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A DESCRIPTION OF THE Ju 88 AIRPLANE ANTI-ICING EQUIPMENT

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RESTRICTED BULLETIN

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SUMMARY

In conjunction with the current ice-prevention research being conducted at Ames Aeronautical Laboratory, the National Advisory Committee for Aeronautics has obtained and examined a part of the anti-icing equipment for a Ju 88 airplane from the Army Air Forces, Materiel Center, Wright Field. The Ju 88 airplane anti-icing equipment includes exhaust-air heat exchangers, control valves, air duct system, and air-heated wing panels. One exchanger and a part of one wing panel have been examined at Ames Aeronautical Laboratory. The examination and analysis indicates that the system would prevent the formation of ice on the wing surfaces.

DESCRIPTION OF EQUIPMENT

The Ju 88 airplane is powered with two 12-cylinder liquid-cooled Junkers Jumo 211G engines which develop 1150 horsepower at 15,000 feet. The exhaust system consists of six ejector stacks projecting from each side of the engine. A heat exchanger (see fig. 1) is built around each set of stacks, making a total of four heat exchangers on the airplane. The ejector stacks pass through a rectangular shroud 4 by 5 inches in cross section. Three rectangular steel fins, 4 by 6 inches by 1/32 inch spaced at 1-inch intervals, are welded to each stack in the region enclosed by the shroud. These are staggered on adjacent stacks. The heater is divided into three readily detachable units, each of which encloses two ejector stacks. The stacks are spaced approximately 7 inches on centers, and the over-all length of the heater is approximately 50 inches.

Air is led to the heat exchanger from an intake scoop, not shown in figure 1, and is heated as it passes over the finned ejector stacks. The heated air leaves

the heat exchanger through a $3\frac{1}{2}$ -inch round tube and is then piped to the wing leading edge. The path followed by the heated air is shown in figure 2.

The wing plan form in figure 2 was reproduced from pictures and sketches in technical magazines and is not drawn to scale. The outboard panel dimensions shown agree with measurements taken on the actual outer-wing panel. It is believed that the other dimensions shown are sufficiently accurate for the general analysis contained in this report.

Figure 3 is a typical section through the outer-wing panel. The inner leading edge skin, which is 0.020 corrugated sheet spot welded to the outer skin, extends rearward about 10 percent of the wing chord from the leading edge. The corrugations have a mean pitch of 1.18 inches and draw of 0.25 inch. At the leading edge, part of each corrugation is cut away to provide an opening through which the heated air enters the interskin ducts, formed by the outer skin and the inner corrugated sheet. At the outlet end of the corrugations, there is a thin metal spanwise flange, which is bent back over the corrugations. The probable purpose of this flange is to regulate the spanwise distribution of the air flow in the corrugations. Located at about 4 percent of the chord rearward from the leading edge is a spanwise baffle which forms the rear wall of a spanwise D-shaped duct. This duct acts as a distributing plenum for the heated air before it flows between the double skin. Figure 4 shows a section of the leading edge cut from the outer-wing panel and illustrates the elements described above.

Heated air from the heat exchanger is conducted to the spanwise duct, region 1, figure 3, then flows through the interskin passages, region 2. While flowing through the corrugations, the air loses heat to the outer skin, thereby raising the temperature of the outer skin. On leaving the double skin region, the air travels through the afterbody of the wing, as shown in figure 3. The main spar webs are solid, so that in passing the spars, the air is forced through the gaps between the outer skin and the spar flanges. The air empties from the wing afterbody into the aileron and flap slots, where it mixes with the free air stream.

