PUBLISHED
APRIL 27, 1943.
BY A. P. C.

G. BOULET
SYSTEMS FOR COOLING A FLUID
CHARGED WITH THERMIC ENERGY
Filed April 18, 1940

Serial No.
330,429

7 Sheets-Sheet 1

Fig. 3

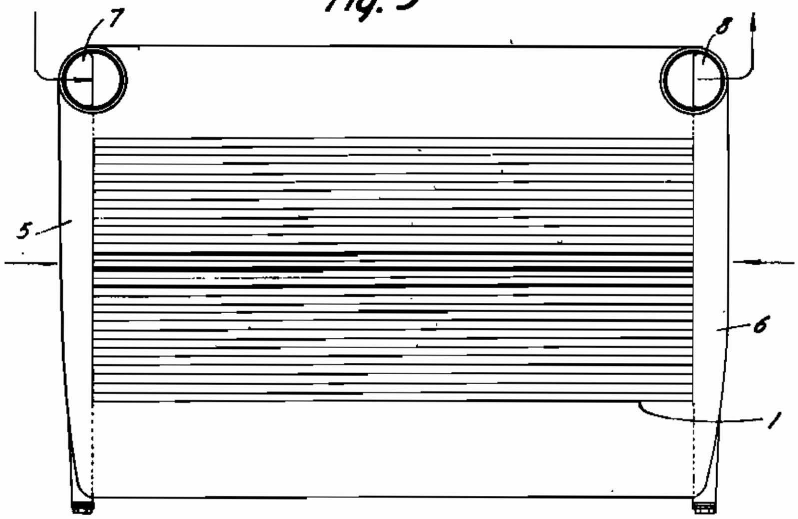

Fig. 1

Fig. 7

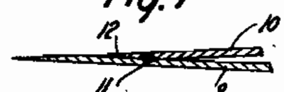

Fig. 5

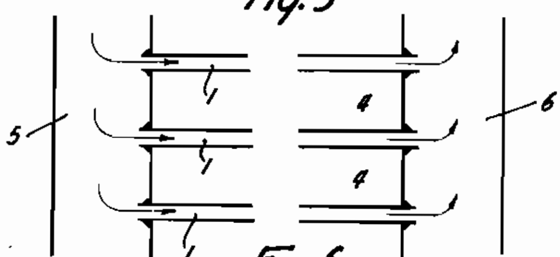

Fig. 6

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7 Sheets-Sheet 2

Fig. 2

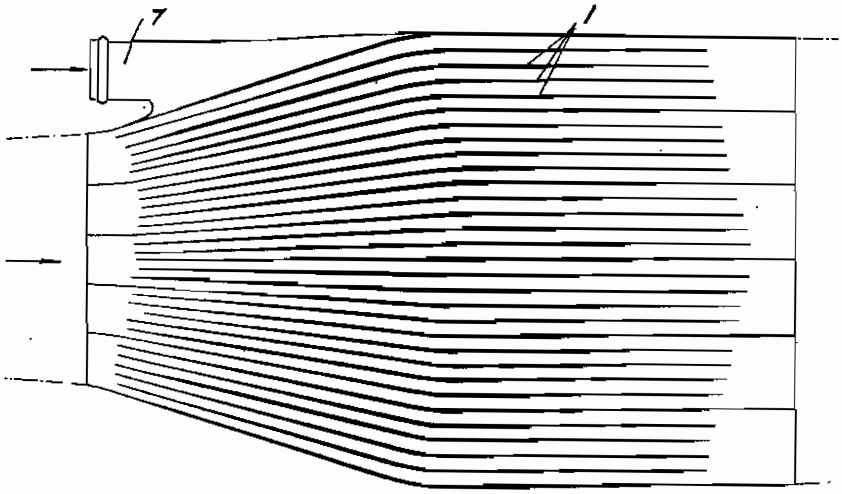
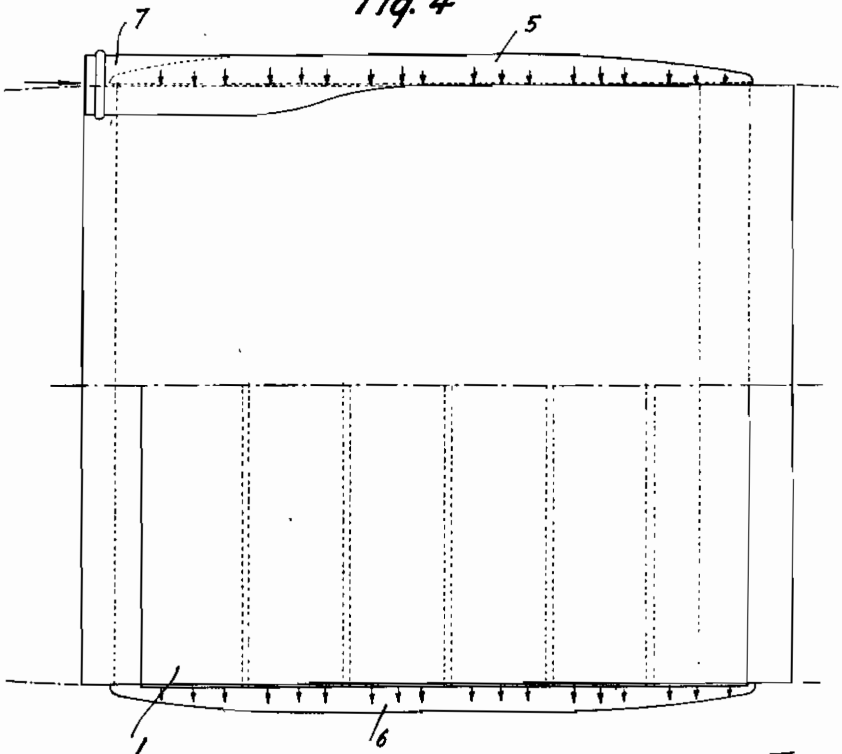


