REPORT No. 43.

SYNOPSIS OF AERONAUTIC RADIATOR INVESTIGATIONS FOR YEARS 1917 AND 1918.[1]

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During the past year an extensive series of experiments has been conducted at the Bureau of Standards to determine the properties of cooling radiator cores now manufactured for airplanes and to develop improvements in design. The analysis of the problem on which this work was based, and consequently the experimental method employed, is different from that commonly used. Instead of attempting to test complete radiators, either full size or in models, uniform sections representing different types of core construction have been tested and an analysis of the results made with a view to determining independently the various factors which influence its performance. From these results deductions may be made as to the performance of a radiator under any conditions.

The factors considered are:

(1) The characteristics of the core structure, including depth, size, and shape of air and water passages, nature of the metal and of the surfaces from which cooling takes place, and the amount and design of indirect cooling surface or fins.

(2) The conditions of use, including the amount of air flowing through the core (mass flow), the relation of the location on the plane to the amount of air flowing through the core as influenced by the plane speed, the effect of variable temperatures of air and water, variable air density, and the effect of variable rate of water flow.

The performance of a type of core is expressed by giving the properties of the core as defined below, together with general relations showing the change of properties with change in conditions and characteristics from which the performance of any radiator of the same core structure can be predicted.

Since the completion of this work, reports received from England and France have shown that many of these questions have already been studied there, and the results agree substantially with those obtained by this bureau. The work on altitude has, we believe, not been duplicated elsewhere, and the range of air speeds over which the observations extend has been increased in most cases.

In the work done in Europe, the heat dissipated by the radiator has commonly been measured by placing the radiator specimen to be tested in a wind tunnel, the cross sectional area of which was at least three times that of the specimen, since this was supposed to represent most nearly the conditions found in actual use. The method of attack adopted in this investigation calls for a more definite description of the condition of air flow through the radiator, in order to allow the performance of a radiator in any position on the plane to be determined.

A careful distinction must be made between the speed of the air approaching the radiator, or the speed at which the radiator is being carried through the air (free air speed), and the amount of air which actually passes through the radiator (mass flow). When experiments are made in a bulkhead tunnel (a tunnel in which the specimen completely blocks the channel) all the air which flows through the tunnel is forced through the tubes of the specimen; while when the specimen is supported in a tunnel whose cross sectional area is large relative to the specimen, the amount of air flowing through the specimen depends upon the character of its design.

In the British reports mention is made of the differing results obtained as affected by the kind of tunnel used. Their conclusion was to use the results obtained in the free air tunnel.

[1] This Report was confidentially circulated during the war as Bureau of Standards Aeronautic Power Plants Report No. 42.

The French attempted to measure the "penetration de l'air" by means of pitot tubes placed at various distances in front of and behind the radiator, but the results are only comparative and furnish no measure of the actual mass flow of air.

Since the air which actually flows through the core determines the heat dissipated, determinations of the heat dissipated in terms of free air speed are not applicable directly to radiators placed in any position where the flow of air is obstructed. Consequently, heat transfer and other properties of cores have been measured and expressed in terms of the mass flow of air through the core. A specially designed air Venturi has been devised with which this mass flow of air can be measured, at least roughly, under almost any conditions, and can be obtained by laboratory tests in the case of a radiator placed in the free air with all the accuracy required.

In general, the mass flow constant will be defined as the ratio of the mass of air actually passing through the radiator to that which would pass through the same area if it were unobstructed.

From the above discussion of mass flow and free air speed it is seen that there are two general classes of positions in which a radiator may be placed on the plane, either that in which the mass flow through the radiator is dependent solely on the properties of the core, or when it depends also upon the location on the plane.

If the radiator is placed so that the air may pass through or around it without obstruction, it is said to be in an unobstructed position, and the properties of the radiator so placed are dependent solely upon the characteristics of the core, so that the effect of the radiator on the plane may be computed from the results of laboratory tests. In particular, the power which is required to carry the radiator, that is, to lift its weight and overcome its head resistance, may be computed.

