Oct. 20, 1959 **B. O. HOWARD** **2,909,161**

ENGINE COOLING APPARATUS

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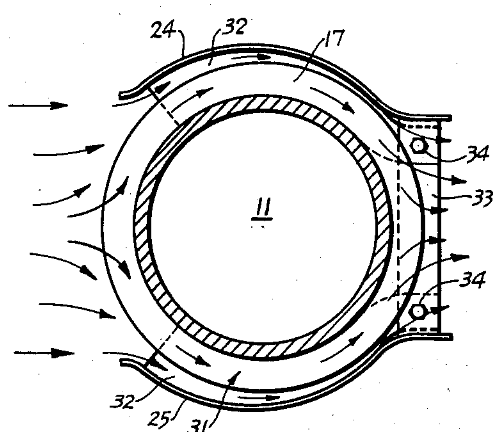

FIG_3

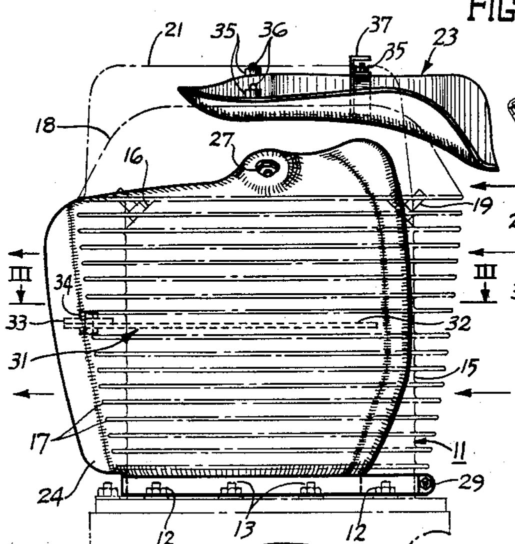

FIG_1

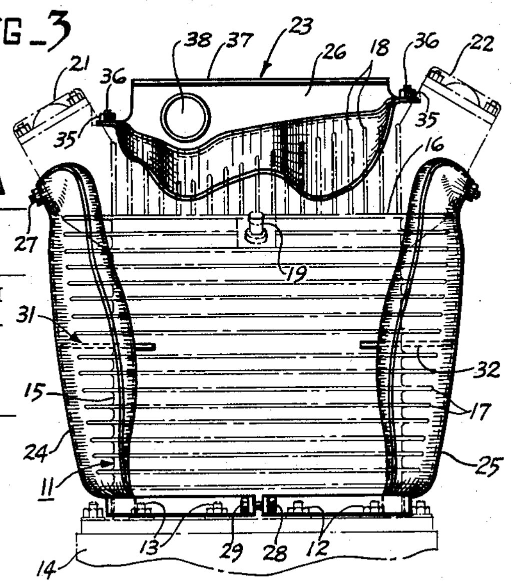

FIG_2

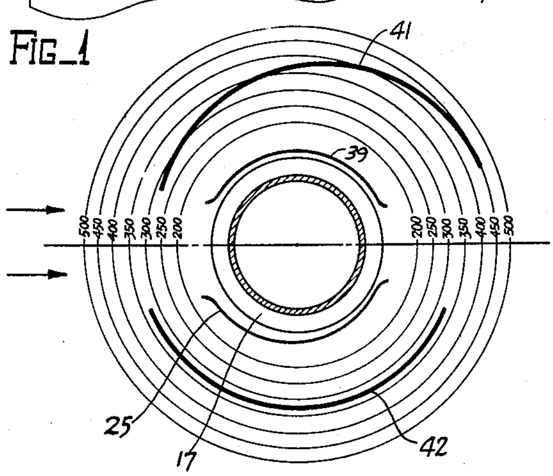

FIG_4

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ENGINE COOLING APPARATUS

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The present invention relates to engine cooling systems and more particularly to an engine cooling system which embodies baffle means for directing a flow of cooling air.

