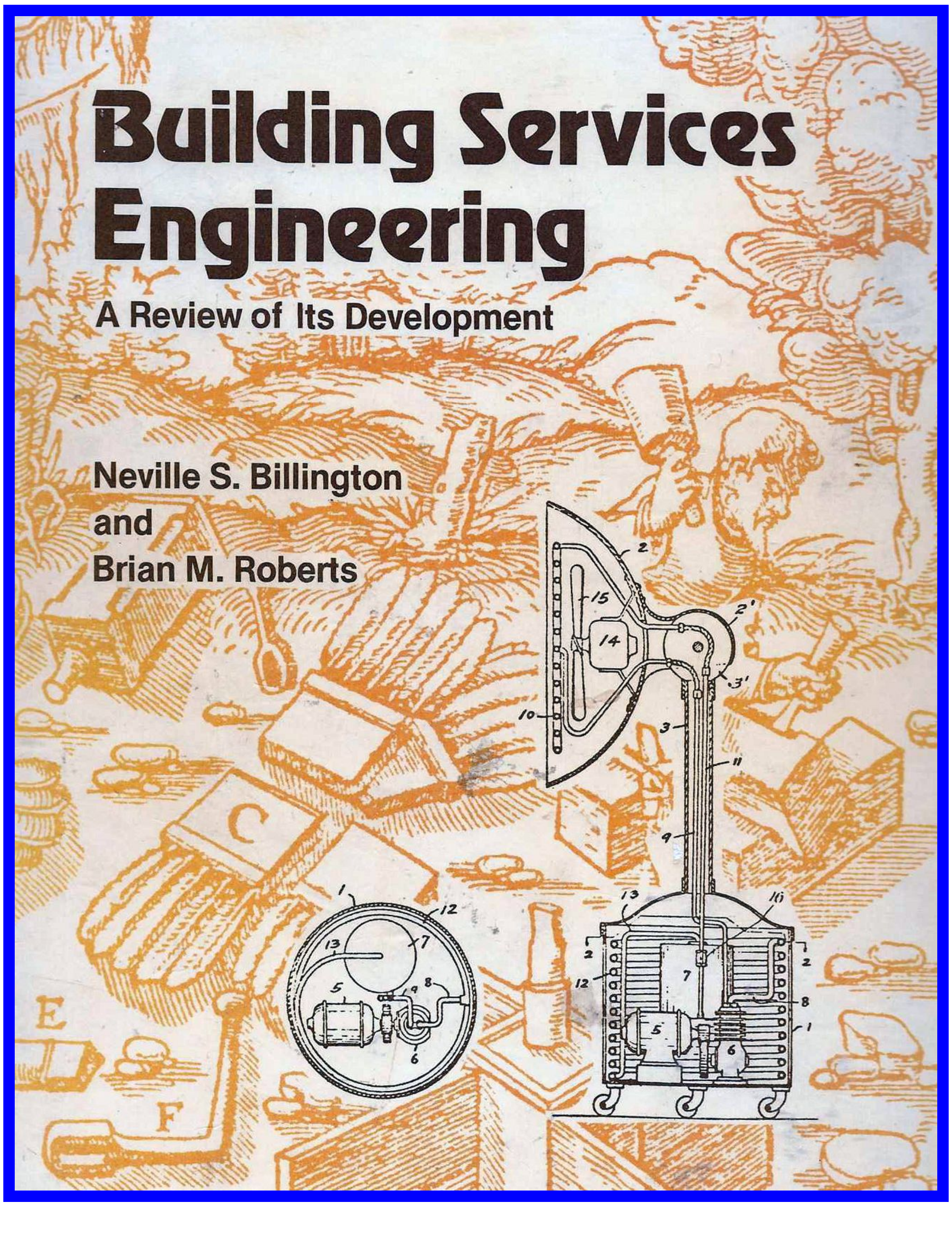
EARLY HISTORY OF FANS
From Building Services Engineering
Billington & Roberts 1982



BUILDING SERVICES ENGINEERING

A Review of Its Development

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PERGAMON PRESS

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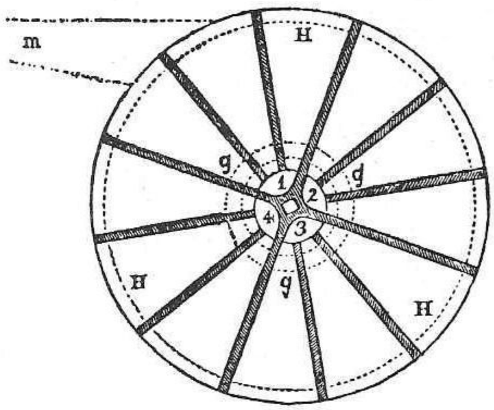
A—Drum. B—Box-shaped casing. C—Blow-hole. D—Second hole. E—Conduit. F—Axle. G—Lever of axle. H—Rods.

Fig. 4.18. A selection of mine ventilation fans.[4]

4.5.3. Desaguliers' "fanning wheel"

The mechanical fan, or "fanner" as it was originally called, was invented in 1734 by Dr Desaguliers, specifically for ventilating purposes. His original model was no more than a paddle wheel within a circular casing. The paddles or blades were 0.3 m broad and the wheel had a diameter of 2.1 m.

"The wheel H was enclosed in a concentric case B, which had a 'blowing pipe' m on the upper part of its circumference, and a suction pipe S, that communicated by a funnel d, with the central opening in the wheel, which was turned by a handle A, attached to the axis that went through the case and rested on a standard. The 'fanner' was adjusted to revolve easily, but as closely to its concentric casing as possible, and it had no communication with the air except through the suction and blowing pipes. By the revolution of the wheel, the air entering through the central opening into the spaces gg, formed by the radiating partitions, was thrown by the centrifugal motion towards the circumference, where it was confined by the concentric casing, and carried round until it arrived at the opening of the blowing pipe m, into which it was impelled by each radiating partition in continuous revolution" (Fig. 4.19).



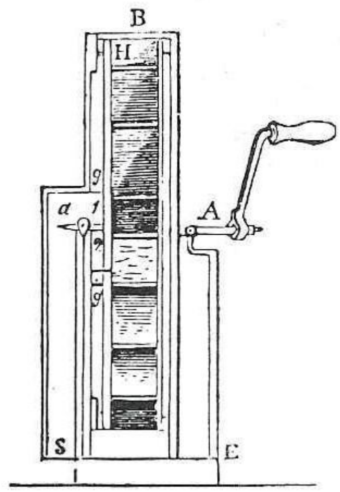


Fig. 4.19. Desaguliers' fan.

He envisaged the fan being used either to supply or to extract air from a room, or merely to keep the air of the room in motion. One of his fans was installed in the House of Commons in 1736, where it remained in use until 1817.

4.5.4 *19th century development*

Many of the earliest fans consisted of a number of radial blades mounted on one side of a rotating disc. The wheel was so mounted that the blades moved close to a stationary plate on the inlet side of the wheel. Later paddle fans of this type had two discs, with the radial blades fixed between them. One of the discs was solid, while the other was an annular ring forming the inlet "eye". Other early fans, like some modern vacuum cleaner fans, drew air in at the centre from both sides of the wheel, discharging it round the whole extent of the circumference. These fans without a casing were typical of designs in use prior to 1830, and were intended merely as exhausting devices.[44]

The first cased fans, like Desaguliers' design, had circular casings, fitting close to the wheel, with an opening at one point to serve as the outlet. Guibal showed that a casing is essential to achieve full pressure development. A scroll casing, fitted eccentrically, was shown in a drawing in Dr Ure's *Mechanical Dictionary* published in 1844. A similar arrangement, but using a convolute casing, was illustrated by Reid at about the same time. With this form of casing, the outlet was normally a plain rectangular opening without any further expander.

Walker held the view that the eccentric fan of 1850 was better suited to manufacturing than to ventilation purposes, and for developing pressure rather than moving large volumes of air. At high speed, these fans made considerable noise which was transmitted along the air shafts. He preferred the air screw — a screw 4 ft (1.2 m) in diameter revolving at 500 rev/min was said to be able to deliver 5000 ft^3/min (8500 m^3/h).

