May 24, 1960 E. F. CUNNINGHAM 2,937,803

AIR FLOW COOLING APPARATUS AND DRIVE THEREFOR

Filed June 5, 1957 2 Sheets-Sheet 1

Fig. 1

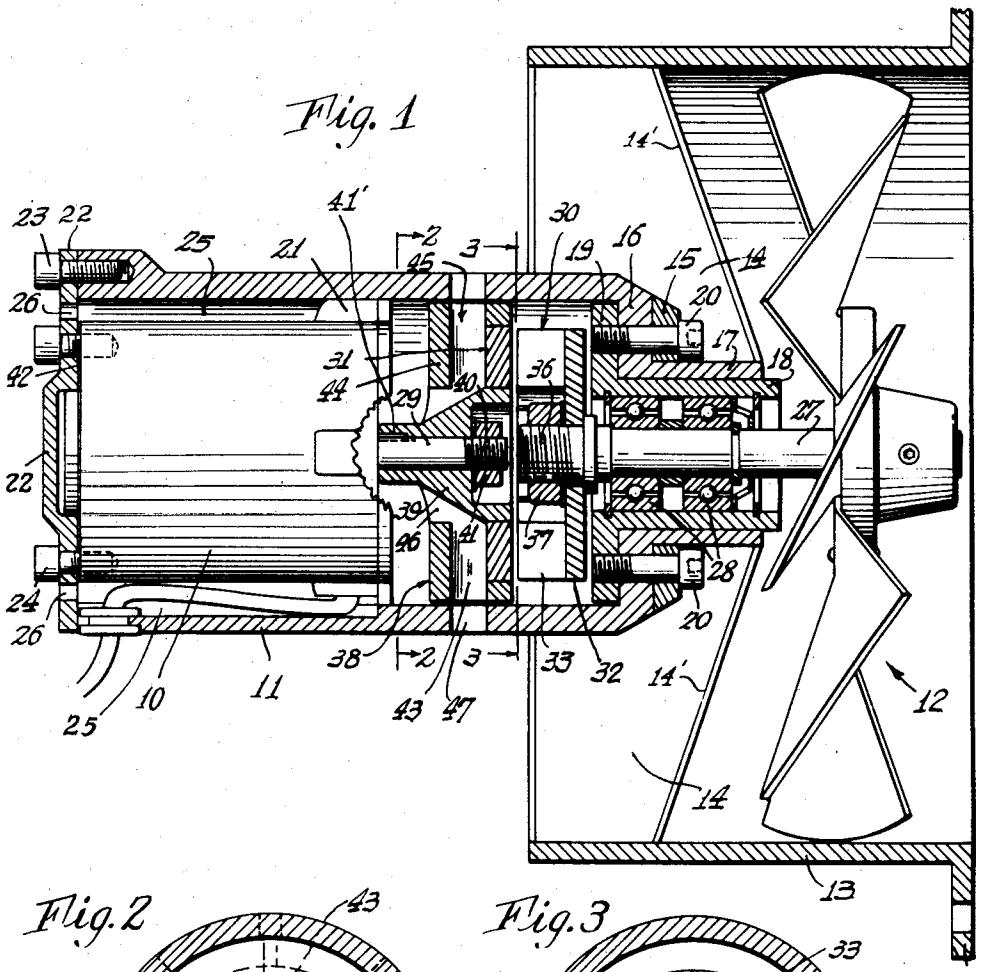


Fig. 2

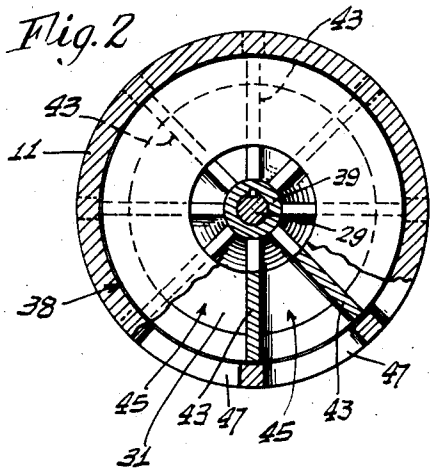
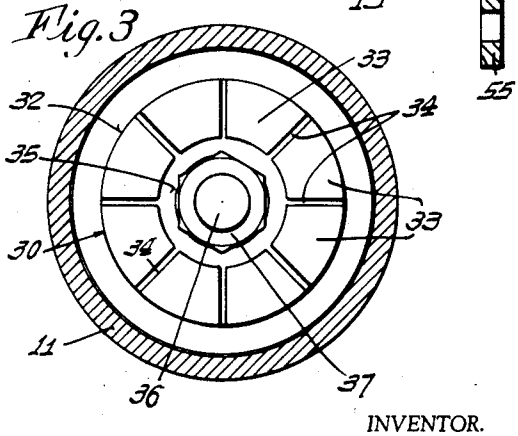


