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DISCUSSION OF THE GENERAL ELECTRIC PROPOSAL TO DEVELOP A COMPUTER PROGRAM TO SELECT THERMAL COATINGS FOR PASSIVE TEMPERATURE CONTROL OF SATELLITES

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Scope of G. E. Proposal

The General Electric Company, Missiles and Space Division, submitted a proposal to NASA for the development of an IBM 7094 computer program which would select the exterior surface coatings for passively controlling spacecraft temperatures. G. E. claims that the "trial and error" procedures currently used can be accomplished more rationally and can therefore be programmed for a digital computer. In the ASME paper, 63-HT-41, which was presented at the ASME-AIChE Heat Transfer Conference at Boston in August, 1963, Costello, Harper, and Cline, described the procedures that have been used at G. E. to develop a coating selection program subject to the following restrictions:

1. Steady-state conditions prevail,
2. Heat transfer occurs by radiation only,

3. Temperatures are optimized at only one interior point in the spacecraft, and
4. Only the solar absorptance of the external coatings is varied to optimize temperature. The emittance must remain constant at initially specified values.

General Electric proposes to develop a generalized program in three steps:

1. The program would vary both solar absorptance and hemispherical emittance to obtain the optimum coating patterns;
2. Temperatures would be optimized at more than one interior point; and
3. The equations would be modified to account for both conduction and radiation heat transfer.

In the development of the general program, the scope would be restricted to steady-state heat transfer. Since the thermal designs of most spacecraft are based primarily on nearly equilibrium conditions, the proposed program could have wide application. An obvious extension of the proposed program would be to account for transient temperatures.

Examples

To illustrate how the present program works, two examples are discussed. The first is very simple and the second is a little more complex.

Case I. - Consider a simple spacecraft which can be represented by equations describing the heat transfer at two locations or nodes. One node would represent the internal compartment which contains the electronic modules, batteries, etc. and the second node would represent the skin of the spacecraft. It is assumed that the internal compartment is isolated thermally from the skin, as in the case of the Vanguard Satellites, so that the predominant mode of heat transfer is by radiation. The temperature of the internal compartment is a function of: (1) a/e of the external surfaces of the skin, and (2) the average per orbit of the solar and planetary heat fluxes incident on the skin. Consider finally three orbits that represent typical and extreme environments. The internal temperature, T, in degrees absolute to the fourth power is simply a linear function of the a/e of the surface coatings as shown in Figure 1. If T_d is the desired temperature, then an a/e can be selected so that the maximum difference between T_d^4 and T^4 for the three orbits is a minimum.

A selection criterion can be stated formally by defining a parameter Δ_j such that

$$\Delta_j = (T^4 - T_d^4)^2$$

where j represents a particular orbit. For a given a/e, one would obtain three values of Δ_j, one for each orbit. The optimum coating would have an a/e such that the maximum value of Δ_j for a given a/e would be a minimum, as shown in Figure 2, where Δ is plotted as a function of a/e.

The procedure for applying the selection criterion in a way that can be programmed for a computer can be visualized by referring again to Figure 2. The first step would be to assume a trial a/e, to compute the three Δ_j's and to select the maximum Δ_j. The next step would be to make an incremental change in a/e such that the new maximum Δ_j would be less than the previous value. The process would then be continued until no further decrease in the maximum Δ_j could be obtained.

Case II - Consider next a cylinder in a polar orbit near the earth with the axis of the cylinder parallel to the velocity vector and with one side of the cylinder always facing the earth. It is assumed that there are 10 possible orbital conditions based on launches at 8, 10, 12, 2, and 4 o'clock in summer or winter. Temperature is to be controlled at one internal point which is radiatively coupled to the skin. To show the advantages of a coating pattern over one uniform coating, the optimum a/e's are shown in Figure 3 for 1, 2, 4, and 8 surface nodes. Included in Figure 3 is the maximum deviation in ^{o}F of the internal temperature from the desired temperature. It is noted that when 8 surface nodes are used the maximum temperature deviation is reduced considerably compared to the deviation for one node. In addition, the coating pattern for the eight node case appears to be rather unusual. It would have been interesting to compare this solution to an independent solution by conventional methods using the same number of nodes.