The Guibal "chimney" or discharge tube was invented and applied to centrifugal fans in 1860 (Fig. 4.20). This device was a venturi, continuing the scroll at the point of delivery to form a trumpet-shaped expander. By its use, some of the kinetic energy of the air leaving the fan was converted to pressure energy, so increasing the pressure developed by the machine.

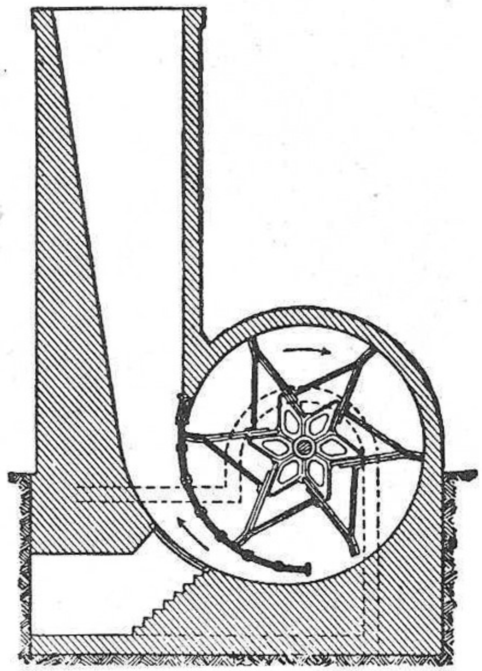


Fig. 4.20. Guibal fan and chimney.

The exact date of the introduction of curved blades is not known. It is usually ascribed to Combes. Reid noted in 1844 that curved blades were sometimes used, and that the form of the curve was of some importance. The blade curvature was varied according to the speed of the fanner and its purpose. Figure 4.21, taken from Péclet's *Traité de la Chaleur*, illustrates a Combes fan. The curvature of the blade at its root was calculated to avoid shock losses, while that at the tip was chosen so that the leaving air speed was low. The blades were mounted on a circular plate driven by a pulley. The wheel was placed immediately behind a fixed plate with a shaped orifice to admit air to the centre of the wheel. Air was discharged round the whole circumference of the wheel. This fan was intended as an aspirating device. Combes' fans were used in a number of Belgian mines. Glepin estimated their efficiency at around 27%, but Trasenter thought an error had been made in computing the energy input, and set the efficiency down to 15%; Péclet thought that fans with curved blades were little, if at all, better than straight-bladed fans.[43]

In an attempt to eliminate air leakage between the blades and the fixed plate, Combes devised a water seal round the entry orifice. Glepin observed that the agitation of the water led to loss by entrainment, and a continuous water feed was necessary. A paddle wheeel fan with backward curved blades fitted to one side of the rotating disc was illustrated in 1854: again the design of the blades was due to Combes. Tests on fans with these curved blades showed lower efficiencies than for fans with straight blades. W. Buckle presented the results of some tests on backward curved fans in a paper to the Institution of Mechanical Engineers in 1847. From these tests he deduced the optimum dimensions of a fan to be as follows:

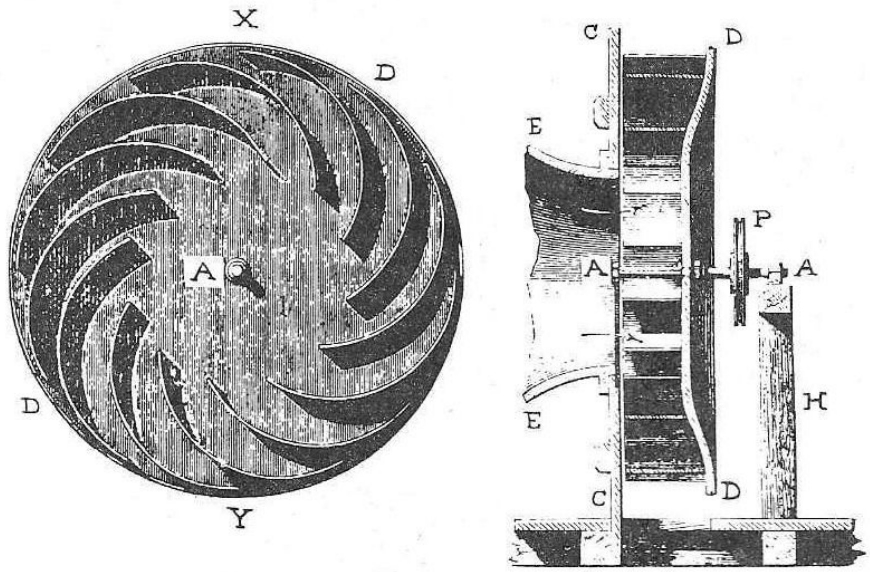


Fig. 4.21. Combes' fan.

Diameter of outlet	D
Diameter of inlet eye	0.50 D
Width of wheel at outlet circumference	0.25 D
Width of wheel at inlet circumference	0.50 D
Radial length of blade	0.25 D

These suggestions were only very little different from the common practice in fan design some sixty years later.

The Rankine fan was built to a design suggested by Professor Rankine in 1857. It is notable in that it used the spiral or scroll shape of housing to reduce the velocity of discharge, rather than depending on the chimney outlet.

The multi-vane fan — of which the Ser fan, designed in 1878 was an early form — initially had forward curved blades. It comprised a circular plate with up to 32 blades on each side, and air entered the wheel from both sides. It had a scroll casing and a Guibal chimney. Ser fans were made in sizes up to 2.5 m diameter and 0.5 m wide. A fan of this size, running at 186 rev/min, could deliver 40 m^3/s.

On 25th April, 1890 M. Levet was granted a French Patent for a centrifugal fan depicted as having forward-curved blades, with the tips advanced beyond the heel of the blade (Fig. 4.22). The principal feature of the patent was the generous use of guide vanes, in both the inlet and outlet of the fan.

On 18th February, 1896 a further French Patent for a centrifugal fan was granted to Fournier and Cornu, for what was the forerunner of the modern narrow-blade multivane type fan. It consisted of a wheel having curved blades mounted on a central revolving disc. One of its main features was the unobstructed inlet. Also, according to the patent, the fan blades were twice as long as their radial dimension, and the blade spacing was equal to the depth of the blade.

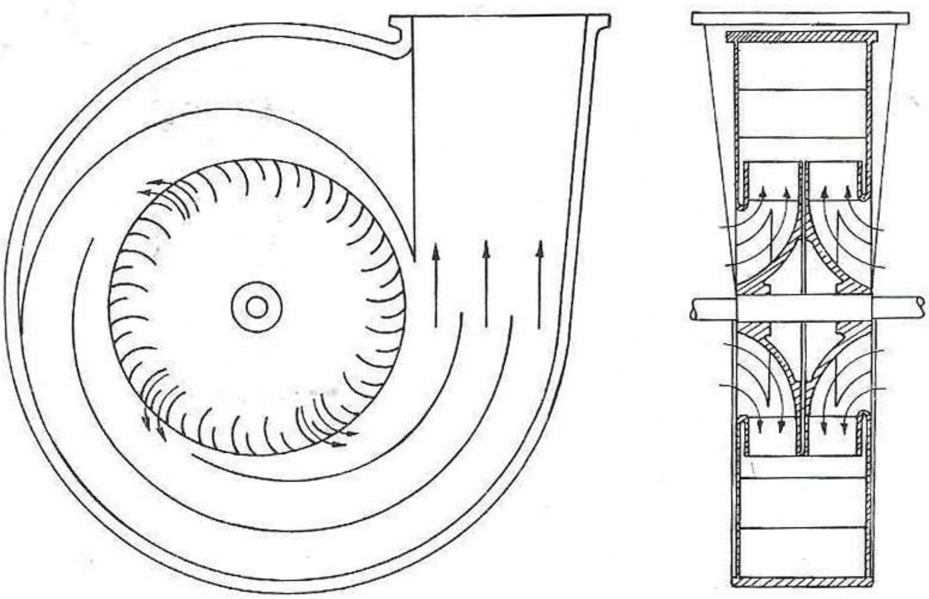


Fig. 4.22a. M. Levet Patent. April 25, 1890.