Fig. 4



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7 Sheets-Sheet 3

Fig. 8

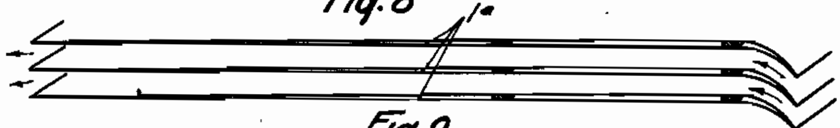


Fig. 9

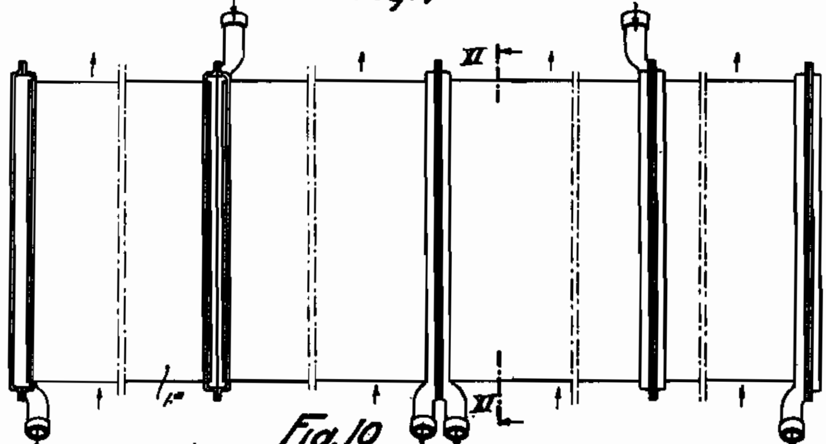


Fig. 10

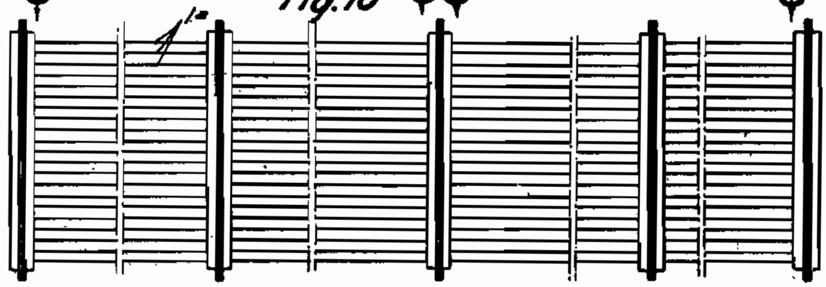


Fig. 11

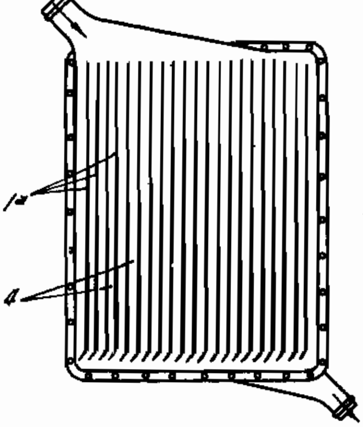
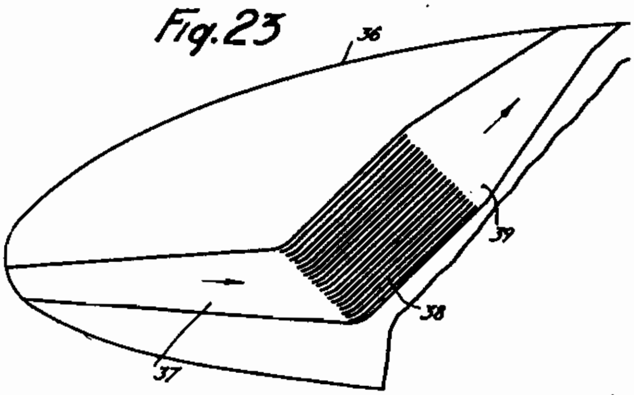


Fig. 23



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Serial No.
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Fig.12