Fig. 3



INVENTOR.
EDWARD F. CUNNINGHAM

BY

Edward H. Eames
ATTORNEY

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Fig. 4

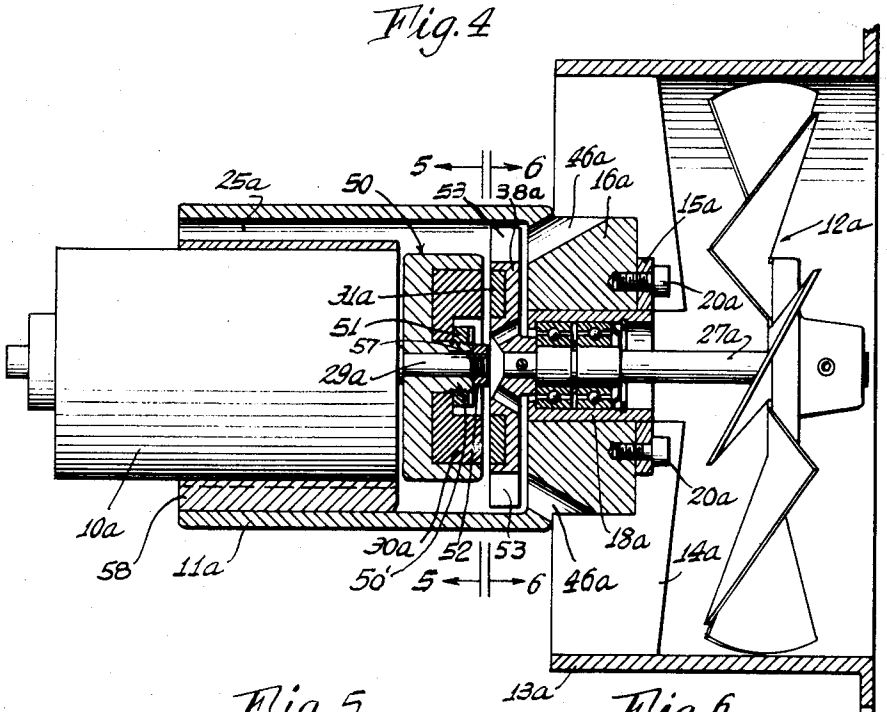


Fig. 5

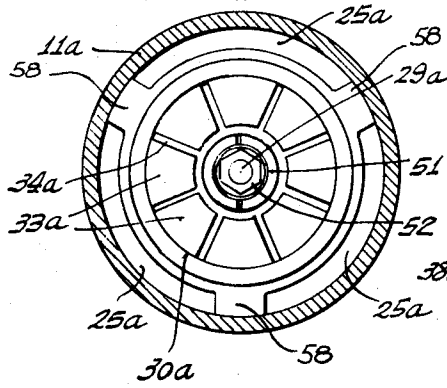


Fig. 6

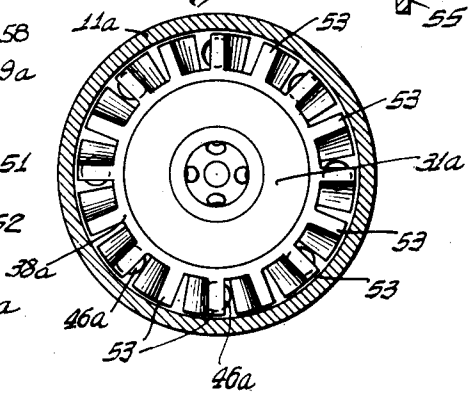
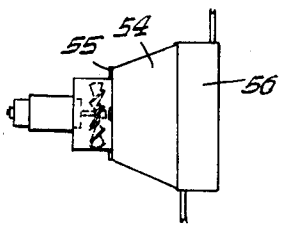