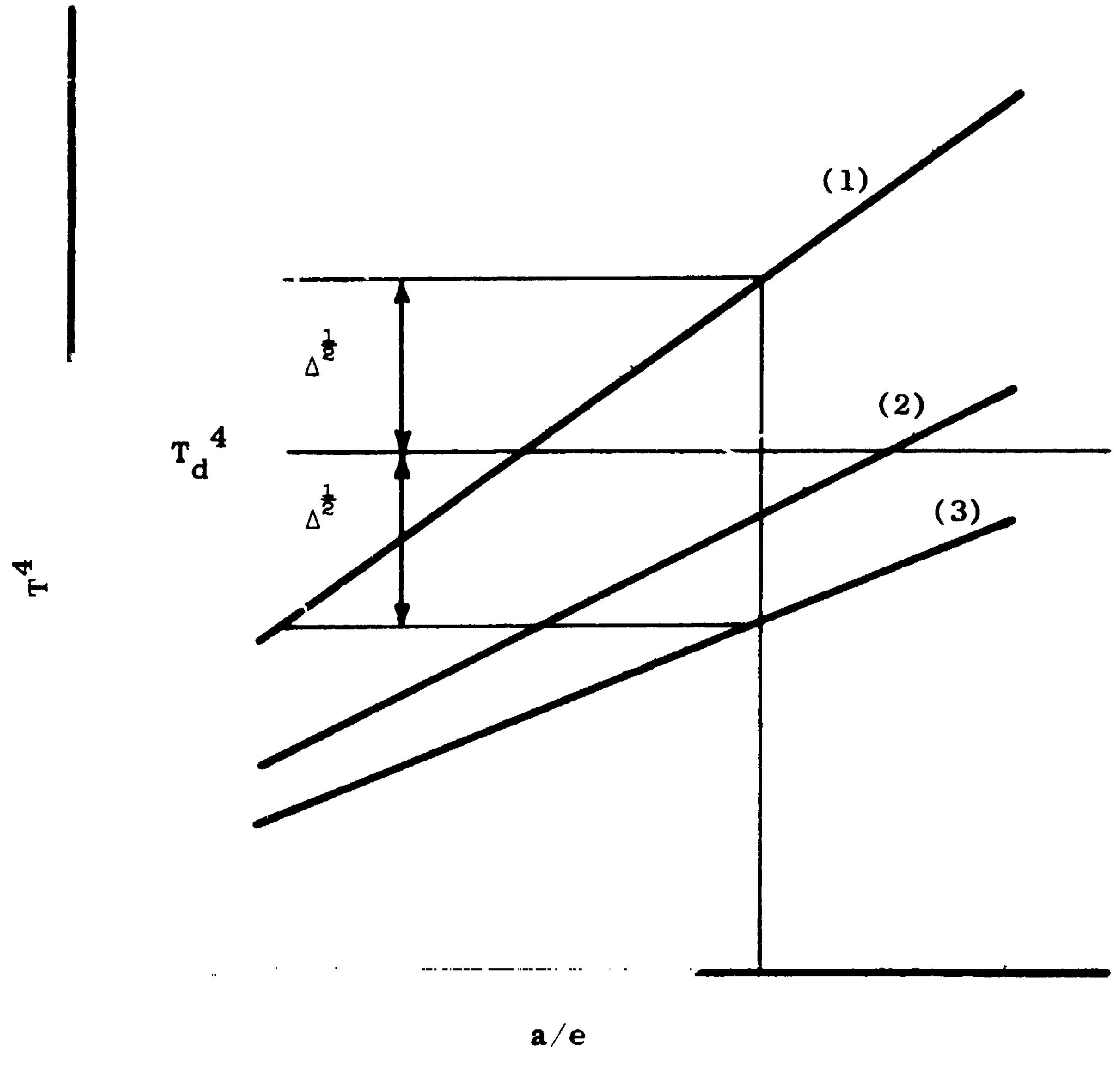

FIGURE 1 - Case I T^4 vs a/e

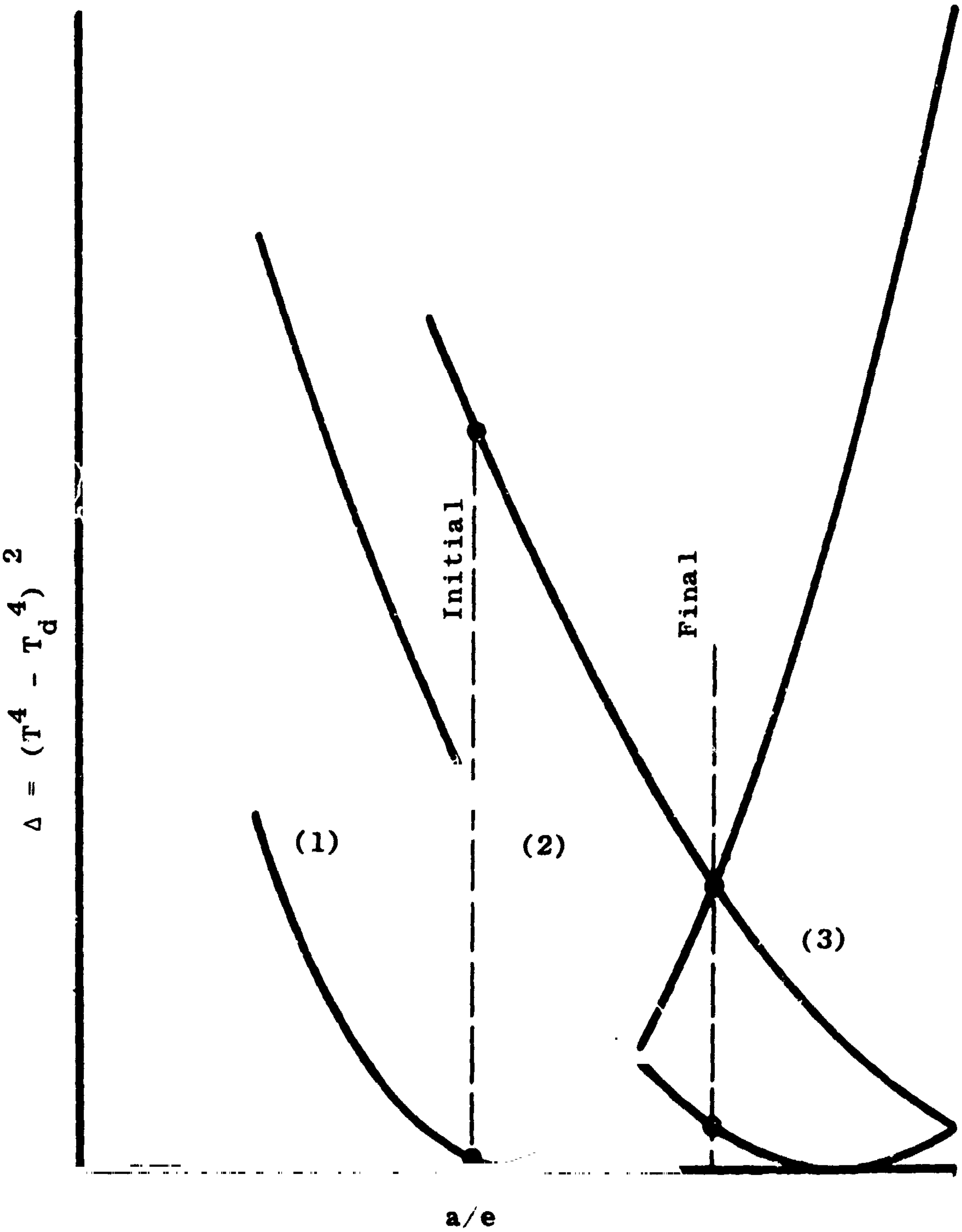

FIGURE 2 - Case I Δ vs a/e

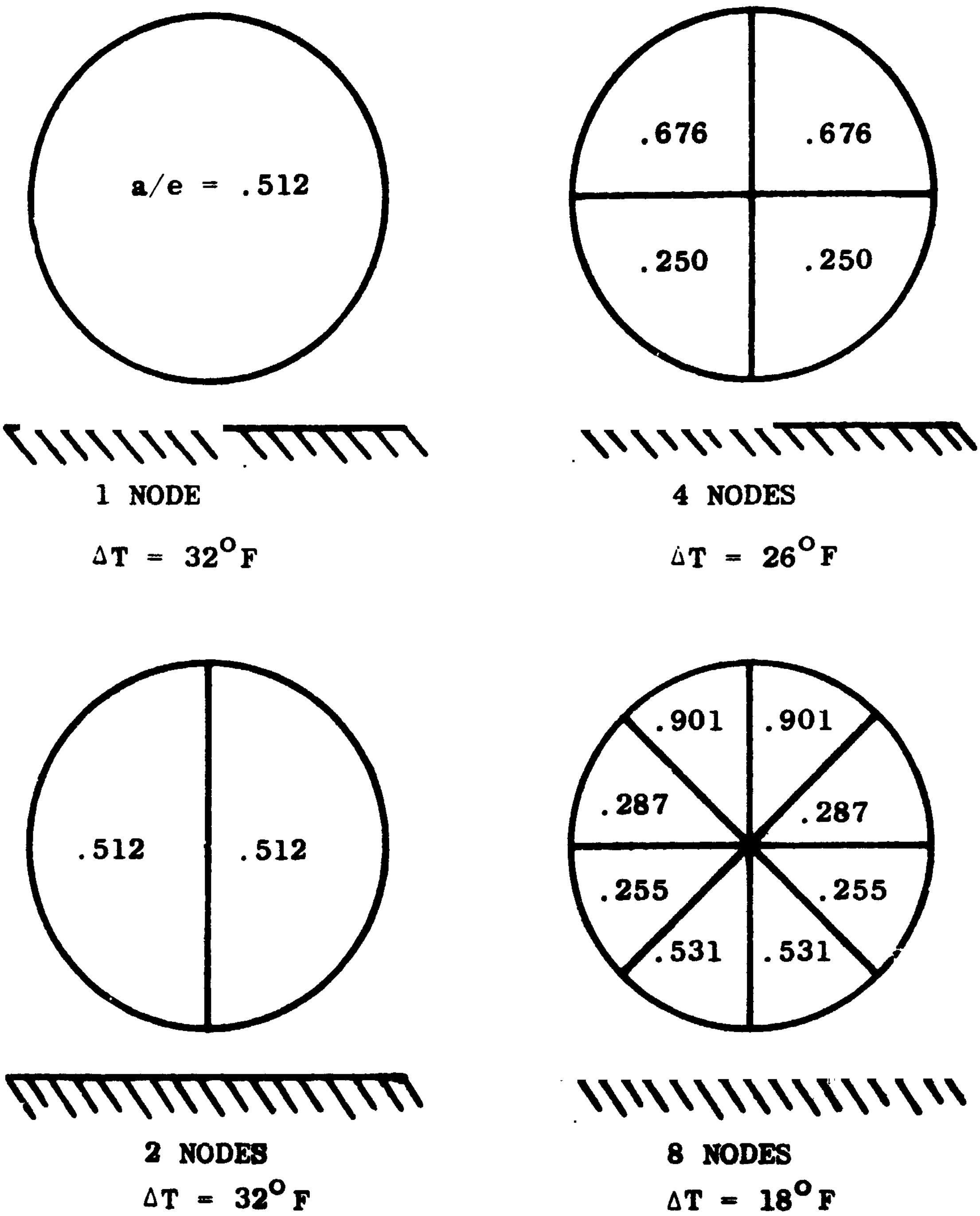

FIGURE 3 - Case II a/e and ΔT for 1, 2, 4, and 8 surface nodes. $\Delta T = (T - T_d)_{max}$

Comments on the Proposal

There are a number of advantages which could be derived from a coating selection program. The program would save the engineering time in the coating selection phase of the thermal design. In addition, it would save the time lost between the many trial solutions that are run on the computer. For example, in the present trial and error procedure for coating selection, several steps are required. First, it is necessary to decide what coatings are to be applied hypothetically to each surface. Then it is necessary to punch new input data cards for the heat transfer computer program and to submit the deck to the computer. Without priorities over other work for the computer (and priorities are extremely difficult to obtain) several hours or more are lost before the solutions can be analyzed to determine what adjustments should be made in the coating pattern for the next trial.