Heretofore it has been common practice to cool engines, particularly aircraft engines of the internal combustion type, by causing a stream of cooling air to flow against the forward portions of the engine cylinders, and subsequently changing the path of that airstream to direct it upon the rearward portions of the cylinders. This flow of air at the rear of the cylinders was necessary to dissipate the heat generated within the cylinders, which heat could not otherwise be dissipated by reason of the comparative inaccessibility of the rear cylinder areas to the cooling airstream. The prior art baffles generally utilized to accomplish this end were formed to fit about the periphery of the cylinders, or about the usual heat radiating fins thereof, at a substantially uniform distance, with the air inlet and outlet openings thus formed being fixed in size so that a predetermined quantity of cooling air was permitted to flow therethrough. Since the amount of air allowed to enter is governed by the cooling requirements of the hottest cylinder areas, usually the rearward cylinder areas, the baffle openings were adjusted to allow an amount of air to pass which was just sufficient to satisfactorily cool such hot areas. However, it will be apparent that to provide a sufficient flow of cooling air over the hotter rearward portions of the cylinders (where the cooling air will be hottest from having previously cooled the forward cylinder areas) requires that the quantity of air flowing over the forward cylinder areas be in excess of that needed at the forward areas. This results in inefficient overcooling which in turn, it has been found, undesirably increases the aerodynamic drag upon the aircraft. In addition, it will be apparent that cylinder areas intermediate the forward and rearward areas also suffered from undesirable overcooling, the amount of such overcooling depending upon their relative positions along the path of the airstream. Thus, the prior art baffles are ineffective to provide substantially uniform cooling of the engine cylinders, and the uncontrolled and inefficient utilization of cooling air is apparent.

In accordance wth the present invention, fairing or baffle means are provided which are particularly adapted to fit about the usual finned aircraft engine cylinder to provide uniform cylinder cooling. The baffle, which is preferably made in sections, is spaced from the cylinder at various predetermined distances, these distances each being established in conformity with the local cooling requirements of the particular cylinder area with which that portion of the baffle is associated. Thus the available air mass flow at each area can be predetermined to fit the needs of such area. For example, it can be calculated

by known methods, using temperature measurements of the area to be cooled, that a certain quantity of heat generated at that area must be dissipated in order to cool the area to some predetermined, desired operating temperature. Knowing the heat which must be dissipated, the baffle of the present invention is arranged adjacent the area to be cooled at the particular distance therefrom which will effect a speed of air flow corresponding to the heat transfer which should take place to achieve the desired cooling. The baffle distance is varied in accordance with the individual heat transfer requirements of each cylinder area to be cooled, as will be more particularly explained hereinafter, whereby a most efficient utilization is made of the available quantity of cooling air. More particularly, at the cooler forward cylinder areas the baffle is spaced from the cylinder a distance such that the speed of the stream of cooling air is made comparatively low with respect to the cylinder fins. However, by reason of the present construction the speed of the cooling air is progressively increased rearwardly so that a high speed cooling stream is provided at the hotter rearward fin areas. Also, a higher speed of cooling airflow is provided in intermediate cylinder areas to compensate for the gradual heating up of the cooling air as it travels about the cylinder. Thus, a controlled utilization of the available cooling air is provided, and the cooling air is used much more efficiently than was the case with the cooling baffles of the prior art. The amount of cooling air required is greatly reduced, which in turn lowers the drag associated with the intake of the cooling air to thereby effect an improvement in the overall performance of the aircraft.

It is noted that although the cooling system of the present invention will be described in association with an air-cooled aircraft engine, it is obviously adapted to modification and is therefore to be considered applicable to various types of engines.

It is therefore an object of the present invention to provide an engine cooling system which is adapted to make a highly efficient utilization of the available cooling medium.

Another object of the invention is to provide a unique cooling baffle which is adapted to be arranged adjacent to and spaced from a heated surface in a manner which will direct a predetermined mass flow of air against such surface for the cooling thereof to a substantially uniform temperature throughout.

It is another object of the invention to provide a novel baffle for directing and controlling a predetermined mass flow of cooling air about an engine cylinder, and which is arranged along the cooling path of the air to progressively effect an increase in the speed of flow of such air as the air passes toward the rearward areas of such cylinder.

Still another object of the invention is to provide a novel cooling baffle which is adapted to be spaced at various distances from a surface to be air-cooled, the distance of the baffle from each local area of such surface progressively diminishing from the forward to the rearward portions of such surface along the path of the cooling air in accordance with the heat transfer requirements of such local area.

An additional object of the invention resides in the provision of an improved cooling jacket for an engine cylinder which is adapted to be disposed about the cylinder at predetermined distances which are substantially governed by the heat to be dissipated and the air mass available for cooling.