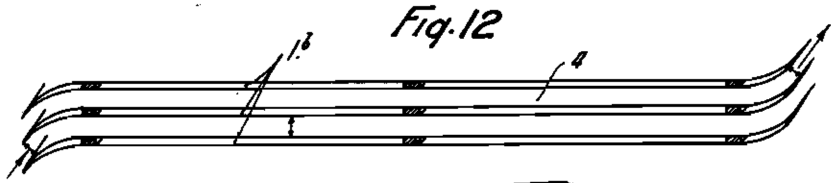


Fig.13

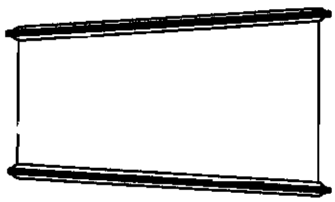


Fig.14

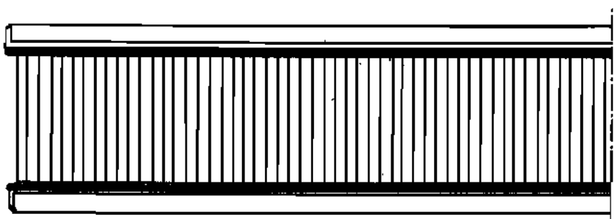


Fig.22

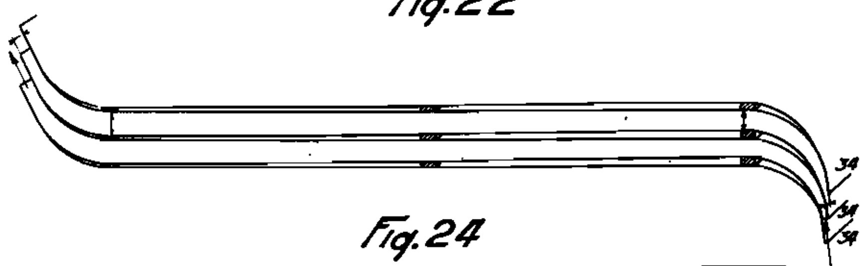
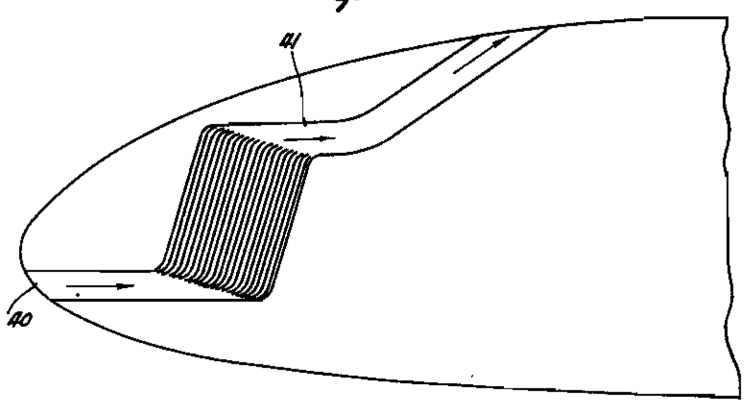


Fig.24



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7 Sheets-Sheet 5

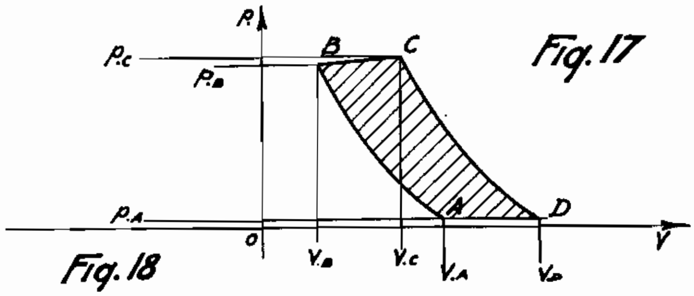


Fig. 17

Fig. 18

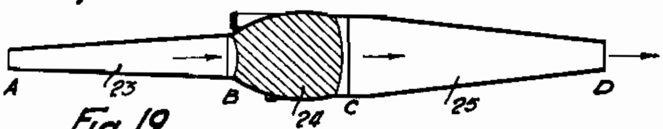


Fig. 19

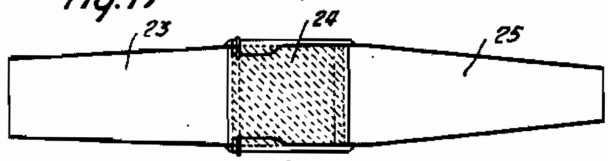


Fig. 20

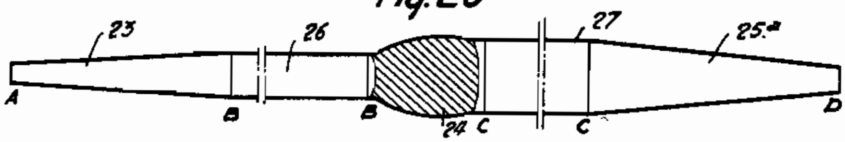
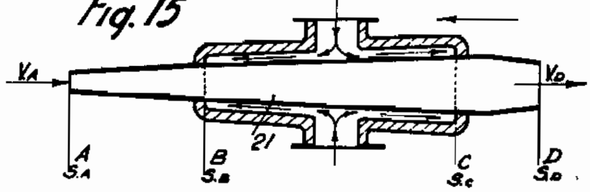