PERFORMANCE ESTIMATE

A heat transfer analysis was made on the heat exchanger. In the analysis, the heat transfer coefficient, from stacks to air, was calculated from empirical formulas, found in standard textbooks on heat transfer, for the heating of air flowing normal to tube banks. The temperature of the stack walls was assumed to be 1000°F and the inlet air temperature assumed to be 0°F . The wall temperature of 1000°F is assumed as a result of flight tests on somewhat similar equipment. The air temperature of 0°F has been taken as the critical air temperature for the design of anti-icing equipment at Ames Aeronautical Laboratory and is based on flight tests in various types of natural icing conditions. A calculated effective area of the fins was added to the surface area of the ejector stacks. The performance of the heater was calculated by balancing the equations:

$$Q_1 = h A (t_w - t_a) \quad (1)$$

$$Q_2 = W c_p (t_{\text{out}} - t_{\text{in}}) \quad (2)$$

$$Q_1 = Q_2 \quad (3)$$

where

- Q_1 heat transferred from stacks and fins to air, Btu/hr
- Q_2 heat added to air, Btu/hr
- h heat transfer coefficient from stacks to air, Btu/hr, sq ft, $^{\circ}\text{F}$.
- A effective surface areas, ft^2
- t_w average stack wall temperature, $^{\circ}\text{F}$
- t_a average air temperature, $^{\circ}\text{F}$
- t_{out} temperature of air leaving heater, $^{\circ}\text{F}$
- t_{in} temperature of entering air, $^{\circ}\text{F}$
- W mass flow of air, lb/hr

c_p specific heat of air at constant pressure taken at the average air temperature, Btu/lb, °F

The results of the calculations are presented graphically in figure 5.

The cruising speed of maximum range (which is believed to be the design condition for thermal ice-prevention equipment) for the Ju 88 airplane is probably about 150 mph, at which the dynamic pressure is 11.2 inches of water. If approximately one-half of the dynamic pressure head is employed in forcing air through the heat exchanger, a round figure of 2000 pounds of air per hour appears to be a conservative estimate of the flow rate, according to figure 5. If the rate of air flow is 2000 pounds per hour, the heating capacity of the exchanger, also according to figure 5, will be 100,000 Btu/hr. Dividing the heater output by the surface area covered by the double skin results in a specific input of 4670 Btu/hr, sq ft. Calculations based on a mass flow of 4000 pounds per hour, a heat input of 200,000 Btu/hr and a uniform spanwise distribution result in an average skin temperature, for the forward 10 percent of the outer panel leading edge, of about 70° F above 0° F dry ambient air temperature.