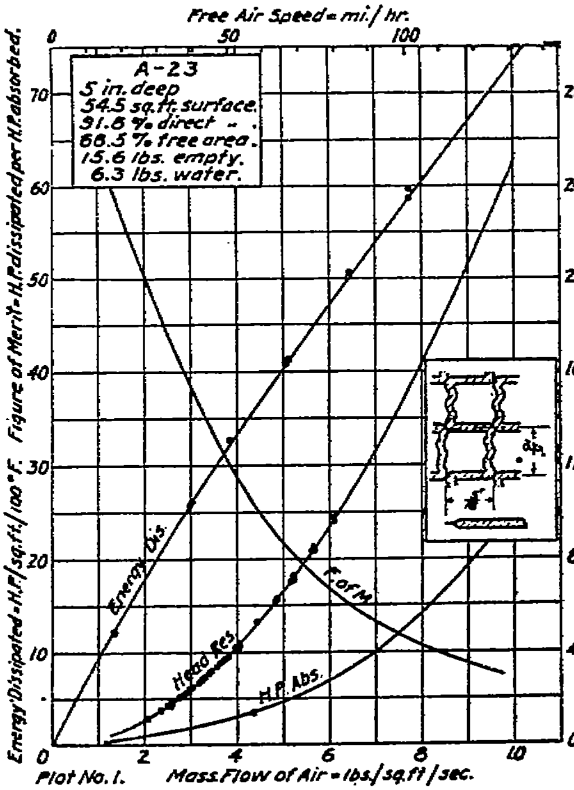
If the heat dissipated by an unobstructed radiator is expressed in horsepower (1 H. P.=42.4 B. t. u. per minute) this quantity may be divided by the power absorbed in carrying the radiator, both at the same free air speed, and the result will be a quantity which expresses the efficiency of the radiator and may be used to compare various types of core. This quantity is called the "Figure of Merit," and is the criterion for a core to be used in an unobstructed position.

When the air flow around the radiator is materially interfered with by other parts of the plane, the radiator is said to be obstructed. The nose of the fuselage and in the plane of the wing are the most important obstructed positions. The air flow through such a radiator (i. e., its mass flow constant), and consequently the cooling and other properties depend, not only on the type of core, but on the position and surroundings. If the air flow through the core is known, the heat transfer can be found from tests such as have been carried out on a large number of cores at this bureau. The absorption of power which is *chargeable* to the radiator depends, however, not only on the properties of the core but on what decreases in total resistance could be obtained by structural alterations in the plane if the radiator were not required. The figure of merit of such a radiator can consequently be found accurately only by experiments on models of each type of plane or by tests on full size planes.

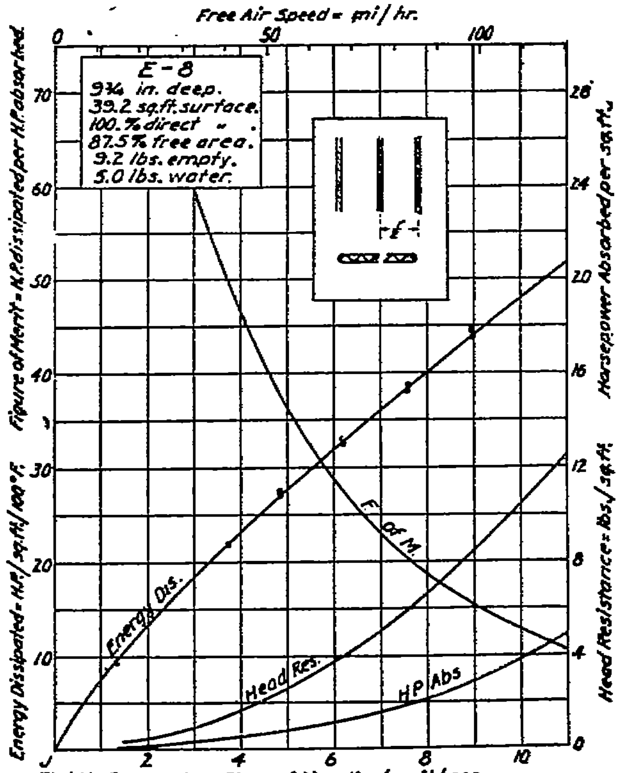
An indication of the desirable properties for such a core can be obtained by noting that the resistance to the flow of air through the core is composed of the resistance of the core and the resistance offered by the surrounding portions of the plane. In the case of a core placed in the nose of the fuselage the latter resistance is large compared with the resistance of the core itself. It is therefore desirable to use, in an obstructed position, a core having a large amount of effective cooling surface per square foot of frontal area so that with a given air flow the maximum amount of heat may be dissipated.

At the end of this report there are given curves showing the properties of two of the best types of core for use in unobstructed positions (plots 1 and 2) and two of the best types for use in obstructed positions (plots 3 and 4) that have been tested.