Fig. 21

Fig. 15



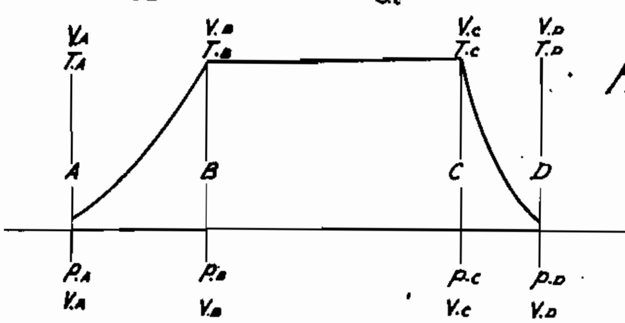


Fig. 16

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7 Sheets-Sheet 6

Fig. 25

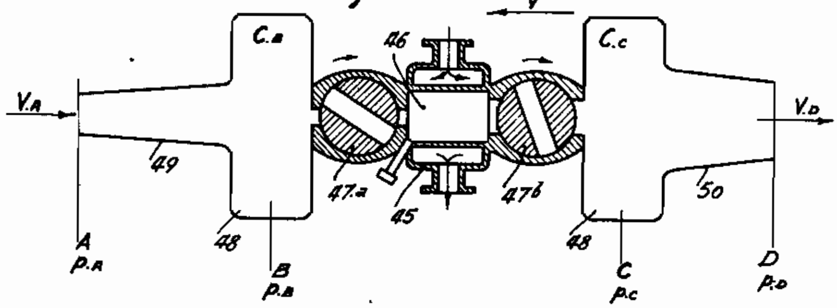


Fig. 26

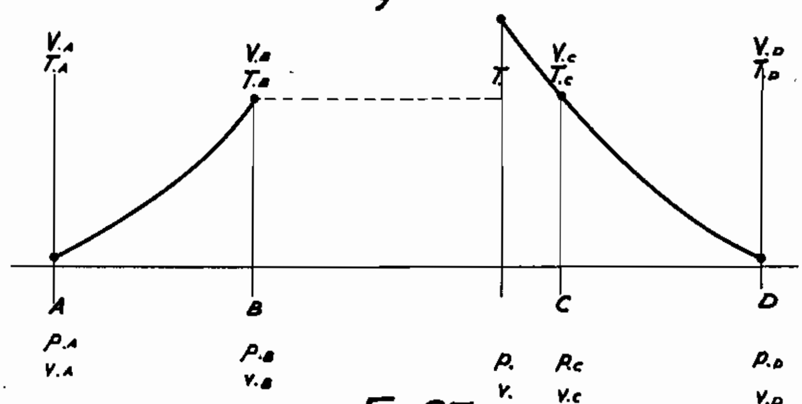


Fig. 27

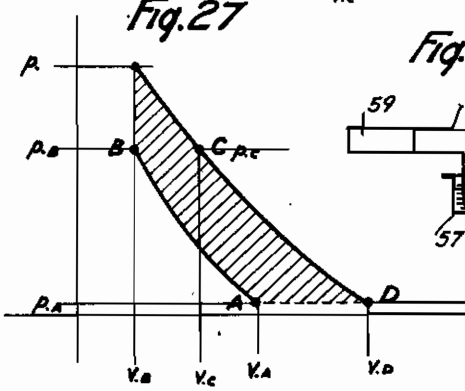


Fig. 30

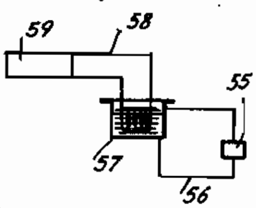


Fig. 28

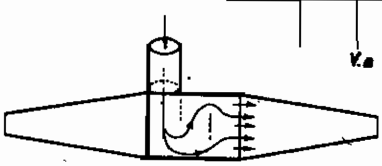
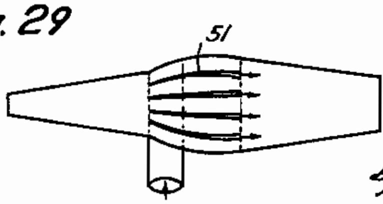


Fig. 29



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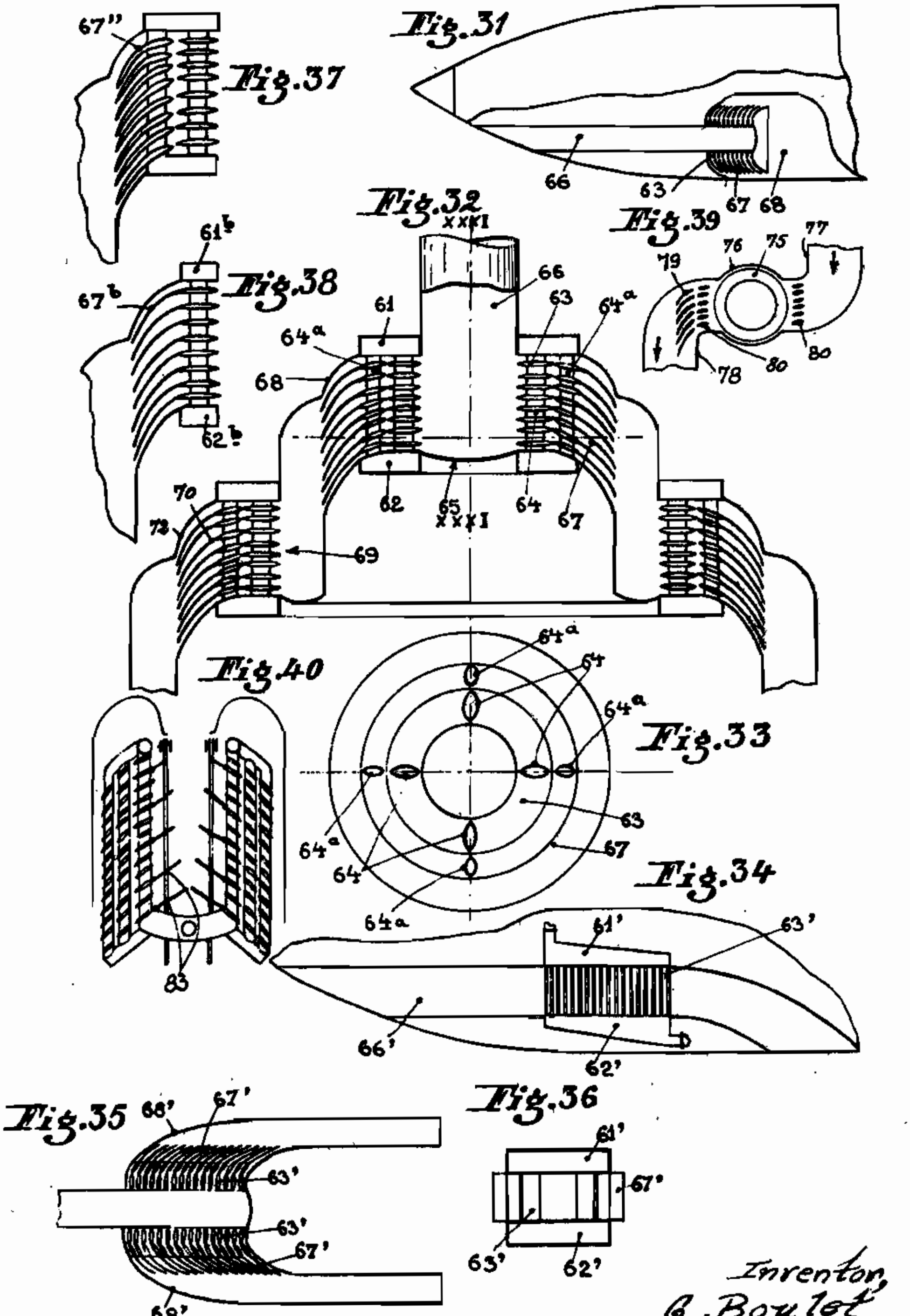
7 Sheets-Sheet 7



