COOLING

another problem for the electronics engineer

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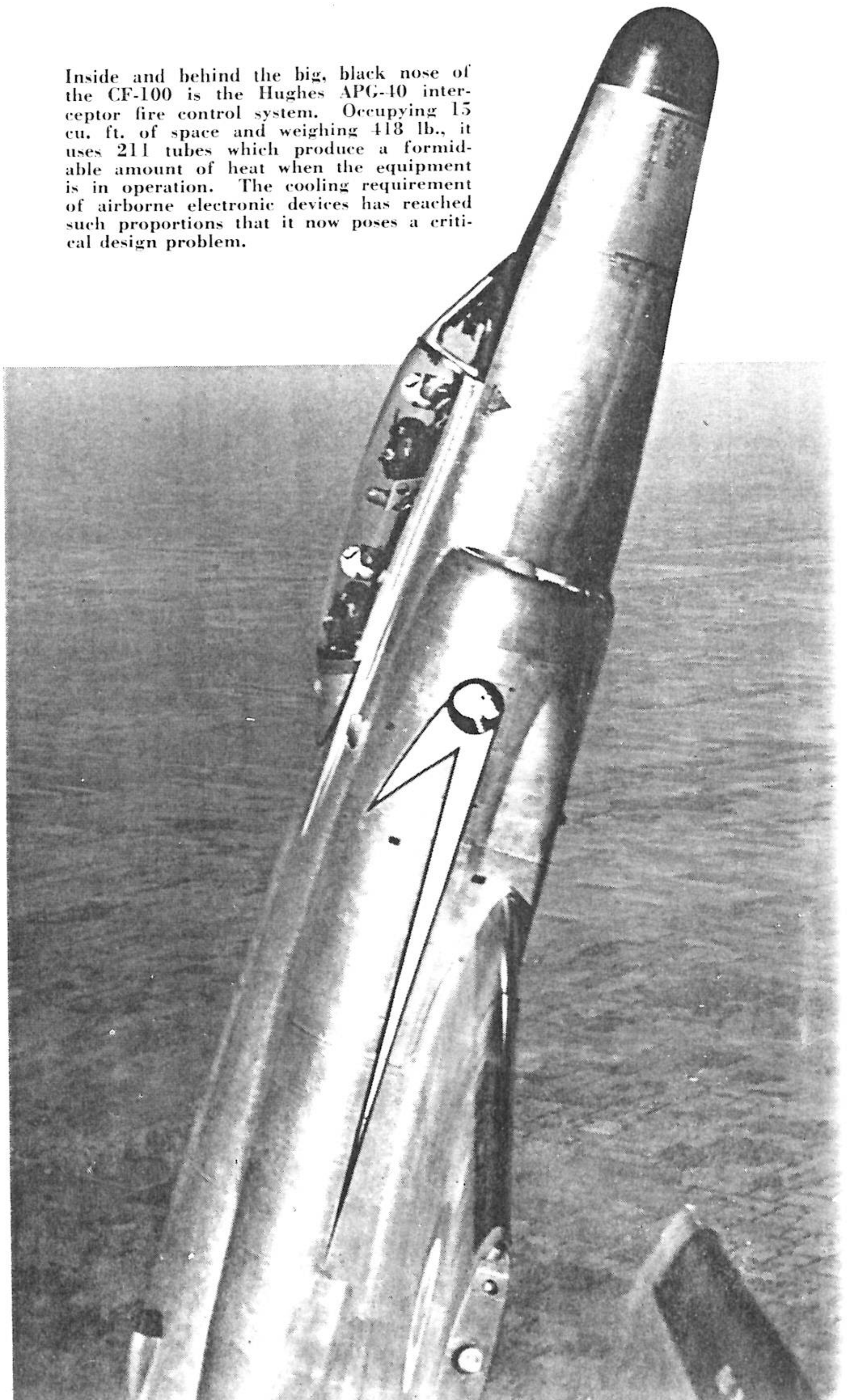
Airborne cooling apparatus is rapidly becoming a major item in weapons systems. It is the electronic design engineer's responsibility to be constantly aware of his cooling requirements so that redesign of his equipment to meet temperature conditions does not, at a later date, hold up an aircraft program unnecessarily.