Yet another object of the invention is the provision of a novel combination of a finned engine cylinder and a cooling jacket disposed thereabout in spaced relation, the distance therebetween being varied to adjust the speed of air mass flow over the cylinder cooling fins at each local cylinder area so as to effect cooling of the cylinder to a substantially uniform temperature.

Another object of the present invention is to provide an improved cooling system which is comparatively simple in construction, easy to install, and economical to manufacture.

Other objects and features of the present invention will be readily apparent to those skilled in the art from the following specification and appended drawings wherein is illustrated a preferred form of the invention, and in which:

Figure 1 is a side elevational view of the preferred embodiment of the cooling system of the present invention, illustrated in association with a conventional aircraft cylinder;

Figure 2 is a front elevational view of the invention illustrated in Figure 1;

Figure 3 is a view taken along line III—III of Figure 1; and

Figure 4 is a diagrammatic representation of the cooling arrangement of Figure 1 and of a common cooling arrangement of the prior art, together with comparative temperature gradient curves to indicate temperatures along the path of the cooling air.

Referring to the drawings and more particularly to Figures 1 and 2, there is illustrated an embodiment of the cooling system of the present invention which will hereinafter be described in connection with the cooling of a typical aircraft radial internal combustion engine. It is to be understood, of course, that the embodiment described is merely illustrative of a particular application and the present invention is not to be limited thereto.

A cylinder of the engine is designated generally by the numeral **11**, and is characterized by the usual and conventional construction of a typical air cooled aircraft engine cylinder. Cylinder **11** is rigidly secured, as by nuts **12** threaded onto engine studs **13**, to an engine crankcase **14** of the engine. Other cylinders are similarly secured to crankcase **14**, and the cooling of cylinder **11** and the other cylinders is effected by permitting a flow of cooling air to be directed upon the forward faces of the cylinders and guiding that flow in a particular manner around and behind the cylinders, as will be more particularly described hereinafter.

The flow of cooling air, which may be ram air or air provided by any suitable source, passes about the cylinders, picking up and carrying away excess heat, and finally passes from behind the cylinders into the airstream at an exit temperature considerably higher than its inlet temperature. The technique of individually air cooling a plurality of engine cylinders is well-known in the art and for this reason will not be described in any great detail. Instead the present invention will be described in connection with the cooling of the single engine cylinder **11**, it being understood of course that the present cooling system described in connection with cylinder **11** is readily adapted for similar association with other engine cylinders, which cylinders are arranged either in a single or a double bank, or in radial or in-line relationship, for the efficient cooling of a complete engine.

Cylinder **11** is of usual construction and embodies a barrel portion **15** and a head portion **16**, portion **15** being provided with a plurality of usual horizontal cooling fins **17**, and portion **16** being provided with a plurality of usual vertical cooling fins **18**. Fins **17** and **18** are commonly varied in depth according to the amount of heat generated in the area with which they are associated, the deeper fins having a greater surface area whereby they are adapted to transfer a greater quantity of heat from cylinder **11** to the cooling airstream, as compared to the shallower fins which transfer less heat for the same speed of airstream. Cylinder **11** also includes one or more spark plugs, one of which is indicated at **19**, and a pair of valve rocker boxes **21** and **22** for housing and supporting the conventional valve operating mechanism for cylinder **11**. Boxes **21** and **22** are an integral part of cylinder **11**, except for removable cap portions thereof which permit access to the valve mechanism, whereby boxes **21** and **22** are adapted to provide rigid support for portions of a baffle means or assembly **23**, as will be seen.

Baffle assembly **23** serves to accept a portion of the cooling airstream flowing against the face of cylinder **11**, and guide that portion about cylinder **11** and over fins **17** and **18** thereof in a manner calculated to derive the maximum cooling effect from the action of such given portion of cooling fluid flowing over fins **17** and **18** and about cylinder **11**.

Baffle assembly **23** comprises a pair of side baffles or baffle sections **24** and **25**, which are disposed about cylinder **11** at the sides thereof in close association with cooling fins **17**. Assembly **23** also comprises an upper or top baffle or baffle section **26**, which is disposed over the head portion **16** of cylinder **11** in close association with cooling fins **18**. With this arrangement it will be apparent that the frontal openings formed by cylinder **11** and the forward or upstream edges of baffle means **23** provide an inlet for a limited quantity of cooling air, which is subsequently distributed by baffle means **23** about cylinder **11**.