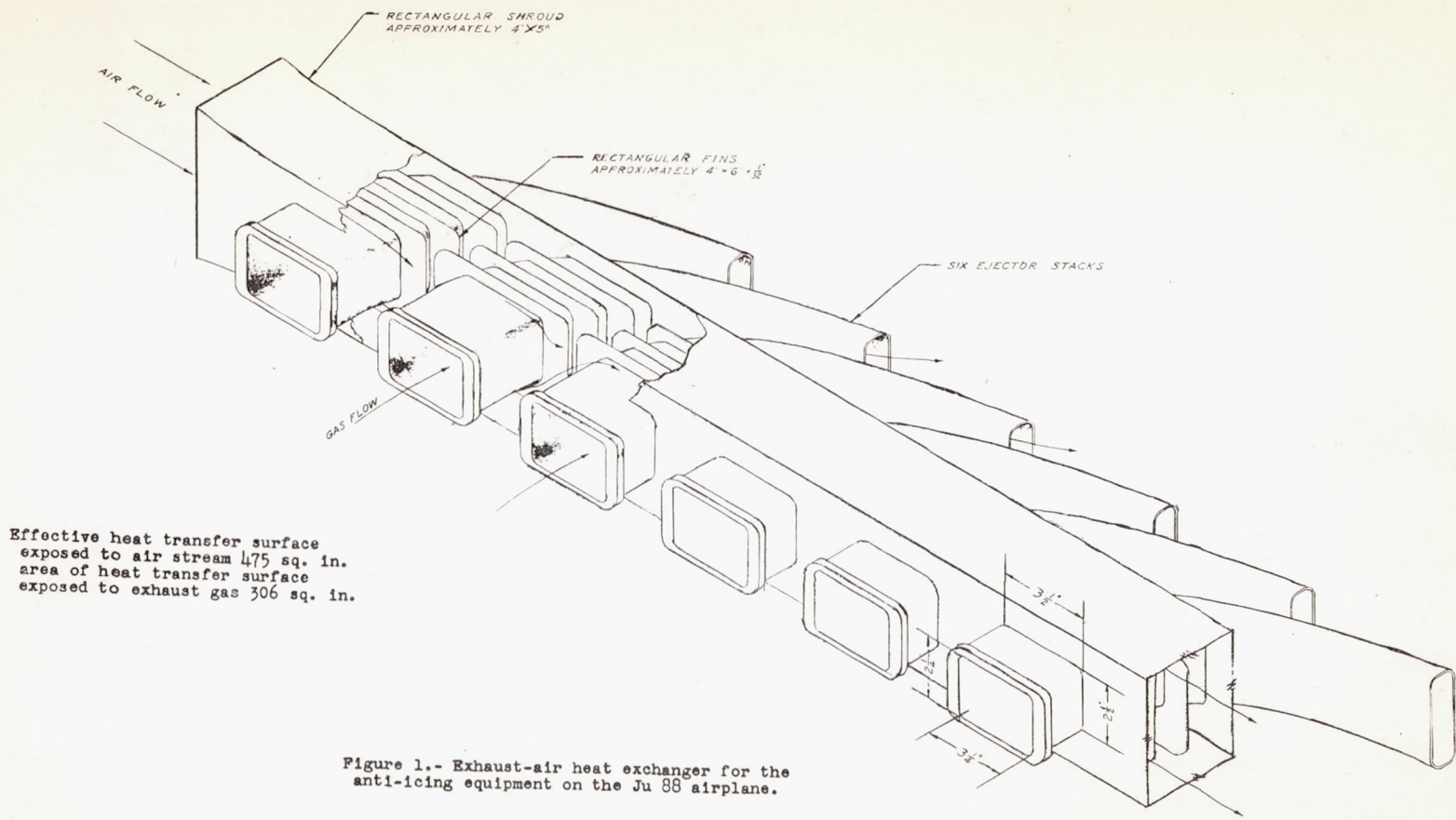
In flight tests made in actual icing conditions with a Lockheed 12-A airplane, reported in reference 1, the stabilizer was protected from ice by a double skin, air-heated leading edge. The heated leading edge kept the entire stabilizer free from ice in three separate tests, one of which was in severe icing conditions.

Comparison of the Ju 88 airplane air-heated wing leading edge with the Lockheed 12-A airplane air-heated stabilizer leading edge shows that the calculated specific heat input of the Ju 88 airplane system is higher than the highest specific input of the Lockheed 12-A airplane used during the flights in icing conditions. It appears, then, that the Ju 88 airplane thermal ice-prevention equipment can maintain the outer-wing panel free from ice.