Inside and behind the big, black nose of the CF-100 is the Hughes APG-40 interceptor fire control system. Occupying 15 cu. ft. of space and weighing 418 lb., it uses 211 tubes which produce a formidable amount of heat when the equipment is in operation. The cooling requirement of airborne electronic devices has reached such proportions that it now poses a critical design problem.

WITH THE INCREASE in the uses of electronic equipment at high altitudes in near sonic or supersonic aircraft and in weapons systems, the electronic engineer finds that he must expand his activities into yet another field — that of providing means for maintaining safe operating temperatures for his circuits. The lack of attention to the critical problem of cooling has, in some instances, led to the necessity for redesign of otherwise finished products. Needless to say, electronics engineers have been criticized for their apparent lack of foresight.

Between the stages of development and packaging, normal engineering practice requires a thorough assessment of the circuitry for the purposes of eliminating duplication, reducing weight, choosing the best components, increasing serviceability, and in general, achieving maximum efficiency of space, cost and weight. Often the final design is frozen before the problem of heat elimination is noticed. Recent experience among aircraft and guided missile fabricators has revealed that the addition of a blower may no longer be the salvation for the thermal inefficiencies of the electronics "black boxes" which have become so much a part of the modern airplane.

Joint Responsibility: The prevalent failure to foresee the cooling problem might possibly be atrtibuted to engineering management who may have failed to determine cooling as an airframe or as an electronic design problem. On the one hand the aircraft design team may be required to specify

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the conditions under which electronics apparatus must operate. On the other hand, the electronics group might be required to specify the cooling requirements to the aircraft designers. In either case there is a joint responsibility which must be stressed at the beginning of the design program. It can be quite embarassing to find at a later date, that a very fine piece of electronic equipment cannot operate in the aircraft for which it was designed simply because adequate consideration for heat stressing was not given.

Because under such circumstances the likelihood of redesign of the aircraft is slim, it can be expected that redesign of the electronics equipment must be undertaken. For this reason it seems expedient that the equipment designer should consider the heat problem from the outset and demand early information concerning cooling media.

The manufacturers of basic components, such as tubes, resistors, condensers, etc., have put tremendous effort into the design of units having stability under widely varying thermal conditions. Taking advantage of the improvements, the electronics engineer has produced packages of great volume efficiency. This, in turn, has made feasible the utilization of even more types of electronic apparatus by the aircraft industry.

Startling Facts: The round of improvement and increased utilization has been endless. However, suddenly the aeronautical engineers and scientists have made known certain startling facts heretofore unimportant. For example, at sea level ram air temperature is 200° F at Mach 1 and 340° F at Mach 1.5, and even simpler, although often inadvertently ignored, the cooling capacity of air at 60,000 feet has, at the best, one-fifteenth of the cooling capacity of air at sea level.

Further, for those interested in the statistics of the problem, it has been demonstrated that if a modern aircraft of given flight and speed specifications is required to carry additional electronic (or other) equipment equal to 10% of the aircraft's weight, the basic weight of the aircraft must be doubled to maintain the same flight performance.