Side baffles **24** and **25** are each secured at their upper ends to cylinder **11** by a plurality of nuts secured to bolts **27** which are disposed through suitable openings in baffles **24** and **25** and threaded into tapped wells in cylinder **11**. At their bases, baffles **24** and **25** are secured together and supported upon cylinder **11** by a circumferential band or strap **28** which encircles cylinder **11** at its base. Strap **28** passes over the lower periphery of baffles **24** and **25**, and is provided with a fastening means, such as bolt and nut connector **29**, to clamp baffles **24** and **25** in position. In addition, a peripheral band or spacer **31** is carried approximately midway of barrel portion **15** of cylinder **11** between adjacent fin sections, spacer **31** being positioned between barrel portion **15** and baffle sections **24** and **25** to maintain a fixed, spaced apart relationship therebetween. It will be apparent that the width of spacer **31** is made to conform to the distance which is desired to be maintained between portion **15** and sections **24** and **25** for a particular speed of air flow. Spacer **31** includes a pair of arc-shaped side members **32** which are disposed on either side of cylinder **11**, members **32** being joined at the rear of cylinder **11**, Figure 3, by a short strap **33** removably secured thereto by bolts **34**.

Upper baffle **26** is secured in position by a plurality of nuts **35** which are threaded onto the free ends of studs **36**, whose lower ends are suitably threaded into the material of rocker boxes **21** and **22** and with their upper, or free, ends disposed through appropriate apertures in baffle **26**. Baffle **26** includes a transverse member **37** which serves to strengthen baffle **26** and maintain the shape thereof, it being noted that member **37** is suitably cut away at **38** to accommodate ignition wiring (not shown).

In order to establish an air path of a particular size, it will be seen that baffle means **23** is shaped to closely conform to the irregularities of cylinder **11**, and that the exit ends of baffle sections **24**, **25** and **26** are flared outwardly slightly to effect a smoother discharge of cooling air and thereby reduce the aerodynamic drag associated with such discharge.

Particular reference will now be had to Figures 3 and 4, it being noted that Figure 4 is illustrative of a baffle **39** of the prior art, a side baffle **25** of the present baffle means **23**, and the comparative temperature distribution to be enjoyed through the utilization of one or the other.

It is important at this point to emphasize the fact that prior art baffles, such as baffle **39**, were commonly spaced from cylinder **11** or fin **17** at a more or less uniform distance. If insufficient cooling was experienced at some part of cylinder 11, the common solution was to increase the quantity of cooling air, as by merely making uniformly greater the distance between cylinder 11 and prior art baffle 39. This admittedly provided a greater flow of cooling air but, obviously, the arrangement of baffle 39 effected an overcooling of cylinder areas which may previously have been properly cooled. In addition, as illustrated by the temperature gradient line 41, the temperature of fin 17 becomes gradually greater when using baffle 39 because the same size air flow path is present from the upstream to the downstream end, and the speed of air flow is therefore substantially constant. Since the air is absorbing heat from fin 17 all the time, it has less capacity to remove heat at the downstream end of baffle 39 and fin 17 consequently rises in temperature. It is apparent that with this non-uniform temperature distribution pattern that forward cylinder areas must be over cooled in order to achieve proper cooling of the rear cylinder areas. As previously stated, this not only induces undesirable drag, but also produces poor engine performance.

In contrast, baffle section 25 of the present invention adjusts the size of the air flow path to thereby adjust the speed of air flow and effect a uniform temperature pattern, as indicated by temperature gradient line 42. More particularly, the well-established relationship among the variables present in the cooling of cylinder 11 is as follows:

$$\frac{hd}{k}=K\left(\frac{V\rho d}{\mu}\right)^{0.8}\left(\frac{Cp\mu}{k}\right)^{1/3}$$

where

h=heat transfer coefficient
d=distance around cylinder 11
k=heat conductance
K=constant fixed by the units of measurement used
V=speed of air moving around cylinder
μ=air viscosity
C_p=air specific heat
ρ=air density

For temperature changes of the order of 0 to 300 degree Fahrenheit normally encountered in engine cooling the variables k, ρ, μ, C_p and K are substantially unchanged and remain in their effects substantially constant, so that

$$h=K^1d^{-.2}V^{0.8}$$

From this it can be seen that by decreasing the cross-sectional area between the cylinder 11 and baffle section 25 as the air passes downstream, the speed of the air, V, may be increased, increasing the heat transfer coefficient, h. Then, knowing that the cooling air flowing around the cylinder will be rising in temperature as it passes downstream, and since $Q=h(T_s-T_a)$

where

Q=the time rate of heat flow per unit area
h=heat transfer coefficient
T_s=temperature of the heated surface
T_a=temperature of the air

then the value of h is adjusted so that Q is substantially the same at all points around the cylinder, whereby uniform cooling is produced over the entire cylinder. The adjusted value of h will, of course, determine the required cross-sectional area between cylinder 11 and baffle section 25.