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Published Apr. 27, 1943

Serial No. 330,429

ALIEN PROPERTY CUSTODIAN

SYSTEMS FOR COOLING A FLUID CHARGED WITH THERMIC ENERGY

Georges Boulet, Plessis-Robinson, France; vested in the Alien Property Custodian

Application filed April 18, 1940

The present application forms a continuation-in-part application of my co-pending application Serial No. 132,877 filed March 24, 1937.

The present invention relates to systems for cooling a fluid charged with thermic energy obtained, for example from an explosion or an internal combustion engine, mounted on a vehicle, more particularly on board an aircraft. It is known that for a present 1,000 H. P. engine, the fluid, in general a cooling liquid for the engine, carries 450 H. P. away with it and that the mass of fluid represented by the exhaust gases carries 1,600 H. P. away with it.

The primary object of the present invention is to effect a partial recuperation of such energy which has hitherto been dissipated as pure waste in the form of an elevation of temperature of the air.

These cooling systems always comprise a group of hollow radiating elements which are assembled together in such a manner that the opposite faces of the wall of each element are respectively swept by a current of cooling air and by a current of said cooling fluid.

According to the invention, these hollow elements are so shaped that each of the air passages they limit between them is divergent in the direction of flow of the air, the divergence being calculated in dependence on the expansion of the air caused by the thermic energy with which the cooling air is charged as it passes through said passages, in such a manner that the velocity of flow does not undergo any increase due to said expansion.

The foregoing arrangement acquires quite a particular advantage when, according to another feature of the present invention, it is combined with another arrangement that has the effect of at least partly converting into pressure the kinetic energy of the cooling air passing through said passages.

The arrangement which is intended for this conversion may be of a known type and consists for example of a divergent pipe placed in front of the whole of said radiating elements and supplying them with cooling air which then escapes through a convergent pipe placed behind them, or again said arrangement may consist in increasing the divergence given said passages when only the expansion is taken into account so that this conversion of kinetic energy into pressure energy is at least partly effected when passing through said passages.

By way of a non-limitative example, there has been shown in the accompanying drawing:

Fig. 1 is a perspective view of radiator sheets arranged according to the invention;

Figs. 2, 3, 4 are respectively diagrammatical side, elevational and front views of a radiator provided with sheets of the type shown in Fig. 1;

Figs. 5 and 6 are views on a larger scale showing the assembly of the sheets on the collectors;

Fig. 7 is a detail view of the end of the sheets;

Fig. 8 is similar to Fig. 1 and shows a modification of construction;

Figs. 9, 10 respectively show plan and front views of a radiator provided with sheets of the type shown in Fig. 8;

Fig. 11 is a transverse section along the line XI—XI of Fig. 9;

Fig. 12, which is similar to Figs. 1 and 8, shows another modification of construction;

Figs. 13 and 14 show diagrammatically side and front views of a radiator provided with sheets of the type shown in Fig. 12;

Fig. 15 is a diagram of the basic arrangement of a recuperating radiator according to the invention;

Figs. 16 and 17 are diagrams showing the evolution of the cooling fluid during its passage through the arrangement of Fig. 15;

Figs. 18 to 21 show various examples of construction of the arrangement of Fig. 15;

Fig. 22, which is similar to Fig. 1, shows a modified construction of the arrangement of Fig. 15;

Figs. 23 and 24 show diagrammatically two embodiments on an aeroplane of the arrangement of Fig. 15;

Fig. 25 is a diagram representing an energy recuperating radiator according to a modification of the principle illustrated in Fig. 15;

Figs. 26 and 27 are diagrams showing the evolution of the cooling fluid during its passage through the arrangement of Fig. 25;

Figs. 28 and 29 show diagrammatically a radiator according to the invention applied to the recuperation of the energy of the exhaust gases;

Fig. 30 is a diagram of a particular arrangement for cooling a fluid under pressure;

Fig. 31 is an elevational view of a fuselage of an aeroplane equipped with a radiator according to the invention, said radiator being that of Fig. 32, shown partially as in section along the line XXXI—XXXI of Fig. 32;

Fig. 32 is a diagrammatical longitudinal section of a liquid radiator;

Fig. 33 is a partial end view of the radiator of Fig. 32;

Fig. 34 is a similar view to Fig. 31 of a modification of construction;

Fig. 35 is a corresponding plan view of same, and Fig. 36, an end view;

Figs. 37 and 38 are views of other modifications;

Fig. 39 shows diagrammatically an application of the invention in the case of an air cooled engine, and

Fig. 40, an application of the invention to an automobile radiator.

In the embodiment of Fig. 1, the hollow radiating elements through which passes the hot fluid to be cooled are sheets 1 of lenticular cross section, the edges of which form knife edges 2. Bars 3 extending transversely to the direction *f* of flow of the cooling air are located inside each sheet, the walls of which are fixed thereto, preferably by welding, and they reinforce said sheets 1 at the same time as they divide the inside into a number of compartments which do not communicate with each other. Said sheets 1 are so arranged that the air flow passages that they limit between them are divergent, that is to say gradually increase in cross-section, in the direction *f* of flow of the cooling air. It will be observed that from the point of maximum thickness of the sheets, the divergence of the passages 4 is compensated for by the decrease of thickness of the sheets towards their outlet edge so that from this point, the total thickness remains substantially constant.