The energy dissipated is given in horsepower per square foot of frontal area of core when there is a temperature difference of 100° F. between the entering air and the mean of the temperatures of the entering and leaving water. It has been shown that the energy dissipated may be assumed to be proportional to the temperature difference as thus defined and to vary directly as the frontal area of the radiator.



Plot No. 1.



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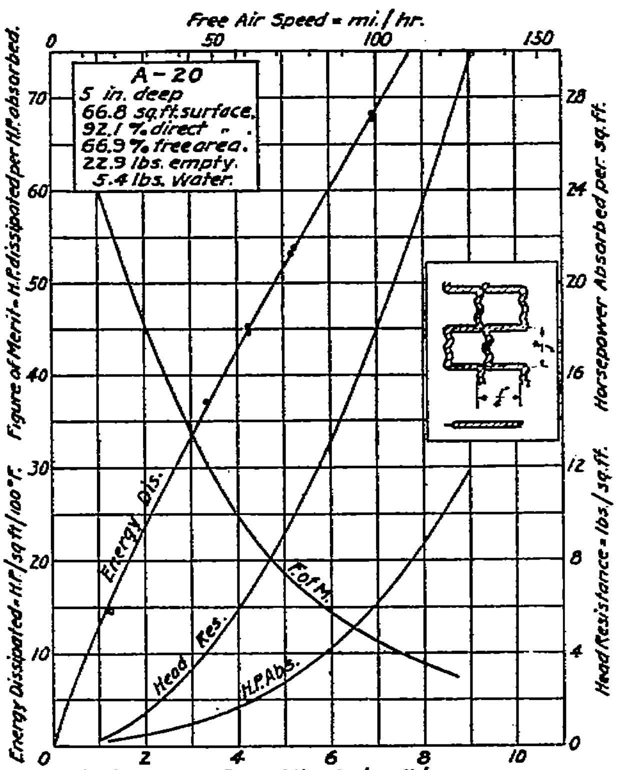

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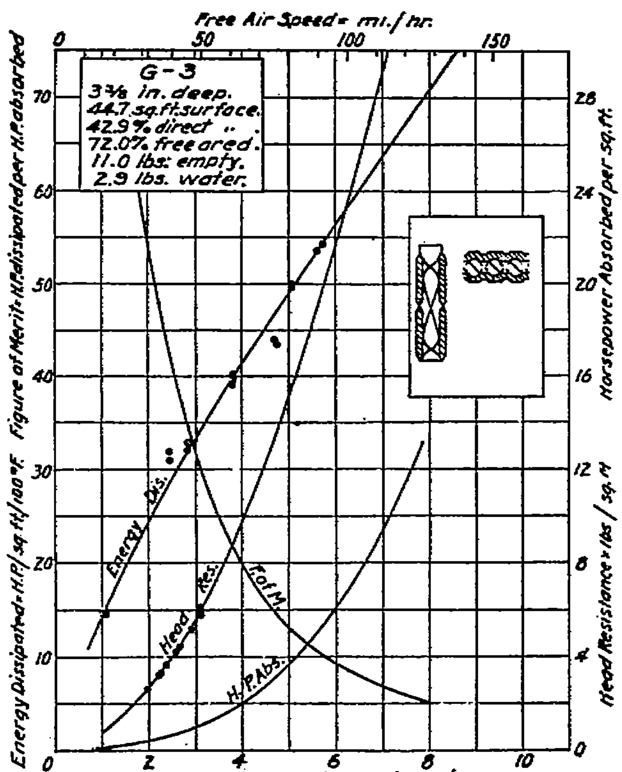