Fig. 7



INVENTOR.
EDWARD F. CUNNINGHAM
BY
Edward F. Cairns
ATTORNEY

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2,937,803

AIR FLOW COOLING APPARATUS AND DRIVE THEREFOR

Edward F. Cunningham, Stony Creek, Conn., assignor to Eastern Industries, Incorporated, East Norwalk, Conn., a corporation of Delaware

Filed June 5, 1957, Ser. No. 663,752

15 Claims. (Cl. 230—117)

This invention relates to cooling devices, and more particularly to impelling means for air and other gases.

In some situations it is necessary, or at least desirable, to move a substantially constant mass of air through a cooling device or across a heated unit regardless of the varying density of the air. One such instance is in connection with cooling electronic or other aircraft equipment by a moving column of air in which the density of the air to be impelled may vary from that at about sea level density to more rarefied air at heights in the order of 60,000 feet. Such rarefied air does not have the same cooling effect per unit of volume as the denser air.

It is an object of this invention to provide means whereby air or other gas to be propelled over a given space and over objects therein is so propelled that a substantially constant mass (as distinguished from volume) of gas is automatically impelled per unit of time, thereby maintaining the cooling effect of the air substantially constant.

This is accomplished according to the present invention by providing an air impeller capable at a predetermined r.p.m. of moving the desired mass of air of least density to be encountered, and a constant torque motor capable of driving the impeller at said predetermined r.p.m. and by connecting the motor and impeller with a magnetic coupling of the hysteresis type, the hysteresis characteristic of which is such that the degree of slip between the driving and driven elements varies over a wide range with the density of the air in which the device is operating, to give an impeller speed which varies inversely with such density in the desired proportion for substantially constant mass air delivery.

It has been discovered that with the use of a magnetic coupling having a permanent multi-pole magnet as the driving element and a coaxial annular member of appropriate magnetic structure and high hysteresis as the driven element and separated from the driving element by a suitable air gap, then the torque exerted on the driven member by the driving member will be substantially constant so that when the load on the driven member tends to increase in air of greater density such as accompanies a shift from higher altitudes to lower altitudes, the slip between the driven member and the driving member increases but the torque transmitted to the driven member remains substantially constant.

Thus at sea level, even though the motor is operating at constant predetermined r.p.m., the impeller will be operating at a substantially lower speed but, due to the density of the air, will be propelling the optimum mass of air across the radiator or unit being cooled by it.

As the aircraft rises into more rarefied air, the load on the impeller tends to decrease, but as this tendency occurs the slip between the driving member and the driven member of the coupling decreases with the result that the r.p.m. of the impeller increases and the latter tends to move a greater volume of air per unit of time to give the same mass of air moved.

This would continue until the air became so rarefied

that little if any slip occurs between the driving member and the driven member of the coupling and the impeller and the motor would move at substantially synchonous speeds. The height at which this occurs may be determined by the characteristics of the motor and impeller and coupling, and the torque may be varied within limits by adjusting the air gap between the driving and driven members of the coupling to meet the desired load requirements within the load capacity of the motor or to match the optimum torque of the impeller and motor.

According to the present invention, one element of the magnetic coupling is permanently magnetized so as to have a plurality of arcuately spaced poles while the other element is permanently magnetized to form within itself a closed magnetic circuit and these elements are juxtaposed so that the second-named element forms a high hysteresis magnetic path for the flux emanating from the other element.

Either element of the pair of cooperating magnetic elements may be driven by the driving means.

Another object of this invention is to provide a compact and efficient unit comprising driving means including an electric motor, means to be driven thereby and a magnetic coupling of the hysteresis type between the motor and the driven means.

Other features and advantages will hereinafter appear.

In the accompanying drawings—

Fig. 1 is a longitudinal section of an air impelling unit made in accordance with the present invention.

Fig. 2 is a transverse section taken on the line 2—2 of Fig. 1 with portions broken away.

Fig. 3 is a transverse section taken on the line 3—3 of Fig. 1.

Fig. 4 is a view similar to Fig. 1 but showing another form of the present invention.