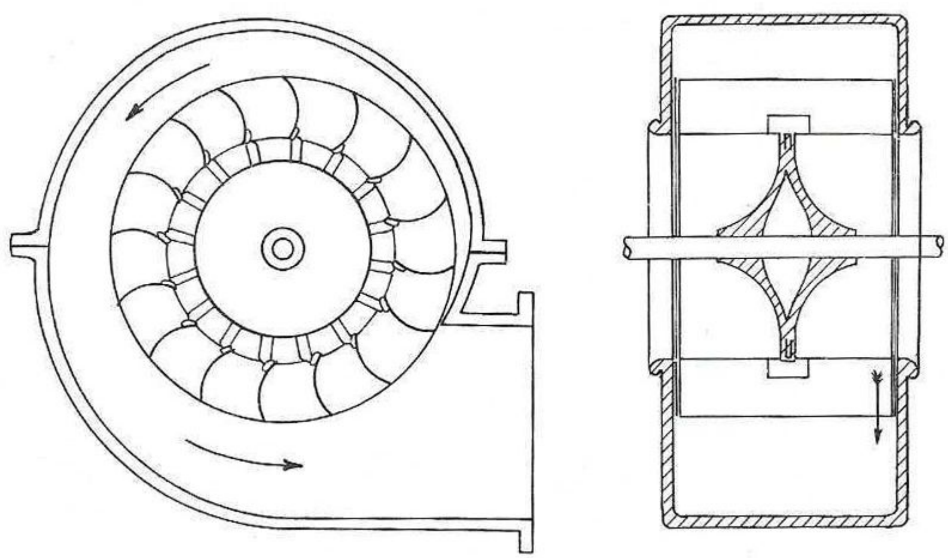


Fig. 4.22b. Fournier and Cornu Patent. February 18, 1896.

Other fan designs mentioned by Innes may be briefly noticed.[31] The Rateau fan (1892) was a centrifugal fan with shaped inlet eye, and the blades were three-dimensional and of prescribed form (Fig. 4.23). A Guibal fan 11 m diameter and 2.5 m wide (a monstrous fan) delivered 72 m^3/s at 65 rev/min. These fans had up to 10 blades, and their maximum speed was 120 rev/min. The Kley fan was a double inlet radial bladed machine. A spiral entry is provided to each eye to give the air a tangential motion in the same direction as the wheel.

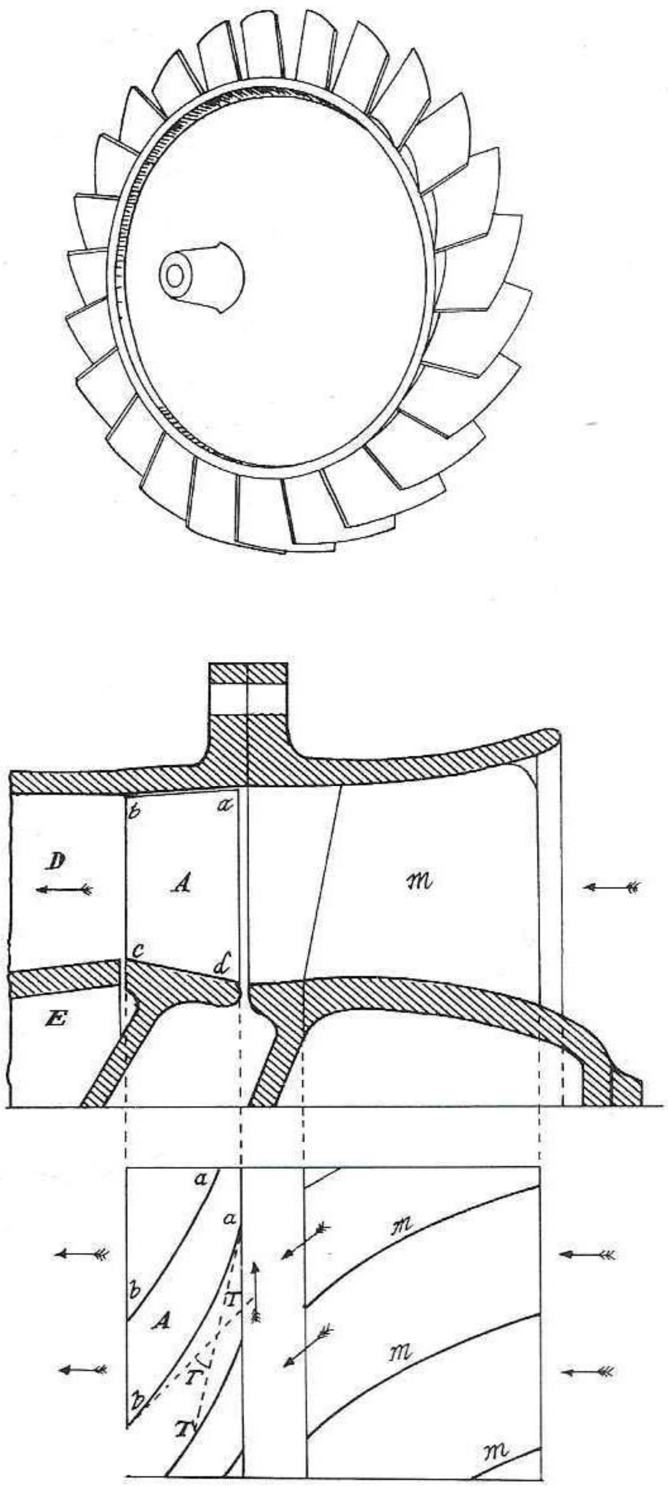


Fig. 4.23. Rateau screw fan. Top: fan wheel. Centre: details of inlet guide vanes, wheel, and outlet diffuser. Bottom: air path through fan.

4.5.5 Mine fans

In the middle of the 19th century, fans were chiefly employed for mine ventilation, and only occasionally for the ventilation of buildings. In 1852 a committee of the House of Commons was set up to consider the methods of ventilating coal mines, and reported:

> "Your Committee are of the opinion that any system of ventilation dependant on complicated machinery is undesirable, since under any disarrangement or fracture of its parts, the ventilation is stopped or becomes inefficient; that the two systems which alone can be considered as rival powers are the furnace and the steam jet.
>
> Your Committee are unanimously of the opinion that the steam jet is the most powerful and at the same time least expensive method for the ventilation of mines."

This view was soon overturned. In 1861, the centrifugal fan at the colliery at Elsecar was described to the North of England Institute of Mining Engineers by J. J. Atkinson, who clearly showed for the first time the superiority of mechanical ventilation over every other system.(29)

The Capell fan was originally designed in 1883 for mine ventilation and continued in use for over 40 years. The wheel comprised a circular plate to which were attached a number (about 10) of "scoop" blades. These were forward curved at the inner radius and backward curved at the tip; in addition, the outer edge, adjacent to the inlet eye was turned in the direction of rotation (hence "scoop"). Between each pair of scoop blades, two narrower, forward-curved blades were fixed at the tip of the wheel.

Rateau designed a mine fan with the blades in a "somewhat inclined position" and projecting into the axial suction space. Another early design by Harzé, used for mine ventilation in Belgium, incorporated a volute casing with a number of discharge points (an idea subsequently adopted for aircraft engine superchargers) (Fig. 4.24).