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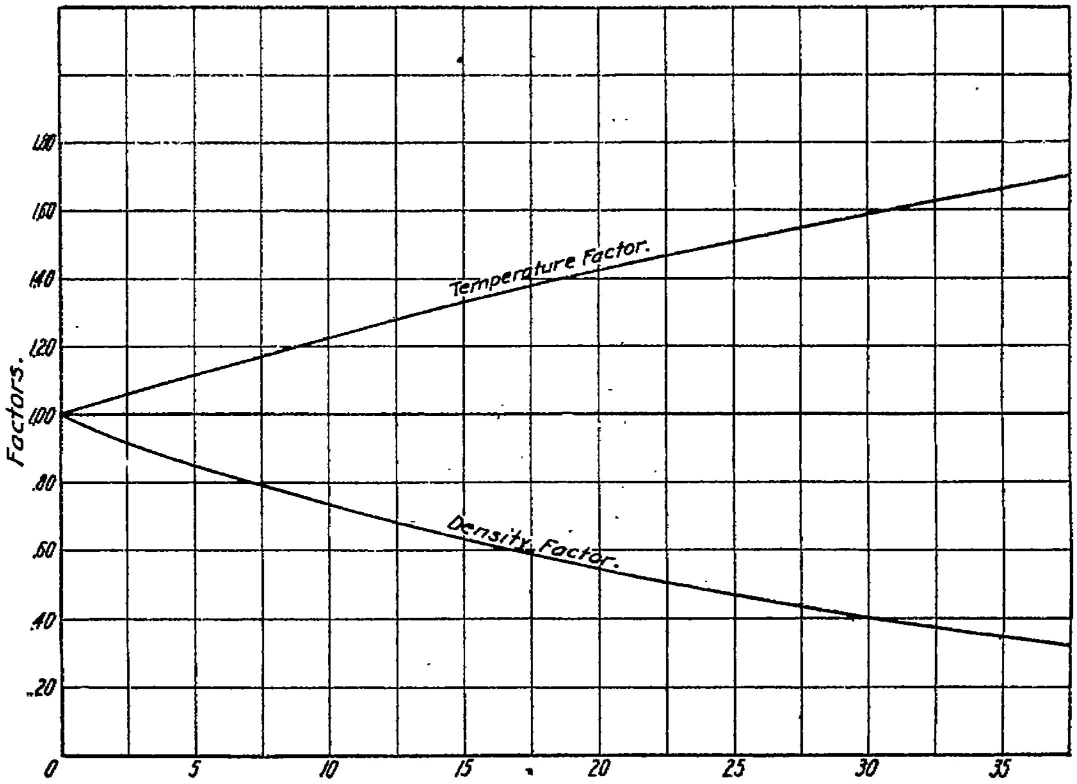
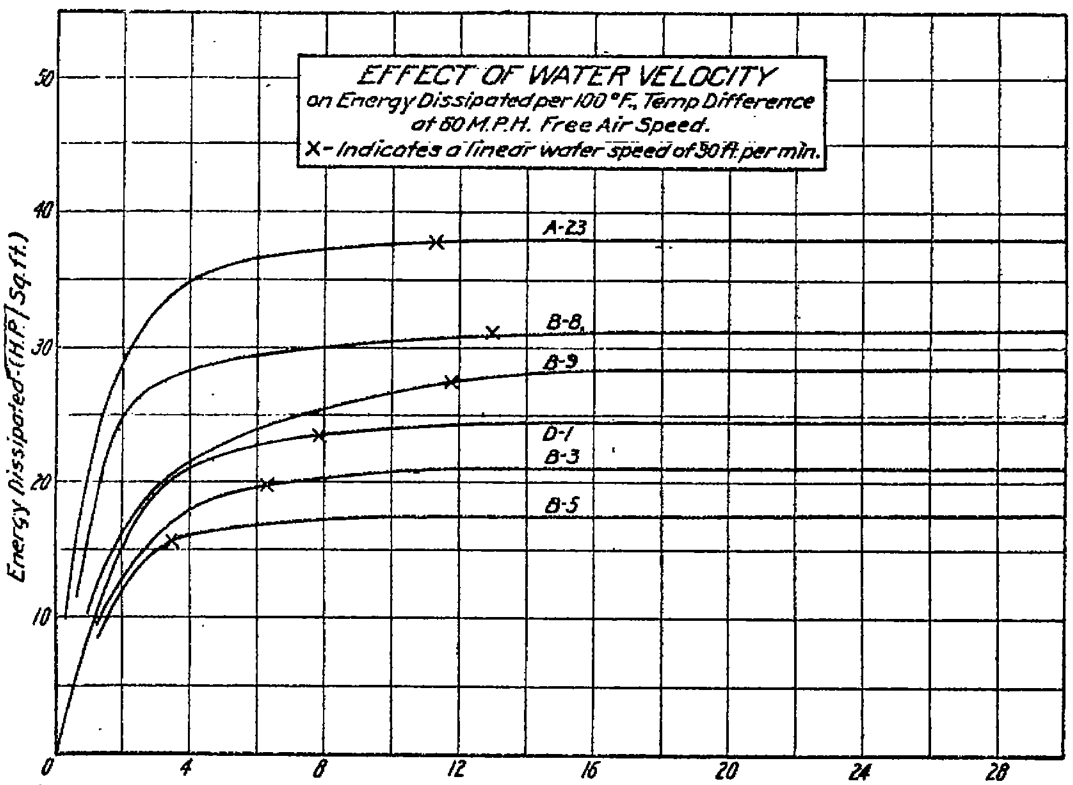


Plot No. 5



Plot No. 6

The head resistance is the force on the radiator when the air strikes it normally. It is expressed in pounds per square foot of frontal area for an air density of 0.0750 pounds per cubic foot.