Figs. 2, 3 and 4 show a general view of a radiator composed of a group of radiating elements of the type of those of Fig. 1. The longitudinal edges of the sheets 1 are embedded and welded in lateral collectors 5 and 6 (Fig. 5), which respectively serve for the inlet and for the outlet of the fluid to be cooled; the collector 5 is provided at its upper part with a tubulure 7 for the inlet of said fluid and the collector 6 with an outlet tubulure 8.

It will be observed that in this embodiment, the divergence of the passages 4 is obtained by increasing only one of the dimensions of their cross-section, in this case the height. It would of course be possible to obtain it by means of an evolution of both dimensions of said cross-section, viz. height and width.

Fig. 7 shows a method of obtaining sheets with knife edges. The two walls 9 and 10 of the sheet, made of thin sheet metal, are welded to each other at 11 and the whole arrangement is moulded after optionally adding material by welding at 12 in order to make the surface of the joint absolutely continuous.

In the modification of construction of Fig. 6, the sheets 1 pass at their opposite ends through metal plates 13, 14 to which they are welded and the projecting ends of the sheets are splayed and welded on the tubes 15 which have holes 16 drilled right through them and opening into the sheets. The tubes located on the same side are connected to each other at one end by a vertical collector not shown, the flow taking place in the direction shown by the arrows.

In the above example, each sheet differs in cross-section from the adjacent sheets and at the most two sheets symmetrically arranged in the whole block have the same cross-section.

For simplifying the construction, recourse may be had to the construction of Figs. 8 to 11. In these figures, the longitudinal section of each sheet also has an evolutional shape of variable thickness, terminating in knife edges, but all the sheets are identical and parallel with each other; in order to prevent the increase of thickness of each sheet from its inlet edge from producing a decrease of the passage cross-section between two adjacent sheets whereas it is precisely desired to obtain a gradual increase of said cross-section, the sheets are suitably curved throughout the portion located between their inlet edge and their point of maximum thickness in such a manner that the curved passage limited by the curved parts of two adjacent sheets has the required divergence.

In the example of Figs. 8 and 9, the divergence of the passages between the sheets 1*a* is obtained simply by the variation of the thickness of the sheets and the curvature of their front part, the sheets being of constant width throughout their length, as shown in Fig. 9.

In the example of Fig. 12, the variation of the thickness of the sheets 1*b* and the curvature of their front part are so calculated that the distance between the walls of the two sheets 1*b* delimiting a passage 3 remains constant, the required divergence being obtained by a progressive increase of the width of the sheets 1*b* (Fig. 13).

It would of course be possible to vary both the width of the sheets as in Fig. 13 and the distance between the walls of the two adjacent sheets delimiting a passage 4 as in Fig. 8.

The sheets of Figs. 8 and 12 are preferably constructed in the manner described above with reference to Fig. 7.

Whatever be their shape, the sheets 1*a* or 1*b* may be assembled on collectors and form a heat exchange block as described above in connection with the sheets 1 of Fig. 1 and shown in Figs. 3 and 6.

The sheets 1 or 1*a* of constant width have the advantage of enabling a plurality of blocks to be juxtaposed side by side as shown in Fig. 9, it being possible for the same collector to be used for the circulation in the sheets of the two blocks between which it is located.

In every case, the evolutional cross-section of the sheets for obtaining divergent air flow passages and knife edge sheets for improvements in the usual radiators, which improvements could moreover be used separately although their maximum efficiency is obtained when they are used simultaneously. One of said improvements have the effect of increasing the permeability of the radiator by improving the guiding of the air and the correlative elimination of vortices, in particular at in the inlet, of consequently decreasing the drag, the other of eliminating the fall of pressure produced in the usual radiators by the expansion of the air, which is expressed by an increase in the velocity of flow of the air.

In the foregoing examples the divergence of the passages 4 may be so arranged that the air flows at a decreasing velocity in order to take into account the decrease in its cooling power as it becomes heated by flowing through said passages.

On the other hand, the divergence of said passages becomes of maximum advantage when it is associated with an arrangement whereby the kinetic energy of the cooling air is at least for the greater part converted into pressure energy, preferably before the air comes into contact with the heat exchange walls, and with an arrangement that then converts a part of the pressure of the heated air into velocity, as shown diagrammatically in Fig. 15 according to which a pipe 21 has a divergent cross-section between the points A and C, a convergent cross-section from C to D and a heating cross-section between the point C and a point B located between A and C. By passing through said pipe 21 a fluid which enters at A at a velocity V_A and flows out at D at a velocity V_D, the diagram of Figs. 16 and 17 is obtained in which V designates the specific volume of the air, T its absolute temperature, v its velocity and p its pressure, the values of these various magnitudes at the various points A, B, C, D being indicated by a corresponding index.

According to said diagram, there is a compression of the air from A to B, a slight compression of the air from B to C by a continuation of the conversion of pressure into velocity at the same time as there is a heating of said air, the divergence of the cross-section B, C being calculated for this purpose, then expansion from C to D. The energy recuperated is represented by the area A B C D of Fig. 17. It is obvious that it is advantageous to increase the pressure of the air as much as possible before heating the latter and bringing it to the point B and that it is also advantageous for said heating to be effected without loss of pressure, whence the advantage, as regards recuperation of energy, of a radiator with divergent passages as described above.