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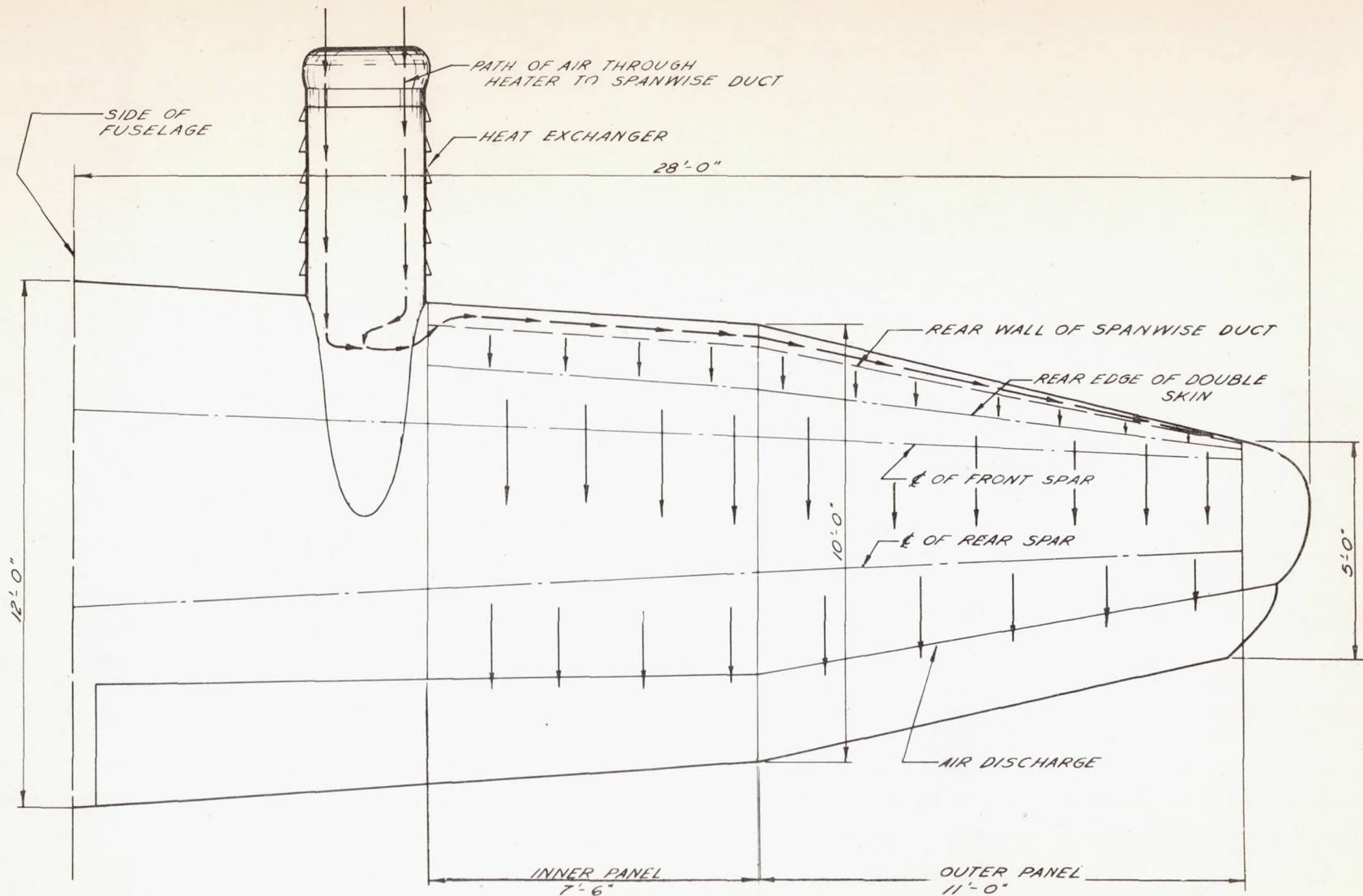
REFERENCE

1. Rodert, Lewis A., Clousing, Lawrence A., and McAvooy, William H.: Recent Flight Research on Ice Prevention. NACA A.R.R., Jan. 1942.



Effective heat transfer surface
exposed to air stream 475 sq. in.
area of heat transfer surface
exposed to exhaust gas 306 sq. in.

Figure 1.- Exhaust-air heat exchanger for the
anti-icing equipment on the Ju 88 airplane.



NOTE:
 ALL DIMENSIONS ARE APPROXIMATE

Figure 2.- Air-heated wing anti-icing equipment on the Ju 88 airplane, showing the path followed by the air.