Fig. 5 is a transverse section taken on the line 5—5 of Fig. 4.

Fig. 6 is a transverse action taken on the line 6—6 of Fig. 4.

Fig. 7 is a schematic view showing the unit of the present invention when used in a cooling system.

Referring first to the form of the invention shown in Figs. 1, 2 and 3 the air impelling unit of the present invention comprises a constant speed electric motor **10** mounted in a casing **11** and an air impeller or fan **12** mounted in a housing **13**. The housing **13** has radial webs or struts **14** attached to a ring **15** and to the housing **13**, as by welding or casting for example, for mounting the motor casing **11** on the impeller housing **13**.

The front end of the motor casing **11** has a flange **16** and a sleeve **17** which receives a bearing sleeve **18** having a radial flange **19** located inwardly of the flange **16**. Bolts **20** passing through aligned holes in the mounting ring **15** and the flange **16** and entering tapped holes in the flange **19** secure the motor casing **11** to the impeller housing **13**.

The motor **10** has ribs **21** spacing it from the inner wall of the motor casing **11** at the front or inner end, while a cover plate **22** secured to the casing **11** by bolts **23** and to the motor **10** by bolts **24** supports the outer end of the motor and spaces it from the casing, thereby providing around the motor **10** an annular passage **25** for air which may enter through holes **26** in the cover plate **22**, and pass out through passages **46** and **45** for cooling the motor and the magnetic coupling.

The impeller **12** is carried by a shaft **27** which is supported in bearing **28** mounted in the bearing sleeve **18** so as to be axially aligned with the motor shaft **29**.

According to the present invention the impeller shaft **27** and motor shaft **29** are operatively connected by a magnetic coupling of the hysteresis type having two juxtaposed elements, one element **30** being permanently

magnetized to have a plurality of fixed poles and the other element **31** being circularly magnetized. One element is connected to the shaft **27** and another element connected to the shaft **29** and so constructed and arranged that, due to the hysteresis characteristic of one of the elements, a substantially constant torque is transmitted from one element to the other while permitting variable rotational slip over a wide range between the elements, with the result that when the load on the impeller **12** tends to vary with increasing or decreasing density of the air, the speed, i.e. r.p.m. of the impeller **12**, automatically varies inversely approximately with the square root of the density of the air, and in such proportion that the mass of the air moved by the impeller will remain substantially constant regardless of the density of the air. There is a slight deviation from this ideal arrangement, by changes in impeller efficiency and bearing friction with increasing speeds, particularly at higher speeds, but such deviation is minor over a wide operating range from sea level to high altitude for example.

It has been found that either of the elements **30** or **31** may be connected to the motor shaft while the other is connected to the impeller shaft. Both arrangements are illustrated herein. In the form of the invention shown in Figs. 1, 2 and 3 the polarized magnet **30** is carried by the impeller shaft **27** and the circular magnet **31** is carried by the motor shaft **29**, while in Figs. 4, 5 and 6 the arrangement is reversed and the polarized magnet **30***a* is carried by the motor shaft **29***a* and the circular magnet **31***a* is carried by the impeller shaft **27***a*. There is no apparent difference in the principle of operation of the couplings between the different arrangements.

Reverting to the form of the invention shown in Figs. 1, 2 and 3, which is the form at present preferred for manufacturing reasons, the polarized permanent magnet **30** is in the form of a disk **32**, made of high magnetic-retentive material such as an aluminum-nickel-cobalt alloy, the disk having on its face a plurality of laterally extending integral segmental pole pieces **33** separated by radial slots **34** and a central recess **35**. The disk **32** has a central aperture to receive the threaded inner end **36** of the impeller shaft **27** and is secured to the latter by a nut **37**.

The circularly magnetized element **31** is a plain annulus, likewise made of high magnetic-retentive material such as an aluminum-nickel-cobalt alloy, and is mounted so as to rotate with and be concentric to the motor shaft **29**. As shown in Figs. 1, 2 and 3 the annulus is carried by a circular body **38** of non-magnetic material, preferably of light weight and high thermal conductivity such as aluminum, which has a hub portion **39** provided with an aperture to receive the threaded inner end **40** of the motor shaft **29**, and is secured thereto by a nut **41** and key **41'**. The annulus **31** is seated in a recess in the face of the body **38** so as to be directly opposite but spaced from the poles **33** of the element **30**. The annulus **31** may be mounted in the body **38** in any suitable manner, for instance by being pressfitted therein.