Another advantage of a selection program is that a computer has infinite patience. It can be required to compare and select from hundreds of numbers whereas an engineer tends to become fatigued. It is therefore quite probable that a computer could arrive at a better thermal design when there are seemingly unlimited combinations to be considered.

There are two reservations about the proposed program. First, how does one program a computer to perform a function in which so much intuition, judgment, and experience is required? And second, how much machine time would be required to run such a program?

In both the ASME paper and the Proposal, none of the essential details were given concerning the method used to determine how to change the coating pattern for each trial so that a minimum number of steps would be required to converge on an optimum solution. Therefore, it is difficult to tell what obstacles must be overcome in developing the general program without actually doing most of the same work independently. However, it is not nearly as difficult to think of ways that most of the trial and error procedure could be programmed for a computer for any type of satellite thermal design problem without necessarily achieving optimum coatings in an efficient manner.

It is difficult to know how to account for tolerances in the coating properties, or to decide rationally whether an optimum coating pattern involving delicate materials would be preferred over a less optimum coating pattern in which only reliable materials would be required.

At the present time, it is convenient to break up problems so that the computer time for any one run is limited to a few minutes. Longer runs must be made at night. For a 50 node problem with about 24 orbital conditions, which is typical for Goddard satellites, the running time for one trial is in the order of a few minutes. It is obvious that a coating selection program would require much longer times.

Although reservations have been expressed, it is believed that the possible advantages outweigh any of these reservations, and that the general coating selection program should be developed.

(On June 19, 1964, contract NASw-960 was awarded to G.E. to develop the program)