The cycle in question may be obtained by means of very varied arrangements as shown for example in Figs. 18 to 21, in which the radiator has been shown diagrammatically and its divergence shown by a divergence of its outer walls, although it may be obtained in any one of the previously described manners. In the example of Figs. 18 and 19, a divergent passage 23 conveys the air directly to a divergent portion 24 and the latter is followed by a convergent passage 25 that opens directly into the surrounding medium.

In the example of Fig. 20, a tube 26 of constant cross-section is interposed between the divergent passage 23a and the radiator 24; similarly a tube 27 is interposed between the radiator 24 and the convergent passage 25a. This arrangement offers the advantage of decreasing the friction in the case in which pipes of great length are used for conveying the air to and from the radiator.

Fig. 21 shows a combination of the two previous ones. A first divergent passage 28 is followed by a pipe 29 of great length, of constant cross-section, itself followed by a second divergent passage 30 opening into a radiator 24. Similarly, the radiator is followed by a first divergent passage 31 followed by a pipe of constant cross-section 32 which opens into a second convergent passage 33. The conversion of velocity into pressure and conversely are thus each effected in two successive stages. The pipes of great length 29 and 32 are consequently of smaller cross-section than the pipes 28 and 27 of Fig. 20, but since the velocity of flow is greater for the same inlet velocity, the losses by friction are greater.

In these arrangement of Figs. 18 to 21, the divergent and convergent passages outside the radiator may be constructed so that the conversion of velocity into pressure and conversely are completely or for the greater part effected therein, the divergence of the radiator being so calculated that at the outlet of the radiator, the velocity of the air is substantially the same as at the inlet or slightly lower. It is possible, instead of this, to do the reverse and effect these conversions in the actual passages of the radiator unit. Fig. 22 offers an example thereof. In this example, the sheets are of the type of those of Fig. 12, that is to say curved at the inlet and at the outlet, but their curvature is more accentuated, the curved portion longer and the front end 34 of the sheets is solid so that said front parts limit divergent passages that the air passes through before coming into contact with the hollow parts of the sheets and wherein its velocity is converted into pressure to an extent that depends on the degree of divergence given to said passages.

Such a radiator unit may be used alone, in which case the air enters and flows out through pipes of constant cross-section (Fig. 24), or again in combination with outer divergent and convergent passages, that is to say that the radiator 24 of Figs. 18 to 21 would be of the type in question, the divergence of the passages of the radiator unit being suitably calculated in both cases.

The use on an aircraft of the above described arrangements may be effected in very different manners. Fig. 23 shows an example in the case of a thick wing 36; in this example, a divergent passage 37 opens into the lower side of the leading edge of the wing and its general direction deviates but little from a line parallel with the chord of the wing; it is followed by a radiator 38 which is in this case of the type shown in Fig. 8 and which is arranged obliquely across the wing; said radiator opens into a convergent passage 39 which opens on to the upper side of the wing.

The example of Fig. 24 is a modification of the previous one; the radiator is of the type shown in Fig. 22; the air is conveyed to it through a pipe 40 which is arranged like the divergent passage 37 but which is of constant cross-section, the divergence of the curved parts of the sheets being so calculated that it is at that spot that all the conversion of kinetic energy into pressure is effected; a pipe 41, similar to the convergent passage 39 but of constant cross-section, exhausts the air that has passed through the radiator, the curved part of the sheets having performed the function of the convergent passage 39.

All the other usual arrangements of radiators on aeroplanes may be used and also the devices intended to vary the inlet and outlet cross-sections in order to modify the cooling.

Instead of constructing a radiator in which the heat exchanges are effected at substantially constant pressure as explained above, it is possible, according to a modification of the invention, to construct a radiator in which the heat exchanges are effected at constant volume. Fig. 25 shows diagrammatically such a radiator which essentially comprises heat exchange elements 45 including air flow passages 46, the inlet and outlet orifices of which are controlled by valves 47a and 47b, in this case plugs rotating at the same speed, each of which is calculated so as to enable it to place one of said orifices in communication with a corresponding collector 48. In the inlet collector opens a divergent air inlet tube 49 and the outlet collector is extended by a convergent tube 50.

The valves 47a and 47b are designed to ensure the following functions:

Filling of the passages 46 with fluid at the pressure p_1 in the inlet collector 48;

Fluid-tightness of the passages 46 during the period of the heat exchange;

Transfer into the outlet collector 48 and expansion to the pressure p_2 equal to or less than p_1.

The relative setting of the two plugs and the relative size of the fixed openings enable the following sequence of operations to be obtained: opening of 47b, transfer to and expansion in the outlet collector 48, opening of 47a, closing of 47b with an overlap of these two operations in order to obtain a scouring and a renewal of the air in the passage 46, transfer to said passage 46 of the fluid in the inlet collector 48, closing of 47a, the of 47b in such a manner that there is a period of simultaneous closing and consequently a heating at constant volume of the air in the passage 46.

There will be in this case, at each half-turn of the plugs, a cycle whereof the diagram is that shown in Figs. 26 and 27 and which is that of the most general and most efficient explosion cycle. This arrangement may consequently be used as a reaction engine by injecting fuel into the passages 46, the elements 45 in that case not serving to convey calories to the fluid passing through the passages 46, but to remove them.

The arrangements described above may be adapted to various applications; in particular, the heat exchangers may be used as radiators for the cooling liquids of liquid cooled engines, as radiators for oil or for cooling by means of the air delivered by the supercharging compressors of an engine, or again as radiators for exhaust gases. In this latter case however, the flow inside the sheets, instead of being effected transversely to the flow of the air, will preferably be effected from one end to the other of the sheets and in the same direction as the air is flowing.

In the example of Figs. 28 and 29, the sheets 51 are open at their outlet end and the inside of each sheet forms a divergent passage throughout its length. The outlet cross-sections and the depth of the sheets are preferably calculated in such a manner that the air and the exhaust gases have the same temperature and the same velocity at the outlet of the sheets in order to ensure the continuity of the flow. There will therefore be in this case, over and above the total addition of the calories of the exhaust gases, a propulsive reaction inside the sheets.