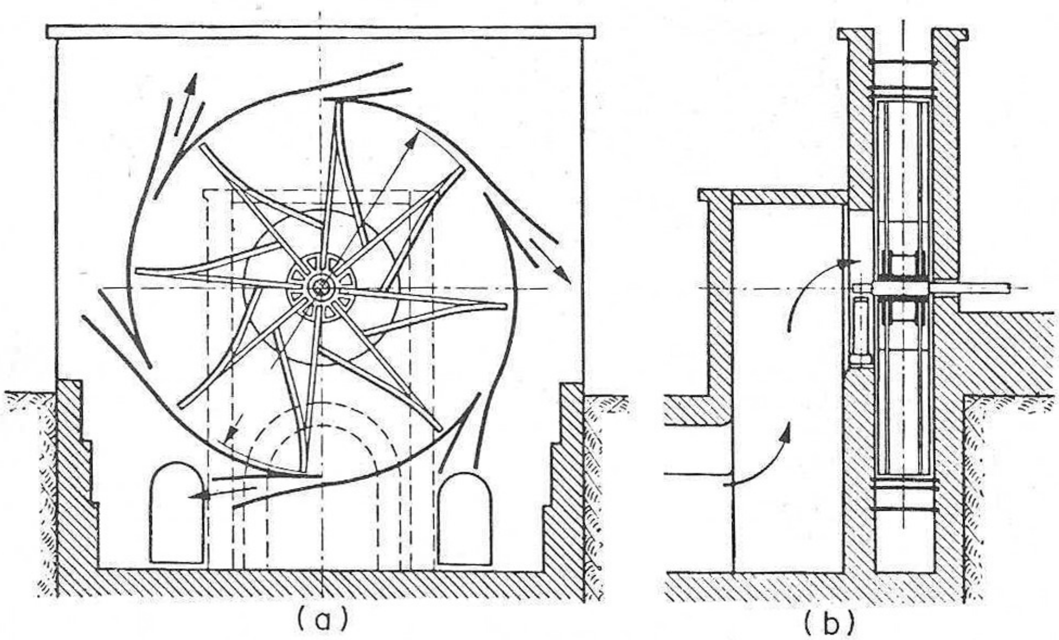


Fig. 4.24. Mine fan of Harzé with free-discharging partial diffusers.

Tests on several types of mine fan were carried out in 1892; these are reported by Innes. Other tests were made by Heenan and Gilbert (*Proc.ICE* Vol.123) to study fan design parameters, and by Bryan Donkin (*Proc.ICE* Vol.122) and others.

For sheer size, some of the early mine fans have not been equalled. The change from slow-speed steam engine drive to electric motor drive resulted in the development of smaller-diameter, high-speed rotors.

Daniel Murgues, engineer to the Colliery Company of Besseges, developed the first satisfactory theory of fan operation, published in 1872, and showed that simple plane radial blades were not compatible with high efficiency. He proposed the use of blades which are tangential to the air flow at the root and radial at the tip. These were in effect forward-curved blades. Kinealy (*ca.* 1904) mentioned that in one fan designed at about that time, the idea of using curved blades was carried to such an extent that the blade extended round one quarter of the fan wheel.

On this point, Kinealy says that all the fans employing curved blades were designed so that the blades were radial at the root and were given a backward curve at the tip. He goes on:

> "this is rather curious in the face of the fact that theoretical considerations indicate that the floats (blades) should be tangent to the radius at the periphery of the wheel and that at the inlet they should make an angle of about 45° with the radius."

4.5.6 Blowers

Amongst other early designs of mechanical fanner, Reid mentions Mr Clarke's patent for a small blower to be used for household fires. This concept remained unused for almost a century before being applied to forced combustion in modern boilers.

M. Fabry, the ventilation engineer at the mines at Charleroi, designed a blower based on a Murdoch patent of 1799, and this was clearly a forerunner of the Roots blower. Fabry's blower comprised two 3-bladed rotors turning in opposite directions within close-fitting cylindrical chambers (Fig. 4.25).[43] Air entered the chamber through the central aperture; it was carried round by the blade and discharged at the top. The auxilliary blades B were intended to seal the space between the rotors and so prevent leakage of air. In Fabry's machine, the blades were 2 m wide and 1.7 m long, and the theoretical discharge per revolution was about 23 m^3 — a quantity never reached in practice. Tests on a Fabry blower in a mine at Chatelineau gave the volume discharged as 9.6 m^3/s, at a depression of 22 mm w.g. when turning at 30 rev/min. The efficiency was about 50%. Jochan's tests indicated that the volume decreased as the depression was increased (due to extra leakage) and that the depression was proportional to the square of the rotor speed. A blower designed by Lemielle worked on a very similar principle.

The Roots' positive displacement blower was invented in the USA in 1866 by two brothers of that name.

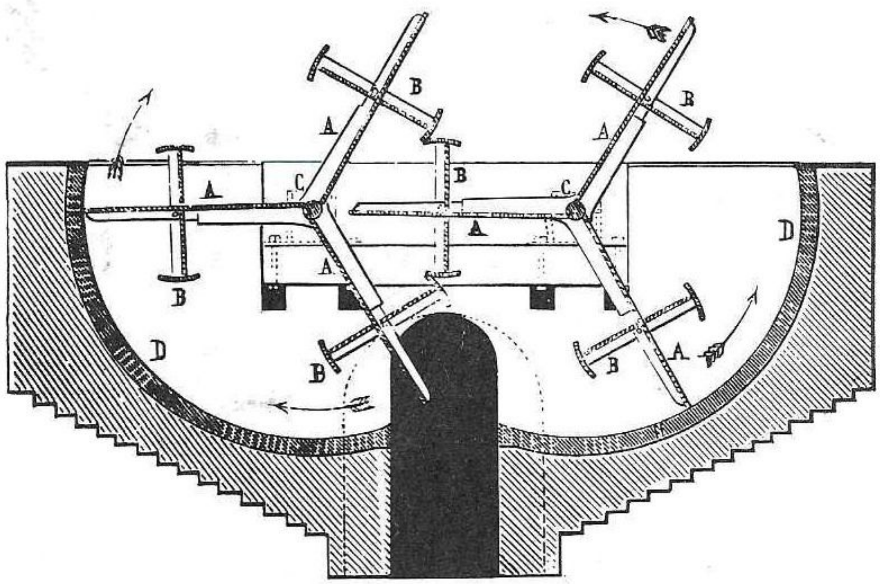


Fig. 4.25. Fabry's contra-rotating blower (early 19th century).

4.5.7 *Helical fans*

A. M. Motte received a prize in 1834 for the application of the Archimedean screw in place of the fanner, and this was used for a time in Belgium and elsewhere (Fig. 4.26). One of these, used in a mine at Sauwarten, was 1.40 m diameter, and had a length equal to half the pitch of the screw. At 450 rev/min it delivered 3.9 m^3/s at a depression of 22 mm w.g; the efficiency was 31%. Some years later, Mr Combe of Leeds used a double-threaded screw which may perhaps be regarded as the first axial-flow impeller. The Archimedean screw soon fell into disuse, and the blades of propellers and of axial-flow fans were made much "shorter" from front to back in more recent designs.[45]

According to Picard helical fans were made by most manufacturers.[44] D'Anthonay's fan was driven by a water turbine designed as an integral part of the machine. The Geneste Herscher fan was basically a modern axial-flow fan: it used helical blades and a large streamlined fixed hub which contained the wheel bearings and drive pulley (Fig. 4.27). A fan of this type was used successfully to ventilate the large hall at the Palace of the Trocadéro (Paris). Large volumes of air were required, at low pressure, and operation had to be quiet; economy was secondary. The Farcot fan used curved triangular blades; its special feature was the manner of its installation in an S-bend of the ductwork to facilitate the drive. It had an efficiency of 20-25% against a pressure of 30 mm.w.g.

The Hattersley-Pickard fan consisted of a large central hub carrying helical blades whose pitch increased along the blade. It was designed to work against a high resistance. An 0.5-m fan running at 700-1200 rev/min delivered 1-1.7 m^3/s. The Rateau screw fan was an axial fan with fixed inlet guide vanes and an outlet diffuser. Rateau also designed a high pressure fan. This machine had a 250-mm impeller driven at 20000 rev/min by a turbine. It was able to develop a pressure of 57.5 kPa, delivering 0.23 m^3/s. The volumeteric efficiency was 18%, and the mechanical efficiency of the fan was 56%.