The horsepower absorbed per square foot of frontal area is computed by dividing the weight, in pounds per square foot frontal area, by a lift—drift ratio (for an average plane) of 5.4, adding this to the head resistance in pounds per square foot frontal area and multiplying the sum by the free air speed in miles per hour and by a conversion factor (1/375) to obtain horsepower. It must be remembered that this quantity is of significance only in the case of an unobstructed radiator, since it is under free air conditions that the head resistance is measured. Considered as a function of the mass flow through the radiator it is probable that this value represents the minimum possible absorption of power in the case of an obstructed radiator, and that to it must be added any resistance due to obstruction of the air after passing through the core. Power absorbed by resistance caused by necessary alterations of the fuselage from the best streamline form possible without the radiator must also be charged to the radiator.

The figure of merit, as explained above, is the energy dissipated by a radiator which absorbs one horsepower. It also is of significance, as computed, only for an unobstructed radiator. It must not be confused with the British "figure of merit," which is a quantity of the same sort, but which is expressed in arbitrary units.

The curve sheets also contain the most important structural characteristics of the cores, namely, the depth, the total area of the cooling surface per square foot front, the percentage of the total surface which is direct (backed by flowing water), the percentage free area (the percentage of the total frontal area which is occupied by the air tubes), the weight of the core empty per square foot, and the weight of the water contained in a square foot of core.

Effect of rate of water flow.—The effect of water velocity on the heat dissipated is shown in plot 6. It indicates that at water flows commonly used in practice the energy dissipated, when the mean water temperature is used in computing the temperature difference, is not affected by the rate of water flow. At low water velocities it decreases rapidly. The same general behavior is shown by all the types of core tested.

Since in practice the temperature of the entering water must not be too near boiling, and the temperature drop in the water will decrease with increased water flow, the mean water temperature may be somewhat higher with a high rate of flow than with a low one. This consideration points to the use of a water flow of from one-fourth to one-half gallon per minute per horsepower to be dissipated, the latter value being desirable if the resistance of the radiator to water flow is not too great.

The work on the performance of radiators at high altitudes (see Report No. 62) carried out in a wind tunnel inclosed in a steel tank from which the air could be partially exhausted, has shown that the heat dissipated by a radiator will be constant for a given mass flow of air, regardless of air density, and that the head resistance probably varies directly as the density for a given free air speed. We may assume that the energy dissipated varies directly as the temperature difference, as defined above.

Plot 5 contains two curves marked "Temperature factor" and "Density factor," respectively. The temperature factor is the approximate ratio of the temperature difference (between air and water) likely to be encountered at an altitude to that to which the ground tests are reduced, viz, 100° F. The density factor is the ratio of the probable density of the air at an altitude to that to which the ground tests are reduced, viz, 0.0750 lb./cu. ft. These two curves are based on the assumption of a mean summer temperature and density of air and a mean water temperature 30° F. below the boiling point. They accordingly represent only one of many conditions that might be met and are given for the sake of illustration.

With these factors and the experimental facts mentioned above, the performance of a radiator at any altitude can be estimated from the performance at ground as follows:

Energy dissipated.—Obtain the mass flow at the given altitude by multiplying the mass flow at ground by the density factor. Obtain the energy dissipated per 100° F. (actual) from the curve of energy dissipated in terms of mass flow, as determined in laboratory tests, and multiply this energy dissipated by the temperature factor.

Head resistance.—Multiply the head resistance at ground by the density factor.

Horsepower absorbed $=\left(\text{Head resistance}+\frac{\text{weight, filled}}{\text{lift-drift ratio}}\right)\left(\frac{\text{speed in mi./hr.}}{375}\right)$, where weight is in pounds per square foot of frontal area.

Figure of merit $=\frac{\text{energy dissipated}}{\text{horsepower absorbed}}$.