract boot **30**, the valve is deenergized so as to shut off the pressure source and vent the boot to the vacuum source so that boot **30** is in communication with the compressor inlet vacuum source conduit **36**.

As seen in FIG. 1, an annular curved wall **40** extends from the housing **20** radially inward and terminates closely adjacent a catching lip or wall **42** which is attached to the housing **20** along the interior side. A formed wall **44** is attached to the inlet fairing **18**. Walls **40** and **44** and the lip **42** define the secondary airpath **28**. Thus, air containing contaminant such as sand and dust passing through the secondary airflow is initially accelerated and then drawn through a turn. The contaminant is deflected onto the outer flow wall **40** because of the centrifugal forces acting on the contaminant particles. The contaminant particles are prevented from continuing to the engine inlet **14** by the catching lip **42**.

Side splitter vanes **29** may be mounted in the inlet to the secondary airpath **28** to prevent a tangential contaminant path and to guide the contaminant particles to improve the separator effectiveness. It has been found that approximately 90% of the air is initially drawn into the engine inlet passage while 10% of the air is caught by wall **42** and passes through passage **46** as carrier or transport air for the contaminant.

The termination edge of flow wall **40** and catching lip **42** define a passage **46** which is in communication between the secondary flow path **28** and the means **22** for removing the contaminant from the airflow. Thus, contaminant and carrier air from secondary path **28** is deflected by lip **42** through passage **46** to a chamber **48** which is upstream of the contaminant removing means **22**.

The contaminated air from chamber **48** passes through a series of centrifugal cleaning stations. Each cleaning station comprises a plurality of cyclonic or vortex type separating tubes which operate in a well-known manner. As an example, the contaminant laden air is admitted past inclined guide blades or through a tangential inlet into a chamber, called a cyclone chamber whereby the air is set spinning therein and by the centrifugal force thus engendered concentrates the particles toward the periphery of the cyclone chamber. The concentrated particles are discharged at the periphery of each chamber and the particle- or contaminant-free air passes on straight through the cyclone separator.

The operation of the series or system of cleaning stations is best depicted in the diagrammatic representation of FIG. 3 where it is seen that the contaminated air passes from chamber **48** to a first bank of cyclonic separator tubes **50** where the contaminant is removed as above described. It is also noted that about 10% of the air passing therethrough is discharged as contaminant carrier air.

In this description, dashed arrows represent the contaminant and carrier air while plain arrows represent the clean air.

In order to have the cleaning system operate, it is necessary to back pressure the tubes **50** by restricting the discharge of the tubes. This is accomplished through the use of a fine mesh screen or similar device **60**. Thus, cleaned air from tubes **50** is transmitted through screen **60** to a cleaned air passage **52** and reenters the secondarry airpath **28** to combine therewith upstream of the engine inlet **14**. Contaminant from the primary tubes **50** plus a small percentage of carrier or transport air, approximately 10% of the air passing through tubes **50**, is transmitted to a second cleaning station bank having a fewer number of cleaning tubes **54** for further cleaning and separation. Clean air from the second bank of tubes is also transmitted through the passage **52** for reentry into the secondary airpath. Inasmuch as the second bank of cleaning tubes is the final separation step, the cleaned air from tubes **54** need not pass through a back pressuring screen but is transmitted directly into the passage **52**. Back pressure is not needed at this stage of the cleaning system. The motivating power required to draw the air and contaminant of the secondary air system through the separator **22** is the velocity head at the engine inlet.

Concentrated contaminant from the second bank of cleaning tubes may be either accumulated in a storage chamber or dumped overboard by any convenient method such as the use of one or more contaminant air ejectors **56** (FIG. 1) which receives a source of high pressure air from the compressor for ejecting the contaminant through an ejection tube **58** to the atmosphere.

The separator assembly **10** incorporates an anti-icing arrangement which operates in a normal manner. As seen in FIG. 2, the leading and interior surfaces of the separator define anti-icing passages **62** and **63** which are in communication, through conduits **64** and **65**, with the ducts (not shown) normally supplying anti-ice hot air to the air frame/engine air inlet fairing. Thus, during icing conditions engine bleed air is transmitted through conduit **64** to passages **62** to prevent icing of the separator assembly **10**.

To protect the engine from the effects of grass, etc., and large foreign object damage, a large area screen, perforated plate, louvered intake, or similar device **66** is used. The screen is attached to the separator in any known manner.

FIG. 4 is a diagrammatic representation of another embodiment of the removal means **22** in which a three-stage cyclonic separator assembly is utilized instead of the two-stage assembly as illustrated in FIG. 3. The operation of the three-stage assembly is identical with the operation above described in the two-stage. Contaminated air enters the first bank of primary tubes **68** and cleaned air **70** passes through the back pressure screen **72** for reentry into the secondary flow path **28**. The contaminant plus carrier air from the tubes **68** is transmitted to a bank of secondary tubes **74** for a secondary cleaning and contaminant separation. Cleaned air **76** passes from the secondary tubes **74** through a back pressure restricting screen **78** for reentry into the secondary airpath **28**. The contaminant from the secondary tubes plus the small amount of carrier air is transmitted to the third stage or tertiary tubes **80** for final cleaning and separation. Cleaned air **82** passes from the tubes **80** for direct reentry into the secondary airpath **28** and concentrated contaminant **84** from the tubes **80** is transmitted for either accumulation or ejection overboard. It should be noted that the staged cyclonic separator cleaning assembly can have any number of cleaning stages or banks of tubes. The system will operate as long as each preceding stage is back pressured and the contaminant is transmitted to the inlet of the next stage. The final cleaning stage is not back pressured.