RACA

FIG. 2

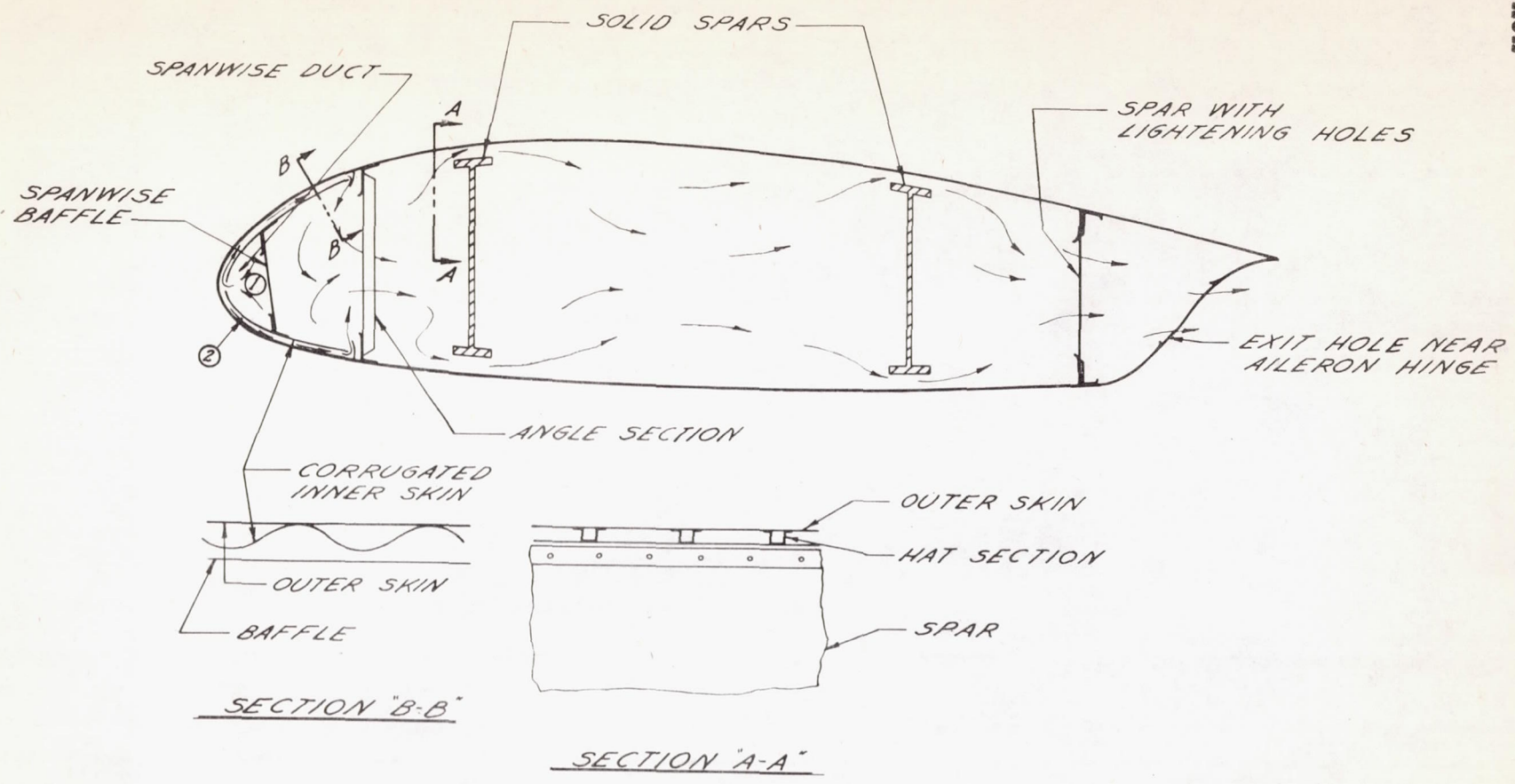


Figure 3.- Typical section through the outer-wing panel of the Ju 88 airplane, showing the principal parts of the wing anti-icing system.



Figure 4.- Two views of the outer-panel wing leading edge anti-icing system of the Ju 88 airplane.