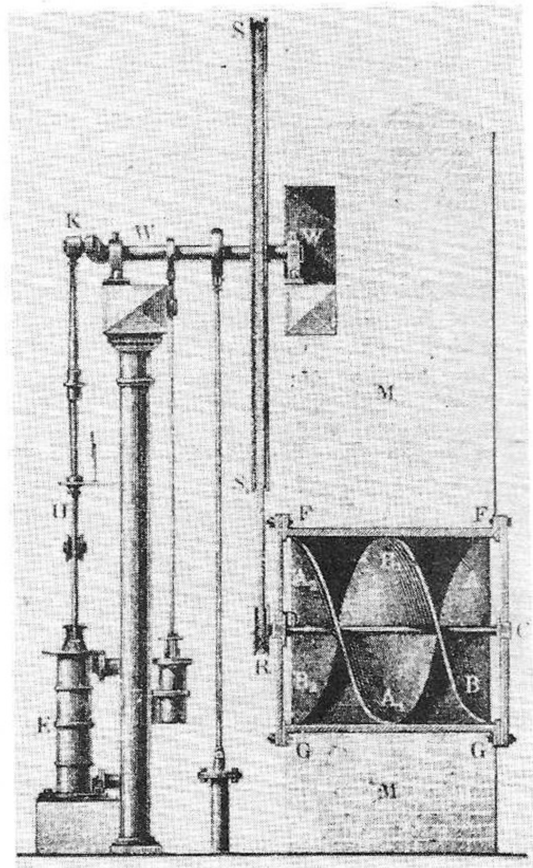


Fig. 4.26. Archimedean screw fan.

Reid also mentions a windmill ventilator which seems very similar to the present-day propeller or desk fan.* The Blackman propeller fan — a wheel with few blades turning in an orifice — was thought by Picard (1897) to be one of the better ones. It had an efficiency of 50%, but its pressure development was only 30 Pa. The electric drive, armature and windings were incorporated within the blade circle.

4.5.8 20th Century fans

The major developments in fan design during the late 19th and early 20th centuries seem to have taken place in the centrifugal fan. Blades have become shorter, and placed along the circumference of the runner, and they have become more numerous. More care is taken in the design of the inlet eyes, the edges curved to reduce turbulence losses, and the eyes themselves are of appropriate size. The scroll

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*A 2-bladed desk fan, manufactured by the Crocker and Curtis Electric Motor Co. of New York in 1883, is generally considered to be the first electric fan to be produced commercially. It had been developed by their chief engineer, Dr Schuyler Skaats Wheeler in the preceding year. The first oscillating electric fan (gear-driven) was produced in the USA by the Eck Dynamo and Electric Company in 1908, superseding the revolving models which had the disadvantage of blowing in unwanted directions. In Britain, commercial production of electric fans was started in about 1888 by B. Verity of London.

casing has also been developed, changing from the original eccentric circular form to spiral and convolute forms. Little attention seems to have been paid, until comparatively recently, to the aerodynamic shaping of the blades themselves.* Even now, this is a continuing subject of research. The vast majority of present-day fans still use sheet metal blades of uniform section. Little has been done to reduce the noise generated at high speeds; and where noise is a serious consideration, either large diameter, slow speed fans are still employed (as in Reid's time), or noise attenuators are provided at fan outlet — and sometimes at the inlet also.

The culmination of all of the best of the ideas of the fan designers of the 19th century is represented in the Davidson patent ("Sirocco" fan) of 1900. In the original Davidson design, the blades are narrower radially and more closely spaced than in fans previously built (the blades were three times as long as the radial dimension, and the blade spacing was about two-thirds of the depth of the blade). The patent also gave special prominence to the unobstructed design of the inlet chamber, and to the blade design, where the tip of the blade is advanced behind the heel. Both these features were embodied in the earlier Ser design, though in the Davidson fans the blades projected their entire depth within the inlet circle.

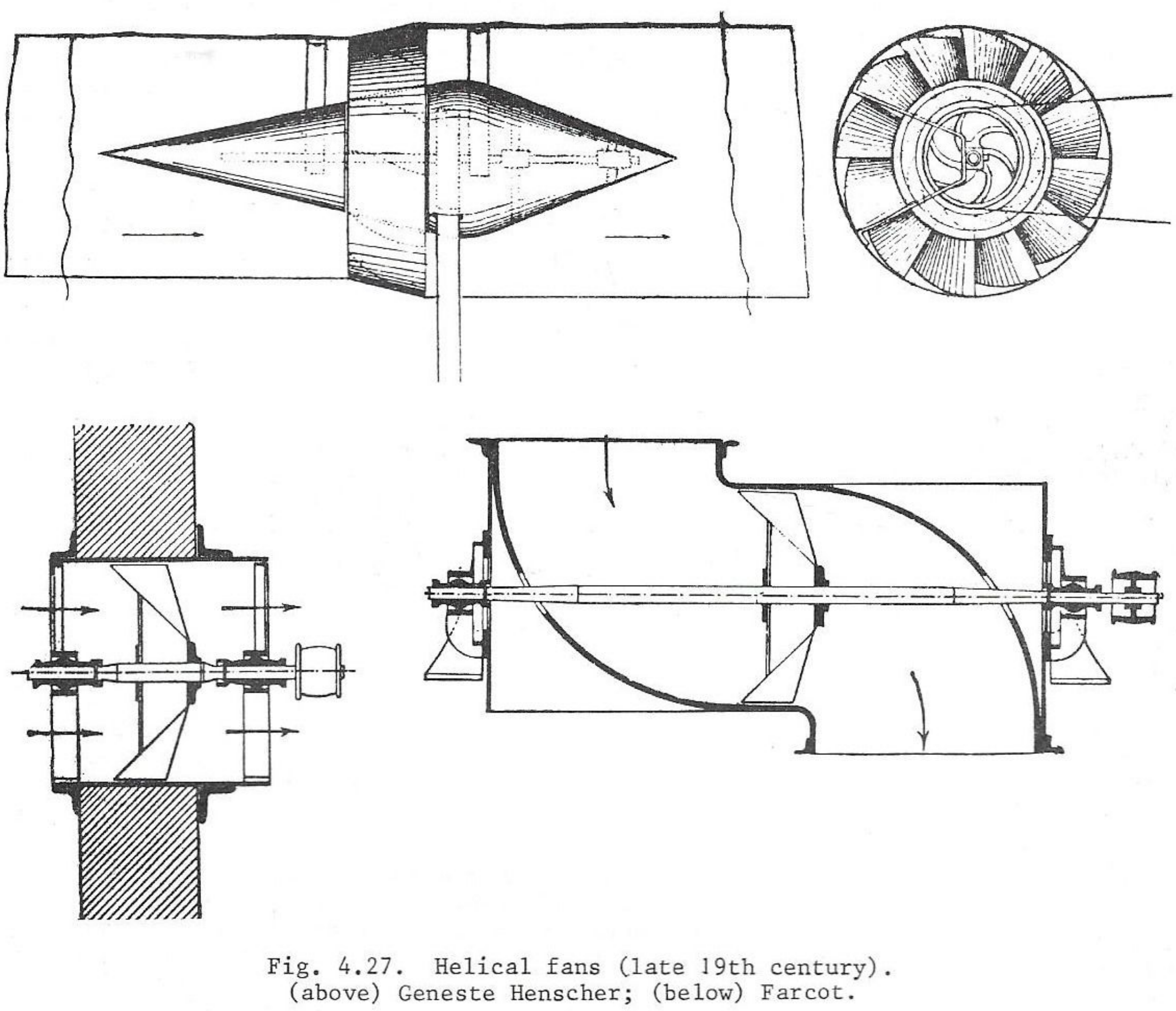

Fig. 4.27. Helical fans (late 19th century).
(above) Geneste Henscher; (below) Farcot.

*Brought about by the increasing use of high velocity air conditioning from the mid 1960's onwards.

It is interesting to quote Bruno Eck's assessment of this original "Sirocco" fan many years later (1973):[18]

"The original design of the Sirocco fan had the following dimensions:

d_1/d_2 = 0.875 (inside/outside impeller diameter)

b = $3/5d_2$ (blade width)

β_1 = 64° (angle of blade to tangent of circumference at point of entry)

β_2 = 22° (corresponding angle at point of discharge)

Z = 54 (number of blades)

The blades were formed precisely as circular arcs.

This design received no attention in the field of research. Although the circular arc was blamed for the poor efficiency (η = 50%), it has enjoyed a success unrivalled by any other design and has been manufactured in greater numbers than any other form of flow machine. Apart from its compactness it is remarkably silent in operation. There is no other fan which operates as silently at comparable pressures."