Another exemplary embodiment of this invention is illustrated in FIG. 5 of the drawings. The separator assembly illustrated in FIG. 5 is very similar to the separator assembly **10**; therefore, such separator assembly will be designated generally by the reference numeral **10A** and parts of the separator assembly **10A** which are very similar to corresponding parts of the separator assembly **10** will be designated by the same reference numeral as separator assembly **10** also followed by the letter designation "A" and not described again. The main difference between the separator assembly **10A** and the separator assembly **10** is in the secondary airpath. In this embodiment, the secondary airpath is comprised of multi-channels **28A** and **28B**. It is seen that channel **28B** is axially displaced relative to the channel **28A**. Each channel has a catching lip **42A** and **42B** for catching and deflecting contaminated air into the separator chamber **48A**. For purposes of this explanation, the conduits or ducts connecting catching lip **42B** and chamber **48A** are not shown. The contaminated air passes from chamber **48A** to the first bank of cyclonic separator tubes **50A** which are back pressured by screen **60A**. Contaminated air from tubes **50A** is transmitted to the second cleaning stage, comprising a plurality of cleaning tubes **54A** for further cleaning and discharge as previously described. The inflatable boot **30A** prvents air from passing through the primary passage **26** when the separator is in the operational mode. It should be noted that any number of secondary air channels may be utilized. In addition, each of the channels is connected individually or in common with the contaminant removal means. One advantage of the multichannel separator is to reduce the overall pressure loss during the operational or separating mode.

The principle of operation is that during a sand ingestion environment the inlet dam is inflated to block off the normal air passage to the engine. Blockage of this channel causes the engine to now pass through the inlet louvered screen and traverse a turn. The air and sand particles are initially accelerated, then they are slung to the outer wall by their inertial force as the airflow is decelerated and turned over 90°. The particles impinge on the channel outer wall that is contoured to control the ricochet angle of the particles so that they bounce and flow into the sand catching lip mounted on the channel outer wall. Approximately 10% of the initial inlet air flowing through the secondary airpath is used as a carrier medium for the sand. About 90% of the carrier air at every cleaning stage is returned to the secondary airpath for transmission to the engine inlet. The suction head available at the engine inlet face is the motive power for the carrier air. The sand may be deposited in the lower section of the separator and either collected or damped overboard by means of a pump, blower, gravity or venturi device. The louvered inlet protection screen is an aid in preventing large objects, grass, etc., from entering the engine intake. The screen area may be large to minimize pressure loss.

During normal operation outside a sand and dust environment the inlet dam is retracted and a normal path is resumed to the engine.

It should be noted that during the normal operating conditions some air will be drawn through the secondary airpath although the primary airflow is through the primary axial flow path. It can be seen that the separator assembly will be in reduced operational mode, due to the small airflow in the secondary airpath, during conditions when the inflatable boot is in the retracted position.

It is noted also that in the preferred form of the invention shown the parts are annular to conform to the engine inlet position and configuration, although important features of the invention could be accomplished by rectangular or other shaped parts having substantially the same general cross-section as shown.

It can be seen that this invention presents advantages not heretofore incorporated in separators for gas turbine engines. Less than 1% of the initial main airstream is lost in cleaning steps. Thus, this invention provides a separator which is of simple and economical construction, is compact and provides for minimum maintenance.

While a present exemplary embodiment of this invention has been illustrated and described it will be recognized that this invention may be otherwise variously embodied and practiced by those skilled in the art.

What is claimed is:

1. In a gas turbine engine assembly including a compressor having an inlet thereto and a main airflow path directed to the inlet, a combustor, and a turbine in serial flow arrangement, a contaminant separator assembly for removing contaminant from a stream of air supplied to the compressor inlet, said separator comprising:

a housing assembly mounted ahead of the compressor inlet and defining a primary axial flow path and a secondary flow path, said paths being combined in a main airflow path upstream of the compressor inlet,

expansible means mounted in said housing adjacent the primary flow path, said expansible means having an unexpanded position and an expanded position, said expansible means permitting axial flow through said primary airpath in the unexpanded position and said expansible means in the expanded position obstructing the primary airpath to prevent flow therethrough wherein air supplied to the engine inlet is all drawn through the secondary airpath,

means for expanding said expansible means to said expanded position and for deflating said expansible means to said unexpanded position,

contaminant removal means mounted in said housing for removing contaminant from air flowing therethrough,

said contaminant removal means being in communication with said secondary airpath and further defining a third flow path downstream of the contaminant removal means, and

said third airpath being in communication with the main airflow path, wherein air and contaminant transmitted to the contaminant removal means from the secondary airflow path will be acted on by said contaminant removal means whereby contaminant is removed from the airstream and the cleaned air is transmitted through the third flow path for reentry into the secondary flow path upstream of the compressor inlet.