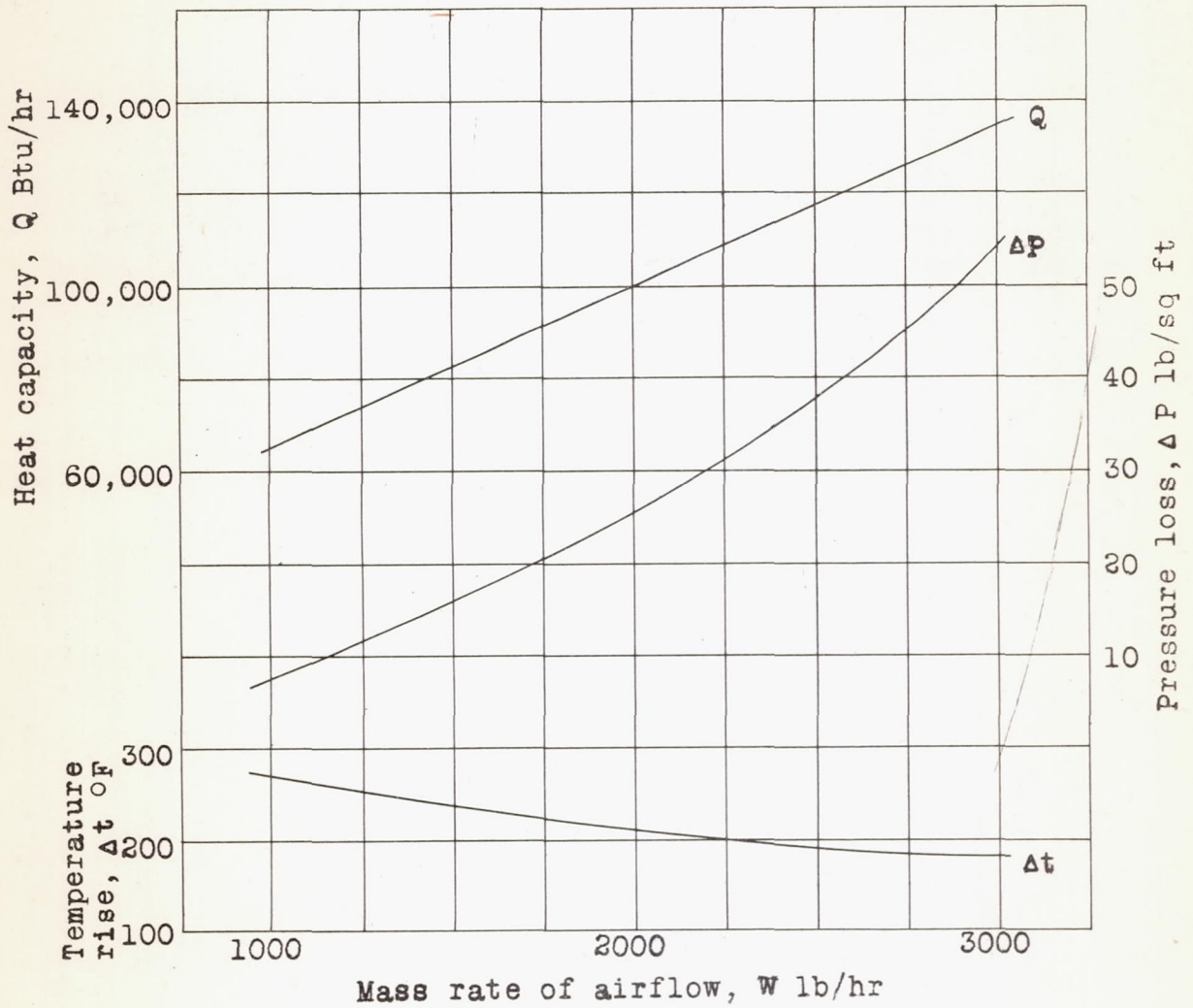


Figure 5.- The calculated performance of the exhaust-air heat exchangers employed on the Ju88 airplane.