But during the first decade of the 20th century the use and development of fans for heating and ventilating in Britain generally lagged far behind what was happending on the Continent and in the USA.

By 1915 centrifugal fans were in widespread use and the Davidson design of 1900 had undergone numerous modifications. Two principal alterations were that the blades no longer projected inside the inlet circle and the fan outlet was greatly enlarged to about the centre of the fan housing (i.e. below the point of "cut-off").

Further design developments were incorporated into the Niagara Conoidal fan. Built at Buffalo, this was again of the multivane curved blade type, but the design embodied two special features, described as follows:

"First, the diverging cone effect is brought back into the fan housing, giving an actual lower outlet velocity and consequent high static pressures; and secondly, the wheel is entirely different in its design from anything previously built. The name was derived from the prevalence of conical sections used in the design, the blast wheel forming the frustrum of a cone and the blades being curved over the tapering surface of a cone.

Around 1951, a significant event occurred in the development of centrifugal fans — the appearance of new high-performance units. The first investigations had looked at the design of centrifugal pumps to see if any of the experience gained could be applied to centrifugal fan design. The type of impeller which resulted from this design was constructed with blades going deep into the intake chamber (a procedure often adopted in pumps to offset the effects of cavitation). The efficiency of this design was in the order of 80%. The other line of investigation was based on aerofoil blades. The design break-through has been described by Eck:

"A completely new method was then used in the design of high performance fans. In contrast to previous designs, *the discharge width was increased considerably; it was, in fact, almost doubled.* The blades had a pronounced backward curvature and the entry was well rounded off. There was no aerofoil profiling or projection protruding into the suction chamber. With this type of impeller a speed coefficient of 0.66 was obtained and it opened up new prospects for the centrifugal fan. For the very first time the efficiency could be raised to nearly 90%."

The 1930's saw the more widespread use of fan characteristics, their construction and application being explained in such IHVE papers as "Centrifugal fans and their relation to air circuits" (Kerr, 1933) and "Fan performance curves" (Gee, 1935), the latter paper including a logarithmic chart presentation.

4.5.9 Axial fans

In spite of the prevalence of designs for helical (axial) fans in Picard's time, they do not seem to have been used much. Their major development commenced in the 1930's, stimulated perhaps by studies of the aerodynamic characteristics of aerofoils during aircraft development, and by the establishment of an adequate theory of fan design.

At Gottingen, Prandtl founded the world-famour Kaiser Wilhelm Institute for the study of fluid flow, where he defined the theory of the boundary layer. Among his many brilliant collaborators was Theodor von Karman, originally of Budapest, who went on to work in the USA. It was on the work of Prandtl, von Karman and others that the design of aerofoil-bladed fans was to be based. As Eck relates:

> "This success was due in part to the assumption of a frictionless fluid, and aerofoil theory achieved a remarkable correlation with actual results. In 1922 Bauersfeld already showed a way in which aerofoil theory could be applied to turbines. In this case also the theory was applied with great success."[18]

The axial fan has since been the subject of much experimental study, and this has brought to light the factors which are now known to influence the performance — factors such as pitch angle, hub ratio, clearance and the use of guide vanes.

An axial flow fan necessarily imparts a rotary motion to the air passing through it, and the purpose of the guide vanes is to reduce the waste of energy in the rotary movement. In addition, adjustable inlet guide vanes are used for volume control. More recently, the idea of imparting an equal and opposite rotation by using a second impeller turning in the opposite direction has led to the development of contra-rotating axial-flow fans. Contra-rotation was first used for aircraft propellers (1923), and it seems to have been applied to fans first by de Bothezat (USA) and by Poole (BP 399619 of 1932-3). The first British contra-rotating axial fans were supplied in about 1944 for use on aircraft, and later on boilers (Fig. 4.28).[60]

Variable-pitch fans (analogous to variable-pitch propellers) were introduced to ventilating practice in about 1960, to enable variations in load (whether volume or pressure) to be met with maximum economy of power.

Blade design in axial-flow impellers is less crude than in centrifugal fans, aerofoil forms being used almost exclusively. The theory too is perhaps a little more advanced, though in design much reliance is still placed on empirical laws.

4.5.10 Cross-flow fan

The cross-flow fan differs from the previous types both in its geometry and in its mode of operation. The fan consists of a cylindrical rotor with forward-curved blades extending the length of the cylinder parallel to the axis — its appearance is that of a multi-vane centrifugal fan wheel whose diameter is less than its width. The ends of the rotor are blanked off. The motor turns between two walls — the vortex wall and the rear wall — and the resulting air flow is through the rotor in a direction perpendicular to the axis. The operation of the fan depends on the formation of stable vortex systems in and around the rotor: the form and position of the walls are important in this respect. Clayton gives a review of work on cross-flow fans, concluding with an empirical correlation plot connecting shape and size, from which a fan may be designed for a specific duty.

The first realisation of a cross-flow fan appears to have been due to Mortier (French Pat. 215 662 of 1891).(14) Clayton remarks that the geometry was based on inspiration rather than on an understanding of the fluid mechanics. A Mortier fan 1.2 m long and 2 m diameter rotating at 225 rev/min, was used in an early French installation, and Eck notes that these fans were used in mines at the turn of the century.

Few developments took place during the next 60 years. Dalin's USP 291007 (1928) met with little response, though Buck (USP 1893857 (1933)) applied his machine to fuel injection, with limited success. The major advances were made in the late 1940's by Eck, culminating in his patent (German patent 807978 (1951); since then there have been spasmodic contributions to the experimental and theoretical study of these fans. Commercial interest grew when it was realised that the geometry of the fan made it particularly suitable for applications where a long, narrow jet of air was required, as in air curtains, for example, and domestic air heaters.

In particular, Eck's researches showed that the vortex wall should be given considerable clearance from the rotor (whereas Mortier had sought to minimise clearances, in the belief that this would reduce the return flow of air from the discharge to inlet side). Coester of Zurich (1959) and Dätwyler (BP 988712 (1965)) both contributed to the fan geometry. Coester's design was a complicated one, but Dätwyler's was simpler to manufacture, while retaining some of the important features of Coester's model.