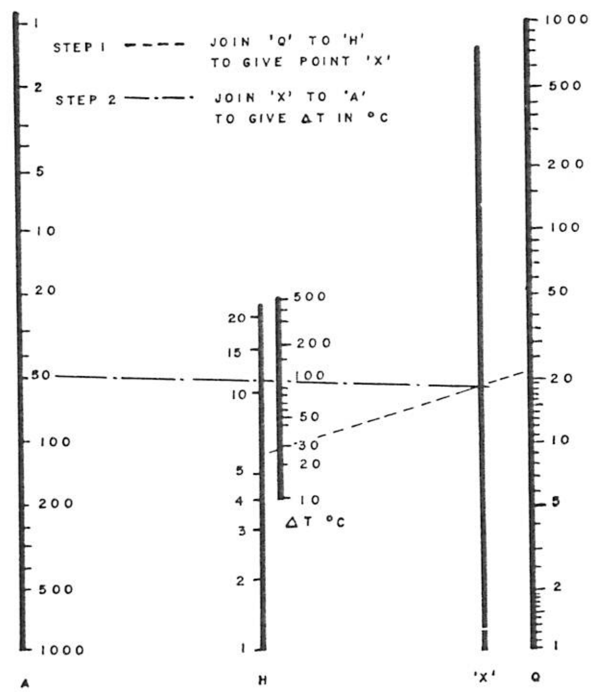


FIGURE I

TEMPERATURE RISE NONOGRAPH BASED ON $\Delta T^{1.25} = 460.\,QH^{\frac{1}{4}}.A^{-1}$ °C
WHERE ΔT IS MEAN TEMPERATURE INCREASE ABOVE AMBIENT
'Q' IS TOTAL HEAT IN WATTS, 'H' IS HEIGHT OF BOX IN INCHES;
'A' IS HORIZONTAL PROJECTION OF AREA IN SQUARE INCHES.
ΔT IS THE FIGURE FOR TOTALLY ENCLOSED SPACE.

The necessity for maintaining a low weight figure in the cooling equipment is, then, apparent. For this reason, the electronics design responsibility should include the detailed study of cooling problems and methods. More thought must be given to the placement of parts, not merely to squeeze them into a given space, but now also to provide natural syphoning of the airflow, where possible, within the units so that heat generating components are washed continuously by heat absorbing air. When small blowers are dictated, the largest portions of the moving air should pass over the sources of heat.

Color Control: Surface finishes should be used to provide maximum heat emissivity and reflectivity. For example, black paint, black enamel or some types of dark green are among the better finishes for casting off heat and should be employed on enclosures of units in which heat is generated. White paint, white enamel and aluminum paint are examples of good heat reflectors useful in protecting components which do not generate heat internally. Dull copper is an example of a material to be avoided, for such a finish often has a dissipation factor of only 10% of that of a black body.

Having taken such primary considerations there still remains the problem of selecting a blower.

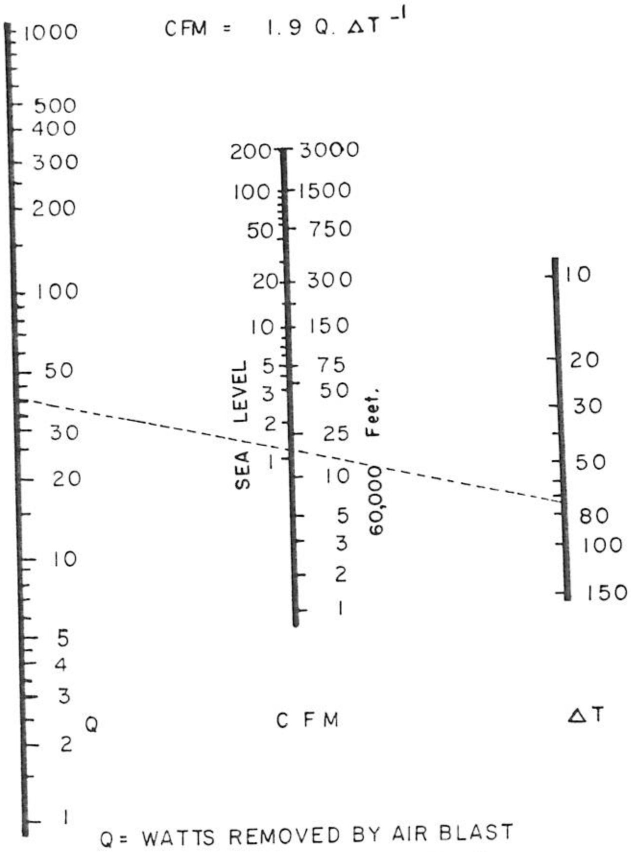
Two nomographs are supplied to assist in calculating average temperature rise and suitable blower capacities. The basis for the temperature rise nomograph, Figure (1), is an empirical formula based on thermodynamics and experimental observations:

$$\Delta T^{1.25} = 460.\ Q H^{\frac{1}{4}} A^{-1}$$

where

ΔT is mean temperature rise—°C above ambient
"Q" is total heat — watts
"H" is height of box in inches
"A" is horizontal area of box in square inches

Answers become inaccurate when the height is greater than twenty-two inches, the constant term having been determined for values less than that amount. However, very few airborne applications tolerate height in excess of two feet, so that the nomograph will be useful for a wide range of design. Typical problems are solved after the



Q = WATTS REMOVED BY AIR BLAST

ΔT = PERMISSIBLE °C RISE ABOVE AMBIENT

FIGURE 2

NOMOGRAPH FOR ESTIMATING BLOWER CAPACITY FOR SEA LEVEL AND 60,000 FEET OPERATION.

description of the second nomograph (Figure 2) which permits rapid selection of the maximum blower capacity required to meet the cooling needs. The basis for this chart is a constant pressure formula CFM $\doteq$ 5.92 (T_1 + 273) Q. △ T which can be reduced to CFM = 1.9 Q. △ T cubic feet per minute where symbols have the same meaning as in figure (1). Using this chart, an adequate blower capacity may be selected for given heat and temperature rise conditions.

Sample Calculations

Example (1) Determine the temperature rise in a box 5″ wide x 10″ long x 6″ high in which 21 watts of heat are being generated.

Solution: See figure (1)

(a) Join 21 on the "Q" line to 6 on the "H" line producing an intersection on the "X" line.

(b) Join "X" to 50 on the "A" line yielding △ T= 100° C.

Example (2) Determine the size of blower required to remove 40 watts of heat in order to maintain a temperature rise of 75° C.

Solution: See figure (2)

(a) Join 40 on the "Q" line to 75 on the △ T line yielding 1.2 CFM for sea level operation and 18 CFM at 60,000 feet.

Example (3) It is required to select a blower to maintain a maximum heat rise of 40° C above ambient in a piece of electronic apparatus containing four 6SN7 tubes and two 6L6 tubes having a total D.C. drain of 300 volts, 100 ma The dimensions of the box are 10″ wide, 15″ long, and 9″ high.

Solution

(a) Compute total watts inside the box

Total heater drain = 18.9 watts
Total plate power = 30.0 watts

Total heat (Q) = 48.9 watts

(b) Horizontal area of box (A) = 150 square inches.

(c) Height of box (H) = 9 inches. From figure (1) the expected mean temperature rise for the above conditions will be 100° C. It is now obvious that a blower will be necessary to reduce the temperature rise to 40° C. In order to determine the smallest size of blower which will be satisfactory it is now necessary to determine how much heat must be removed by the air blast. Therefore, compute how the above dimensions would produce a heat rise of only 40° C as follows:

(d) Enter the chart on the △ T line at 40°, join this point to "A" = 150 square inches giving an intersection on the "X" line. Join "X" to "H" = 9 inches giving at an intersection on the "Q" line of 20 watts. Twenty watts is, then, the amount of heat generated inside a box 9″ x 10″ x 15″ which would produce a heat rise of 40° C above ambient. The remaining 28.9 watts must be removed by a blower.

(e) Enter figure (2) on the "Q" line at 28.9 and join this point to 40° C on the △ T line. This will result in an intersection on the CFM line of approximately 2 CFM at sea level and 25 CFM for 60,000 feet operation.