2. A contaminant separator as set forth in claim **1** in which:

said contaminant removal means comprises a plurality of cleaning stages, each of said stages including cyclonic separator tubes wherein clean air is transmitted to said third flow path and contaminant is transmitted to the next cleaning stage for further cleaning.

3. A contaminant separator as set forth in claim **1** in which said contaminant removal means comprises first and second cleaning stages,

said first stage comprising a plurality of cyclonic tubes in communication with said secondary flow path for receiving contaminated air therefrom wherein cleaned air from said cyclonic tubes is transmitted to said third flow path and contaminant is transmitted to said second cleaning stage, and

said second stage further comprising a plurality of cyclonic tubes wherein cleaned air therefrom is transmitted to said third flow path and concentrated contaminant is accumulated in a collection chamber.

4. A contaminant separator as set forth in claim **3** in which:

an ejector means is mounted within said collection chamber and in communication with said cyclonic tubes wherein concentrated contaminant from said cyclonic tubes is ejected overboard to atmosphere,

said expansible means comprises an inflatable boot, and in which said means for inflating and deflating said inflatable booth further comprises:

a conduit connecting said inflatable boot with the compressor inlet vacuum source and compressor pressure source,

a switching valve connected in said conduit between said boot and compressor wherein the inflatable boot is connected to the compressor pressure source for inflation and the inflatable boot is connected to the compressor inlet vacuum source for deflation.

5. A contaminant separator as set forth in claim **4** further comprising:

a screen mounted over said secondary airpath for preventing large foreign objects from entering the secondary airpath, and

anti-icing passages mounted in said housing, said passages being in communication with the engine bleed air wherein engine bleed airflow through the passages will prevent icing of the separator assembly.

6. In a gas turbine enginge assembly including a compressor having an inlet thereto and a main airflow path directed to the inlet, a combustor, and a turbine in serial flow arrangement, a contaminant separator assembly for removing contaminant from a stream of air supplied to the compressor inlet, said separator comprising:

an annular housing assembly having concentric inner and outer wall members, said assembly being cantilever mounted ahead of the compressor inlet and defining a primary axial flow path adjacent the inner wall, said housing assembly further having an annular curved wall surface extending from the outer wall radially inward and terminating closely adjacent the inner wall,

a formed annular member mounted to the engine inlet in cooperative relationship with said annular curved wall surface to define a secondary flow path, said secondary flow path being in communication with said primary axial flow path wherein said flow paths are combined in a single main airflow path for transmission to the compressor inlet,

an annular catching lip member spaced from the terminating end of said annular curved wall surface and extending into said secondary flow path such that air being drawn through the secondary airpath is drawn through a turn wherein centrifugal forces acting on the contaminants cause the contaminants and a small amount of carrier air to be deflected onto said annular curved wall surface and directed to said catching lip member,

a plurality of contaminant removal stages in serial flow arrangement mounted in said housing, each of said stages comprising a plurality of cyclonic separator tubes, said first stage being in communication with said secondary flow path wherein contaminant and carrier air caught by said catching lip member is transmitted to said first contaminant removal stage,

each of said contaminant removal stage being in communication with said secondary flow path downstream of said catching lip member wherein cleaned air from each of said removal stages reenters the secondary flow path for transmission to the compressor inlet;

an annular inflatable boot mounted in said housing adjacent the primary flow path, said boot having an unexpanded position and an expanded position, said boot permitting axial flow through said primary flow path in the unexpanded position and said boot in the expanded position obstructing the primary flow path to prevent flow therethrough wherein during periods of boot inflation the air supplied to the compressor inlet is all drawn through the secondary flow path and contaminant removal stages, and

means for expanding said inflatable boot to said expanded position and for deflating said inflatable boot to said unexpanded position.

7. A contaminant separator assembly as set forth in claim **6** in which the contaminant and carrier air from each stage is transmitted to the inlet of each succeeding stage, and ejector means in communication with the final stage wherein concentrated contaminant from the final stage is ejected overboard.

8. A contaminant separator assembly as set forth in claim **7** further comprising:

a screen mounted over said secondary airpath for preventing large foreign objects from entering the secondary flow path, and

anti-icing passages mounted in said housing, said passages being in communication with the engine bleed air wherein icing of the separator assembly may be prevented thereby.

9. A contaminant separator as set forth in claim **1** in which said housing assembly further defines a plurality of secondary flow paths, each of said secondary flow paths being in communication with said contaminant removal means wherein air and contaminant passing through each of said secondary flow paths will be acted on by said contaminant removal means.

10. A contaminant separator as set forth in claim **9** in which each succeeding secondary flow path is axially displaced relative to the preceding flow path, each of said secondary flow paths being in communication with said primary axial flow path wherein all the flow paths are combined in a main air flow path upstream of the compressor inlet.

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CARLTON R. CROYLE, Primary Examiner

U.S. Cl. X.R.

55—306; 415—116, 121, 145, 151, 168