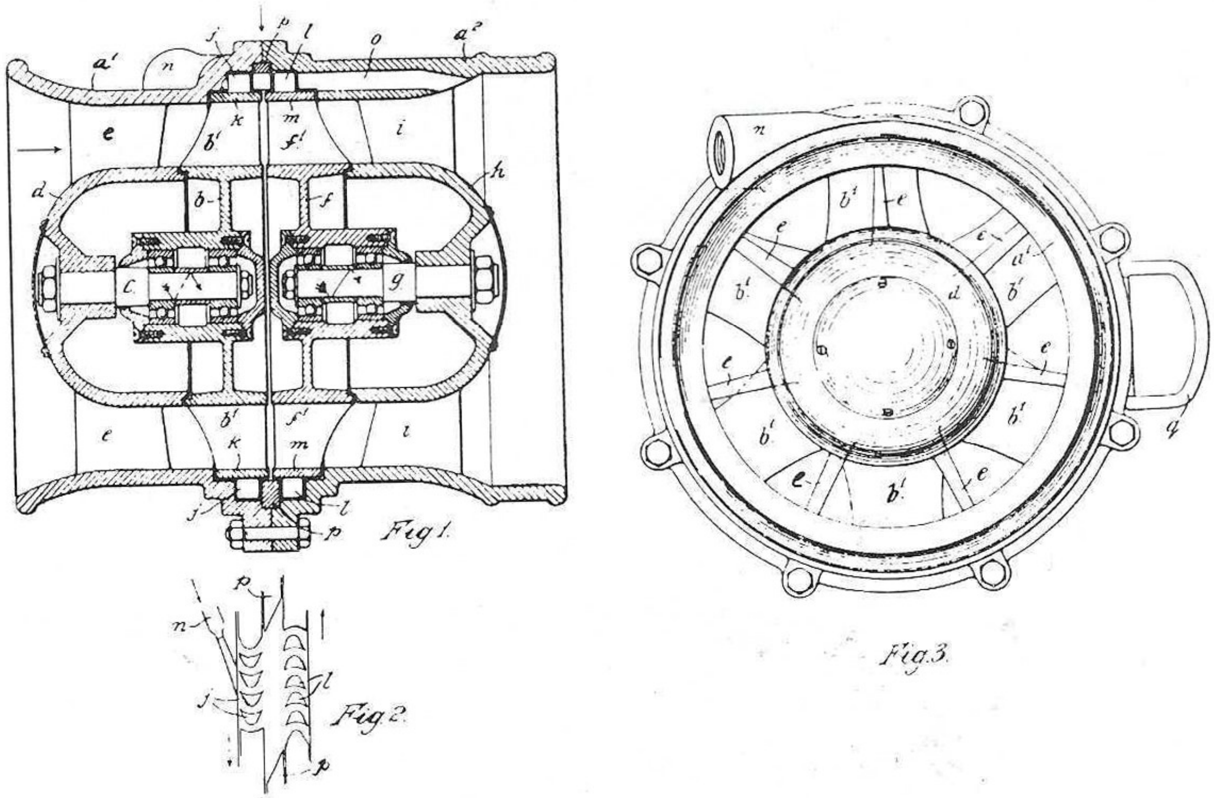

Fig. 4.28. Contra-rotating fan.
(Courtesy, CIBS)

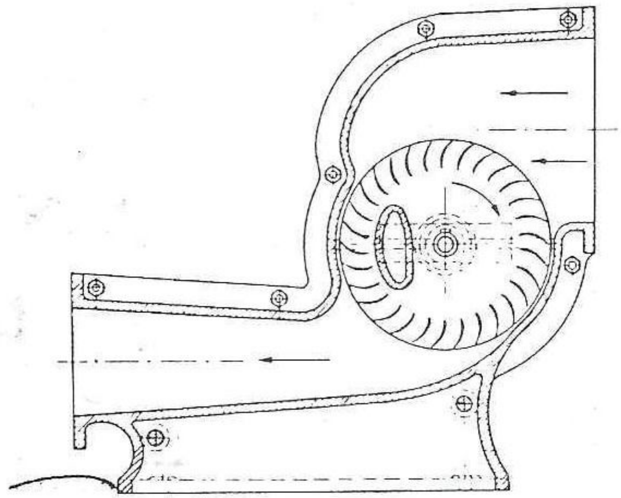

Fig. 4.29. Original fan of Mortier. (1892)

Coester was also the first to attempt a thoeretical analysis, but this was called into question by the experimental work of Ilberg and Sadeh. Further theoretical work was carried out by Ikegami and Murata (Japan), and by Preszler and Lajos in Hungary — these last workers backed up their theory with extensive test data.

In 1960, Westinghouse (USA) marketed an in-line centrifugal fan (the so-called mixed-flow fan). A forward-curved centrifugal impeller rotates within an enclosing cylinder (Fig. 4.30). Air enters the fan eye through a conical inlet, and after leaving the periphery of the wheel, which has aerofoil blades, the air turns at right angles and passes through a set of stationary guide vanes to the outlet diffuser. It was claimed to have a broad efficiency curve and a stable pressure-volume characteristic. The performance of these fans lies between those of the centrifugal and axial types, in that its pressure development is greater, but its discharge volume less, than that of the typical axial fan. It has been claimed that the National Engineering Laboratory devised a similar fan independently of the American Company, but at the same time.

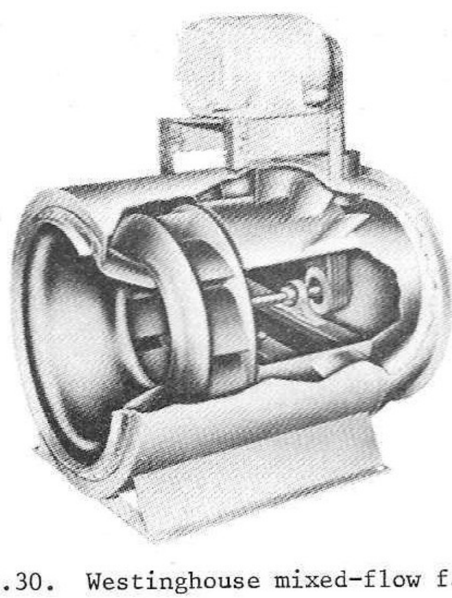

Fig. 4.30. Westinghouse mixed-flow fan (1960).