The circularly magnetized element **31** is in magnetic relation with the polarized element **30** and therefore is magnetically coupled therewith for synchronous rotation under conditions of no load or low load near no load on the driven member such as the shaft **27**, and for a synchronous rotation with progressively varying slip over a wide range while providing substantially constant torque as the load on the shaft **27** tends to vary under substantial load conditions. As the shaft **27** rotates with the impeller mounted on it, the work performed by the impeller in moving the air, which the blades encounter, places a load on the shaft. Any substantial load, tending to exceed the maximum torque of synchronous rotation, reduces the r.p.m. of shaft **27**, and causes the coupling element **30** to lag behind the element **31**, with the result that the magnetic field pattern created in the element **31** by the magnetizing force exerted by the element **30** constantly shifts in position, i.e. rotates with respect to the element **31**, but remains at substantially constant strength, and against the strong coercive force of its magnetic structure provides a substantially constant torque obtained between the element **31** and element **30**. This effect, it is believed, is due to the hysteresis of the circularly magnetized element **31** in the shifting or reorientation of its magnetic structure with the slip, which provides a substantial constant torque over a wide range of difference in r.p.m. of the driving and driven elements, the elements **31** and **30** respectively, in the device shown in Figs. 1, 2 and 3.

Nevertheless, it has been found that using an impeller capable of moving the desired mass of air at a predetermined r.p.m., a constant speed motor capable of delivering the torque required to operate the impeller to move the desired mass of air and coupling the motor with the impeller by a hysteresis drive of two cooperating permanent magnet type elements, one being polarized and the other having a closed magnetic circuit, a substantially constant torque will be transmitted from the motor to the impeller regardless of the speed which the impeller must attain to maintain substantially constant the mass of air moved per unit of time.

It will be understood, of course, that to maintain constant the mass of air being moved, the r.p.m. of the impeller must vary inversely in a determinate proportion to the density of the air, which approximates an inverse square root relation.

As an example, it has been found that with a 9.5 inch impeller, such as shown in Fig. 1, and a motor of ¼ H.P. having a constant speed of 11,500 r.p.m. at rated load, the speed of the impeller varies with the density of the air, reckoned in altitudes as follows, the figures being approximate:

Altitude	Density of the Air (lbs. per cu. ft.) at constant temperature assumed 80° F.	Impeller, r.p.m.
0 (sea level)	.0735	3,170
10,000	.0506	3,775
20,000	.0338	4,675
30,000	.0218	5,840
40,000	.0136	7,375
50,000	.00844	9,150
60,000	.00525	[1] 11,500

[1] (Approximately synchronous with the motor.)

The above figures are taken from constant temperature altitude chamber tests.

In designing the unit of the present invention for a particular purpose, as for instance the cooling of aircraft equipment, having determined the mass of air required to be moved over a radiator or other object to be cooled or from which a constant rate of heat is to be extracted to maintain a substantially constant and operating temperature, the impeller is designed to deliver such mass of air at a speed substantially synchronous with the speed of the motor in air of least density to be encountered, i.e. at the highest altitude to be reached by the aircraft, and the motor is designed to produce the required torque and power to so drive the impeller, as well as to drive the impeller at its reduced speed through the magnetic coupling at the maximum air density as at sea level for example. With the components so selected, the hysteresis coupling is so constructed and arranged to transmit a substantially constant torque from the constant speed motor to the impeller regardless of the speed of the impeller over the operating range, so that at any height from miximum altitude to sea level, where the density of the air is greatest, even though the r.p.m. of the impeller decreases, the same mass of air will be moved per unit of time so required.

The torque transmitted by the hysteresis coupling depends on its size and the strength of the magnetic field of the polarized element and the size and hysteresis characteristics of the cooperating element as well as the air gap between the two elements. Since some variations from standards may occur in the manufacture of the components including the motor and motor casing, etc., the present invention provides convenient means for varying the air gap between the adjacent faces of the two elements of the coupling to adjust for the desired torque. As shown in Fig. 1 this is accomplished by inserting shims **42** between the outer end of the motor **10** and the cover plate **22** which has the effect of moving the element **31** closer to the element **30** to increase the torque for example. If it is required to open the air gap, shims may be placed between the cover plate **22** and the motor casing **11** since this has the effect of moving the element **31** away from the element **30**.