In the above manner the particular proportions or dimensions of baffle means 23, and the arrangement thereof with respect to cylinder 11, is predetermined. Typically, baffle means 23 closes or converges rearwardly to provide a passage for the cooling air which is progressively diminishing in cross section whereby the air speed is progressively increasing. The cooling system of the present invention thus utilizes the relationship of cylinder temperatures, cooling air temperatures, and cooling air velocities to provide baffle means 23 of a configuration which varies in accordance with the cooling requirements of local areas of cylinder 11 so that maximum cooling efficiency is derived from the incoming cooling air. It will be apparent that the improved efficiency resulting from use of the present cooling system permits a desirable reduction in the frontal area of the cooling system, and this results in a corresponding increase in the performance characteristics of the aircraft.

While certain preferred embodiments of the invention have been specifically disclosed, it is understood that the invention is not limited thereto as many variations will be readily apparent to those skilled in the art and the invention is to be given its broadest possible interpretation within the terms of the following claims:

I claim:

1. In a cooling system for an engine, baffle means forming an air flow path with an engine surface to be cooled, said baffle means being contoured and spaced to provide a time rate of heat flow per unit area, Q, which remains substantially the same along the air flow path in accordance with the following formula:

$$Q=h(T_s-T_a)$$

where T_s=temperature of said surface, T_a=temperature of the air, and h=heat transfer coefficient which is related to speed V by the formula: $h=Kd^{-.2}V^{0.8}$ where K=a constant, and d=a distance along the air flow path and V=velocity at any point along said path.

2. In combination with a surface to be cooled, baffle means, means spacing said baffle means in predetermined relationship with said surface to form an air flow path with said surface, said baffle means having a contoured inner surface for varying the cross-sectional area of said air flow path to thereby vary the heat transfer coefficient, h, in accordance with the following formula: $h=K^1d^{-.2}V^{0.8}$ where K^1=a constant, d=distance along the air flow path, so that the time rate of heat flow per unit area, Q, remains substantially the same along the air flow path in accordance with the following formula: $Q=h(T_s-T_a)$ where T_s=temperature of said surface, T_a=temperature of the air.

3. In combination with a cylinder of an air-cooled internal combustion engine, a baffle assembly comprising a pair of side baffles, one carried at each side of said cylinder, and an upper baffle carried adjacent the head of said cylinder, means for disposing said side baffles and said upper baffle adjacent to said cylinder in predetermined spaced relationship therewith to form air flow spaces therebetween, said baffles having inner surface contours such that the area of said air flow spaces changes along the air flow path to establish a substantially uniform heat flow per unit area, said heat flow per unit area being a function of the heat transfer coefficient of said path which is controlled by air velocity which in turn depends upon said area of said air flow spaces.

4. In combination with a finned cylinder of an air-cooled internal combustion engine, a baffle assembly comprising a pair of side baffles, one carried at each side of said cylinder and each spaced from the fins of said cylinder to define an unobstructed air induction area with said cylinder, and spacer means interposed between said side baffles and said cylinder to maintain spaced relationship therebetween, an upper baffle carried adjacent the head of said cylinder, said side baffles and said upper baffle being shaped and spaced from said cylinder in predetermined manner to define substantially unobstructed air flow passages whose area is adjusted along the air flow path to maintain a substantially uniform heat flow per unit area.

5. In combination with a surface to be cooled, a baffle of such inner shape and spacing from said surface such

that air passing therebetween will change in velocity in accordance with the following formula:

$$V^{0.8}=\frac{QKd^{-.2}}{T_s-T_a}$$

where V is the air velocity which determines the spacing desired, Q=the time rate of heat flow per unit area and is held constant along the air flow path, K=a constant, d=distance along the air flow path, T_s=temperature of said surface, and T_a=temperature of the air.

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