From ASHRAE Heat & Cold 1994

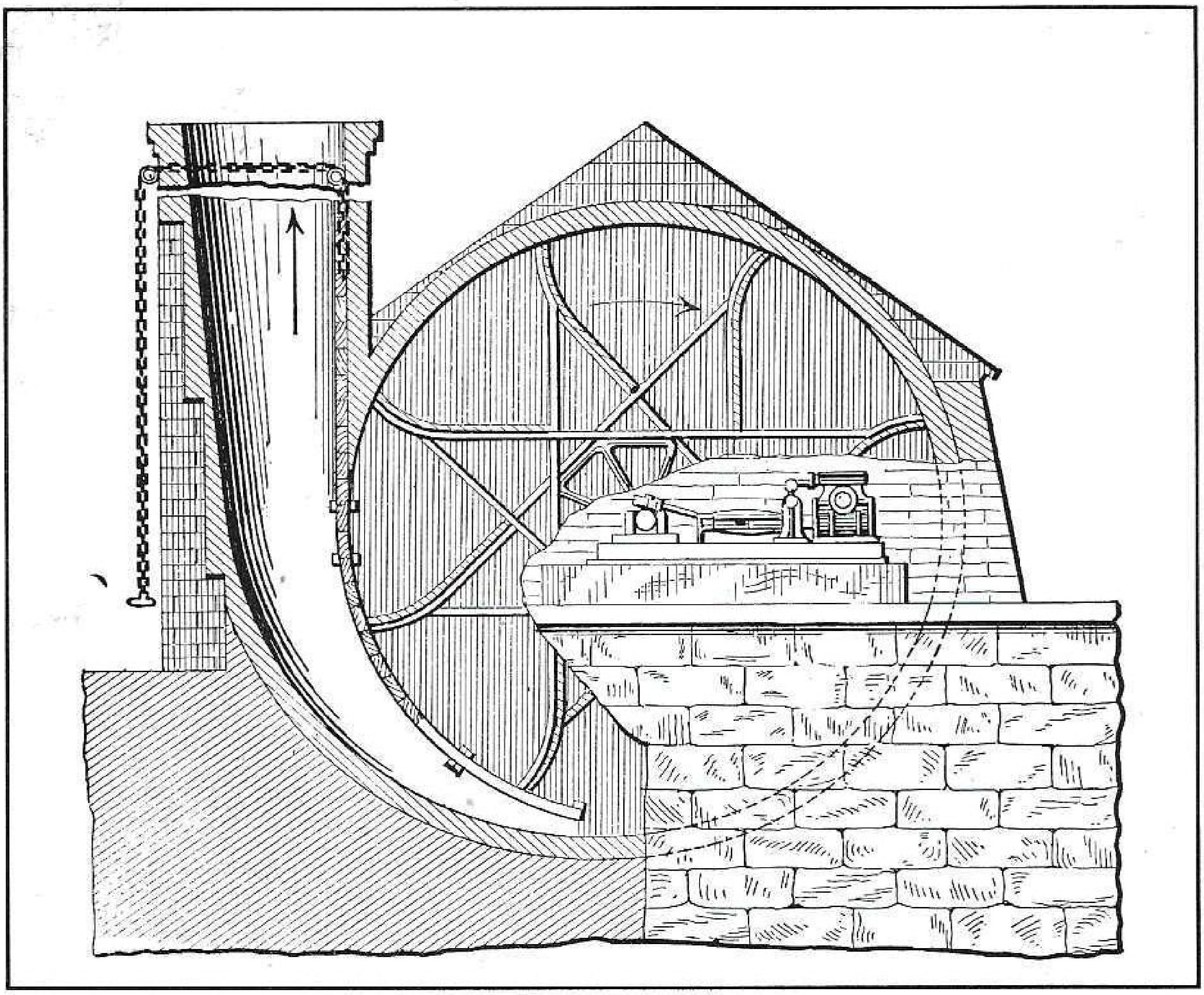

Figure 7-60 *Guibal fan, c. 1878.*

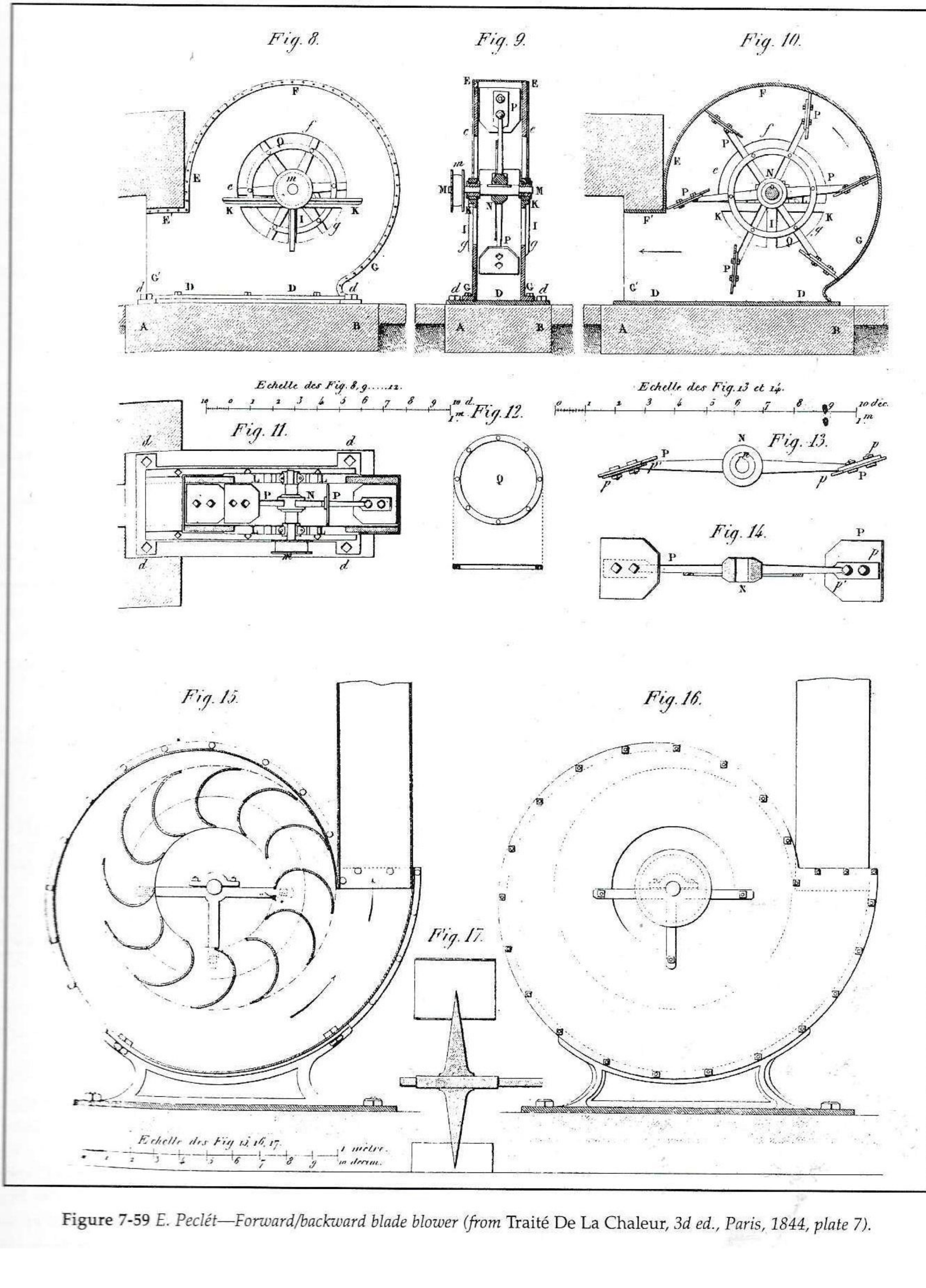

Figure 7-59 *E. Peclét—Forward/backward blade blower (from* Traité De La Chaleur, *3d ed., Paris, 1844, plate 7).*

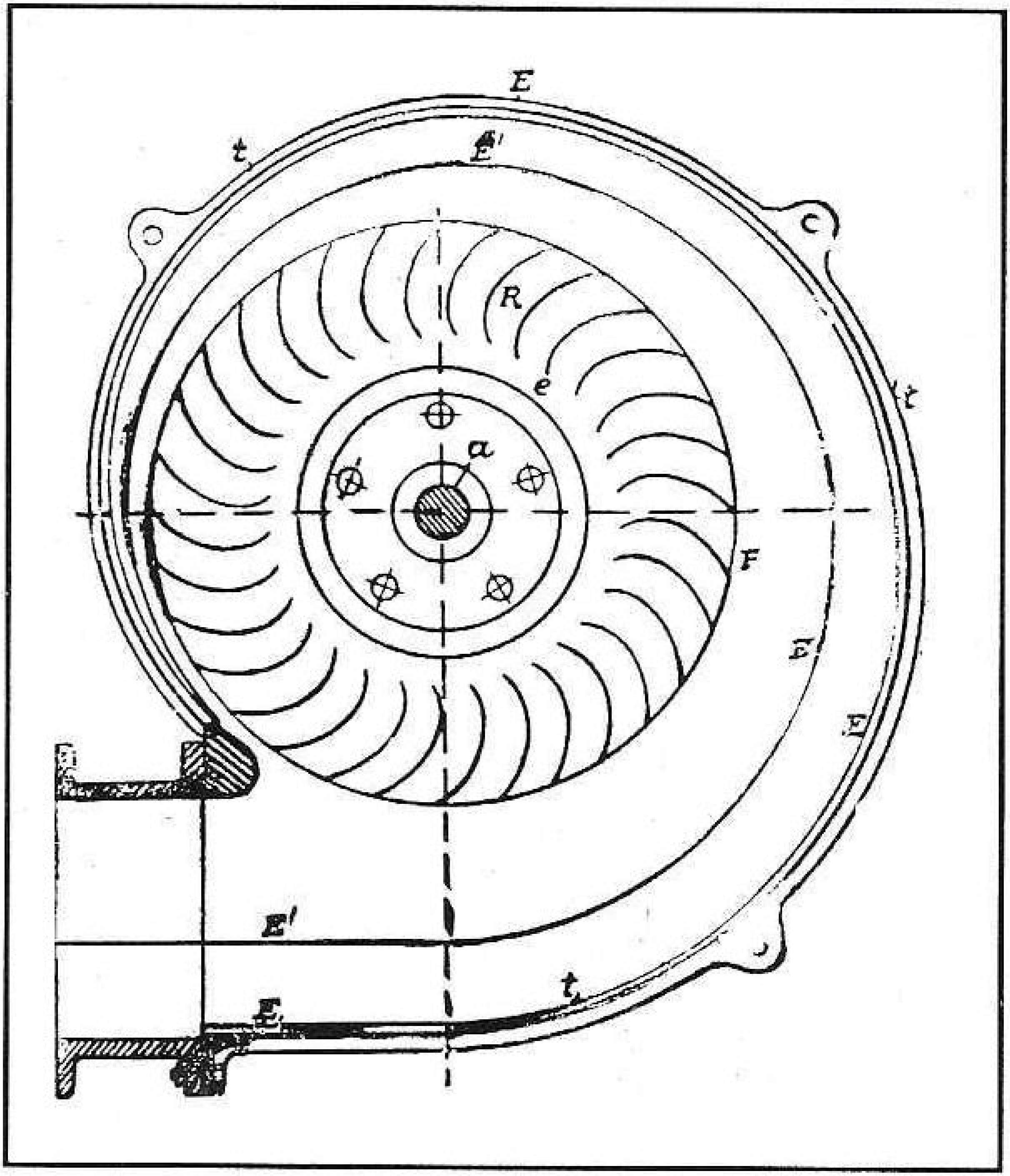

Figure 7-62 *"Ser" fan, longitudinal section, patented 1884 (original design 1878).*