It should be understood that while the objective is to deliver to the equipment to be cooled a substantially constant mass of air, some tolerance may be permitted so long as a sufficient air mass for the purpose is maintained and it is customary to provide some modest margin of capacity. However, the present invention, with its automatic adjustment of impeller speed to air density load makes it possible to provide such small margin of capacity, in contrast with the manifold increase of power that would be required to drive the impeller at constant speed by a positive connection at the maximum speed required at the highest altitude for example without the invention. Any such direct drive would result in moving a greatly excessive mass of air at lower altitudes with the attendant enormous waste of power and greatly increased weight and cost because of requiring a larger motor and other components, all objectionable in aircraft.

The result of the present invention therefore is the automatic provision of adequate and appropriate air cooling at all altitudes reached with relatively negligible loss of power and avoiding unnecessary weight and cost.

The slip, i.e. relative rotation, between the elements **30** and **31**, resulting in constant shifting of the flux pattern in the element **31**, causes heat to be generated in the latter. To avoid the element **31** becoming excessively hot and thus changing its magnetic properties, the body **38** which carries the annulus **31** is so made as to also serve the function of an air impeller, so that outside air will be drawn into the body to cool the annulus. Accordingly the body **38**, which advantageously may be made by die-casting, is provided with more or less radial fins **43** between the annulus **31** and the inner wall **44** forming passages **45** which at the hub **39** meet passages **46** opening into the motor casing **11**. When the body **38** rotates, air is drawn in through the apertures **26** in the cover plate **22** through the air space **25** in the motor casing **11**, passage **46** and into passage **45** from which the air is expelled by centrifugal force through opening **47** in the motor casing **11** and into the air stream created by the impeller **12**, the suction effect of which augments the action of the fins **43**. The body **38** may preferably be made of aluminum for example for light weight and for good heat conduction.

The air thus circulated cools the annulus **31** not only by convection by passing over its exposed surface but also by conduction by cooling the entire body **38** which carries it.

The edges of the struts **14** may be beveled at **14'** for improved air flow.

Many of the features of the present invention described and claimed herein may advantageously be employed in driving units including hysteresis couplings where it is desired to maintain substantially constant torque using a constant speed motor to drive means having a variable speed but a substantially constant load.

The form of the invention illustrated in Figs. 4 to 6, which is a prototype of that shown in Figs. 1 to 3, has

substantially the same principle of operation, differing only in construction.

In the form shown in Figs. 4 to 6 the polarized magnetized element **30***a* of the coupling is mounted in a non-magnetic body **50** being secured thereto by a nut **51** on threaded hub **50'**. The body **50** is mounted on the shaft **29***a* of a motor **10***a* and secured thereto by a nut **52** and key **57**. The motor **10***a* is secured in a motor housing **11***a* so as to leave an air space **25***a* between it and the motor housing. The element **30***a* (see Fig. 5) has radial slots **34***a* forming pole pieces **30***a* on its face.

The element **31***a* is, like the element **31** of Fig. 1, an annulus which is circularly magnetized (having substantially no polar orientation). It is set in a body **38***a* of nonmagnetic material which is secured to the shaft **27***a* on which the impeller **12***a* is mounted. The impeller shaft **27***a* is supported in bearings in a sleeve **18***a* mounted in the closed front end **16***a* of the motor casing **11***a*. The impeller housing **13***a* has radial webs **14***a* secured to a ring **15***a* which is fastened to the end **16***a* of the motor casing by bolts **20***a*.

The motor shaft **29***a* and the impeller shaft **27***a* are coaxial and the elements **30***a* and **31***a* are concentric and are spaced from each other to provide an air gap between them.

The motor **10***a* is spaced from the housing **11***a* by the spacers **58**.

The principle of operation of the unit shown in Figs. 4, 5 and 6 is the same as that shown in Figs. 1, 2 and 3 even though the polarized magnetized element **30***a* is driven by the motor **10***a* while the circularly magnetized element **31***a* is connected to the impeller and drives the latter.