In these calculations, the permissible or safe temperature rise above ambient depends on the maximum value of the ambient. For military applications, operating ambient temperature ranges are normally specified. Such specifications should be brought to the attention of the aircraft designers during the early stages of design for it is then that the decision should be made concerning the cooling method. It can be embarassing to find at a late date that a husky blower will solve the heat problem but that adequate space has not been allotted for its installation in the airframe.

Other Considerations: The decision concerning the cooling method does not eliminate the requirements for careful component study and physical layout having in mind circuit functions, heat generation, air circulation and proximity to other circuit elements. Components should be chosen to permit the highest possible operating temperature to minimize cooling requirements. Thought should be given to the feasibility of pressurization for maximum cooling efficiency of internally circulated air. Metallic vanes for conducting heat to the walls of containers and external vanes for airblast cooling are features which must be considered initially as a design requirement and not later as an expedient.

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indexing of automatic production machinery. Copies from Ferguson Machine & Tool Co., Roller Gear Div., P.O. Box 191, St. Louis 21, Mo.

• **Die Steel:** Detailed information on "Ottawa 60", a new die steel specifically developed to deep draw and form stainless steel, is available in a technical data sheet obtainable on request from the Advertising Department, Allegheny Ludlum Steel Corp., 2020 Oliver Bldg., Pittsburgh 22, Pa.

• **Wet Blasting:** "How to Cut Die and Mold Finishing Time 50% to 94%" is the title of a new bulletin just published by American Wheelabrator & Equipment Corp., 1005 S. Byrkit St., Mishawaka, Indiana. This four-page folder shows the application of wet blasting as done in the company's Liquamatte machines to such cleaning and finishing work as is met in the manufacture and maintenance of forming dies and molds.

• **Hardness Tester:** Gries Industries Bulletin No. A-12 describes new Wolpert-Gries machine for standard Rockwell Hardness tests. Copies from Gries Industries Inc., Testing Div., Beechwood Av. at Second St., New Rochelle 6, N.Y.

• **Brinell Tester:** New four-page illustrated folder describing King portable Brinell Hardness Tester that makes standard Brinell tests and can be used as a bench tester or taken to the job and used in any position, anywhere, has recently been published by Andrew King, 67 E. Lancaster Ave., Ardmore, Pa.

ELECTRONICS COOLING

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The possibility of isolating temperature sensitive components from sources of heat might also include the application of thermal barriers such as plastic foam or aluminum foil. Design of circuit layouts to group heat generators together for simplicity of cooling and to derive maximum efficiency from the cooling air must be kept in mind. The circuit engineer should be aware of these factors at all times so that circuit design may be kept less dependent on the length of lead, or, that the length of lead will permit some latitude in the final layout and packaging phases, thus allowing for advantageous component locations.

By attending to some of the points discussed here, the need for refrigerator cooling of weapons systems and aircraft electronics may, at least, be avoided for some time to come, and with the responsibility for cooling perhaps difficult to allocate as either wholly electronic or wholly aeronautical, the fact that 95% of the energy supplied by the aircraft power plant to electronics apparatus is wasted as heat, it might possibly be safe to say that attention by electronics engineers to their share of the cooling problem is important.

AIR POWER

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attainment of the needed ranges, sensitivities, or the like; and third, whether the pertinent art of manufacture has advanced sufficiently to allow a useful embodiment to be built successfully."

Time Variation: After a team has used this approach to sift out the proper avenues of research and development then the time factor must be inserted into the deliberations. Unfortunately, the research and development phasing, in such a broad and complex field as aeronautical equipment, can be markedly variable. For example, the development of the armament and navigation systems for a typical bomber must be started before the development of the airframe and engine, as illustrated in Figure 1.

And to make matters worse, the time phasing or the ground elements of an air defence or air offense system, may be in a completely different