The sheet radiators which are particularly well adapted for carrying out the invention, have the drawback of badly withstanding an internal pressure. In order to enable this type of radiator to be used in the case of cooling by means of a liquid under pressure (water at 2 or 3 kgs. for example) recourse will be had to the arrangement shown diagrammatically in Fig. 30 and in which the radiator 55 is inserted in a closed circuit 56 through which flows a liquid at a low pressure of flow, which circuit is provided with a heat exchanger 57, in this case a chamber in which bathes a coil of pipe forming part of another closed circuit 58 through which flows a liquid under pressure that circulates in the engine 59 to be cooled. The liquid of the low pressure circuit 56 may be any liquid but preferably, in order to reduce the size of the radiator, a liquid will be used which has a high boiling point, such as ethylene-glycol for example.

This combination of a high pressure circuit with a low pressure circuit may also be used with equal advantage and without exceeding the scope of the invention, in the case of honeycomb radiators or of any other type of radiator, whether or not they are adapted to produce a recuperation of the thermic energy.

The particular shaping of stream lining above described for the air chamber of radiators may also be applied to a ring shaped radiator including coaxially disposed annular sets of heat exchange elements, each set comprising ring shaped tubes disposed in concentric rings. Such a radiator could preferably be placed in a Naca cowling or the like and annular curved air guiding elements may also be provided along the inner and outer ranges of each set.

The radiator shown in Figs. 31 and 32 has two manifolds 61 and 62 formed by hollow coaxial rings spaced from each other and, between said two manifolds, a series of elements 63 formed by hollow flat rings held in suitably spaced position by hollow cross pieces 64 which connect them, to the manifolds 61 and 62 and place the inside of the rings 63 in communication with the inside of the manifolds 61 and 62. The space on the inside of the rings is closed at one end by a cover 65 fixed to the manifold 62, whereas at the other end a conduit 66 which is fixed to the manifold 61, places said space in communication wtih the outer air. Said conduit 66 has a cross-section which is substantially equal to the sum of the inlet cross-sections between the elements 63. Around the elements 63 and coaxially with them, are arranged other elements 67 formed by bodies of revolution the meridian of which is curved like the blade of a tuyere. The assembly of the elements forms the set of recuperator blades. At the inlet of the set of blades, each element 67 is hollow over a certain length and hollow cross pieces 64a, which maintain the spacing between said elements 67, places the inside of the hollow part of each set of blades in communication with the manifolds 61 and 62. Said set of blades is surrounded by a casing 68 which is extended so as to direct the air towards a second stage 69 having a second set of recuperator blades 70 enclosed in a casing 72 which exhausts the air. It is obvious that there may be any number of stages.

The radiator is mounted on an aircraft (Fig. 31) in such a manner that the conduit 66 opens towards the front and the air exhaust conduit at the outlet of the radiator preferably opens into a part of the aircraft which is subjected to a depression.

In the modification of Fig. 34, the air inlet conduit 66′ of the radiator opens into a space enclosed between an upper manifold 61′ and a lower manifold 62′ and vertical cooling elements 63′ which connect the manifolds 61′ and 62′ to each other and are arranged in two rows located at a certain distance from each other, on either side of and parallel with the axis of the conduit 66′; the elements 63′ leave air circulation channels between them which are directed transversely to the axis of the conduit 66′.

Behind each row of elements 63′ is arranged a set of recuperator blades 67′ of which the elements are hollow over a part of their length and open into the manifolds 61′ and 62′ to serve likewise for the cooling. Sleeves 68′ enclose the elements 63′ and the set of recuperator blades 67′. As in the case of Fig. 31, a plurality of recuperator stages can be arranged in series.

Fig. 37 shows a construction wherein the whole surface of each element of the set of recuperator blades 67′ serves for the cooling.

In the construction of Fig. 38, the set of recuperator blades 67b is formed of elements which are hollow over a certain length and which connect the manifolds 61b and 62b to each other, and there does not exist, in front of said set of blades, any non-recuperating elements which only have a thermic effect, as the elements 63 of the previous constructions.

In the example of Fig. 39 which relates to an air cooled engine, each cylinder 75 is surrounded with a deflecting jacket 76 which is connected to an air inlet sleeve 77 and to a sleeve 78 for the outlet of said air. Suitable recuperator blades 79 are arranged inside the sleeve 78. In the case of a mixed air-water cooled engine, hollow blades 80 through which the liquid flows, can be arranged in front of the cylinder 75 and between the latter and the blades 79. The blades 80 can at the same time be recuperating blades.

The radiator of Fig. 40 shows the arrangement, inside the air inlet channel, of directing blades which overlap each other in the direction of flow and which are preferably carried by a frame 82 pivoting at 83, whereby the intensity of the cooling can be regulated.

It will be noted that as all the elements are subjected to slight stresses, it is possible to make them of sheet metal or any other material. The whole arrangement can be very light and can be manufactured by the methods which are usual in the manufacture of radiators. The elements can be round tubes with thc ends flattened in the shape of blades, flat tubes, tubes of crescent-shaped cross section formed of differently curved metal sheets assembled by butt welding, etc.

In al cases the cross-sections of the blades are calculated according to the usual rules applied to turbines. If a plurality of successive sets of recuperator blades are provided, they can all be of the action or reaction type or some can be of one type and the others of the other type.

Of course, the invention is in no way limited to the details of construction illustrated or described, which have only been given by way of example. It is obvious that the arrangements described may be provided with any appropriate device for adjusting the passage cross-section.

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