To dissipate the heat generated in the element **31***a*, the body **18***a* carrying it is provided with a plurality of radially inclined fins **53** and the closed end of the motor casing **11***a* is provided with air passages **46***a* so that as the body **38***a* is rotated to drive the impeller, air is drawn in through the rear end of the motor casing through the air space **25***a* and is expelled through the air passages **46***a*. The air thus passing through the unit cools the body **38***a* and by conduction and convection the magnetic element **31***a* is kept from becoming overheated. The body **38***a* may be of aluminum for example.

The small impeller elements **53** in the form of Figs. 4—5—6 and the small centrifugal impeller elements **43** in the form of Figs. 1—2—3 serve to cool the motor as well as the hysteresis elements.

It will be noted that two forms of assembly of the coupling elements to the shafts have been illustrated in Figs. 1–3 and Figs. 4–6, as examples of different forms which may be employed.

The unit of the present invention may be employed in various ways, one typical example being shown in Fig. 7 wherein the unit is secured to a radiator structure including an air transmission piece **54** to which the unit is secured by ears **55** thereon and a radiator unit **56** at the other end of the piece **54**.

Variations and modifications may be made within the scope of the claims, and portions of the improvements may be used without others.

I claim:

1. An air circulating unit comprising a mounting frame having an impeller housing and a motor casing, an impeller located in said housing, a constant speed motor mounted in said casing, a driving shaft for said motor, a driven shaft for said impeller, and a magnetic coupling of the hysteresis type in said motor casing between said impeller and said motor, said coupling comprising two-coaxial elements spaced to provide a determinate air gap between them, one of said elements being secured to the driving shaft of the motor and the other of said elements being secured to the driven shaft for the impeller, one of said elements being permanently magnetized to provide a plurality of oriented poles thereon and the other of said

elements being an annulus and being permanently circularly magnetized to be nonpolar, the hysteresis characteristics of said magnetized elements permitting variable slip between said elements while transmitting a constant torque to compensate for varying loads per revolution on the impeller.

2. An air circulating unit as defined in claim 1, in which the motor is movably mounted in the motor casing to vary the air gap between said elements.

3. In a power transmitting unit of the character described, a casing, a constant speed motor within the casing and having a driving shaft, a driven shaft mounted in the casing coaxial with the driving shaft, two coaxial rotary magnetic elements within said casing and having juxtaposed faces axially spaced to provide a determinate air gap between them, one of said elements being secured to the driving shaft and the other element being secured to the driven shaft, one of said elements being permanently magnetized to provide a plurality of oriented poles thereon and the other of said elements being an annulus and being permanently circularly magnetized to be nonpolarized, said elements coupled magnetically across said faces and having a hysteresis characteristic attendant upon the shifting of the magnetic field in the circularly magnetized element upon rotary slip between said elements to transmit a constant torque at widely variable slip, whereby a determinate slip occurs between the driving element and the driven element in response to increased load per revolution applied to the driven element.

4. The unit as described in claim 3 in which the circularly magnetized element is supported by a non-magnetic body secured to its shaft.

5. The unit as described in claim 3 in which means are provided for dissipating heat generated in the circularly magnetized element resulting from the shifting of the magnetic field in the circularly magnetized element.

6. The unit as described in claim 3 in which means carrying the circularly magnetized element is provided with means for dissipating heat generated therein and resulting from the shifting of the magnetic field in the circularly magnetized element.

7. The unit as defined in claim 3, in which the polarized element is mounted on the driving shaft.

8. The unit as defined in claim 3, in which the polarized element is mounted on the driven shaft.

9. The unit as defined in claim 3, in which means are provided for varying the air gap between the two coaxial elements.

10. The unit as defined in claim 3, in which means are provided for axially adjusting the position of the motor in the motor casing to vary the air gap between said elements.

11. In a constant torque transmission device comprising driving means including power input means, driven means including power take-off means, and a magnetic coupling of the hysteresis type between the driving means and the driven means, said coupling including two coaxial permanently magnetized elements mounted in axially spaced magnetic relation and having cooperating radial faces, one of said elements being mechanically driven by said driving means and the other of said elements mechanically driving said driven means, one of said elements having oriented poles in its face in a circle about the common axis and the other of said elements being in ring form and circularly magnetized about the common axis and devoid of inherent oriented poles.

12. A constant torque transmission device comprising driving means including power input means, driven means including power take-off means, and a magnetic coupling of the hysteresis type between the driving means and the driven means, said coupling including two coaxial magnetized elements mounted in spaced magnetic relation, one of said elements being mechanically driven by said driving means and the other of said elements mechanically driving said driven means, one of said elements having oriented poles and the other of said elements being a hysteresis element circularly magnetized and devoid of inherent oriented poles, in which each element is mounted on a rotatable body, the body for one of the elements including air circulating means for cooling the hysteresis element and said driving means by impelling air thereby as said body rotates.

13. In a cooling system employing air flow for dissipating heat from craft subject to widely varying air density between high density in sea level conditions and low density in high altitude conditions, the combination of an air impeller having a constant torque requirement for impelling a constant mass of air per unit time by varying its speed inversely substantially as the square root of the density of air, a substantially constant speed motor for driving said impeller at substantially synchronous maximum speed for low density air at a determined substantially maximum altitude, a permanent magnetic rotor element having at least one face and magnetized to provide a plurality of pairs of poles arcuately arranged on said one face, a second rotor element including a ring of permanent magnet material coaxial with the first said permanent magnet rotor element and magnetized generally only in a circular manner with respect to the axis to avoid poles on said ring and arranged to cooperate with the magnetized poles in said face of the first said rotor element with a very small constant air gap to be magnetically coupled thereto for controlled constant torque transmission with variable slip between said rotor elements by hysteresis action in said ring, one of said rotor elements being driven by said motor at its constant speed and the other rotor element being mechanically coupled to said air impeller to provide such constant torque to so rotate said impeller at such varying speed automatically in response to such variation in air density, whereby constant mass air cooling will be provided over such wide range of air densities.

14. A constant air mass air impelling apparatus for circulating air at a variable speed inversely depending upon the density of air comprising, a constant speed motor having a driving shaft, an impeller adapted for moving air and having a driven shaft, a variable slip magnetic hysteresis coupling assembly for coupling the driving and driven shafts, said magnetic coupling including at least two cooperating magnetic elements having an air gap between them and being coaxially positioned with respect to each other and to both the driving and driven shafts, at least one of said elements being permanently magnetized to provide a plurality of magnetic poles on a surface thereof, and the other of said elements including a ring of high hysteresis magnetic material having a surface closely juxtaposed to the magnetically polarized surface of the said one cooperating element, said ring being inherently devoid of oriented poles, said elements being present in position with respect to each other to provide a constant air gap between the magnetically cooperating surfaces to provide a constant torque to said impeller over a wide range of impeller speeds with variable rotational slip between said elements as the air density varies so that said impeller speed will vary inversely substantially as the square root of the air density to impel a substantially constant mass of air per unit of time with widely varying air density.

15. A constant air mass air impelling apparatus for circulating air at a variable speed inversely depending upon the density of air comprising, a constant speed motor having a driving shaft, an impeller adapted for moving air and having a driven shaft, a variable slip magnetic hysteresis coupling assembly for coupling the driving and driven shaft, said magnetic coupling including at least two cooperating magnetic elements having ain air gap between them and being coaxially positioned with respect to each other and to both the driving and driven shafts, at least one of said elements being permanently mag-

netized to provide a plurality of magnetic poles on a surface thereof, and the other of said elements including a ring of high hysteresis magnetic material having a surface closely juxtaposed to the magnetically polarized surface of the said one cooperating element, said ring being inherently devoid of oriented poles, two non-magnetic metal heat conducting members one of which is coupled to the driving shaft and the other coupled to the driven shaft, one of said magnetic elements being mounted directly on one of said heat conducting members and the other of said magnetic elements being directly mounted on the other of said heat conducting members for rotation therewith to cool at least said hysteresis element and its associated heat conducting member, said magnetic elements being preset in position with respect to each other to provide a constant air gap between their magnetically cooperating surfaces to provide a constant torque

to said impeller over a wide range of impeller speeds with variable rotational slip between said elements as the air density varies so that said impeller speed will vary inversely substantially as the square root of the air density to impel a substantially constant mass of air per unit of time with widely varying air density while also providing cooling of the hysteresis element to remove the heat generated as a result of said rotational slip.

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