pointing. The duration of the settling transient for the initial conditions of this run is well within the allowable 3-min specified time. The final pointing accuracy falls with the required ±1 arc-sec, which includes the control system errors, the attitude measurement system errors, and the errors in the FOES. The inset in Fig. 2 shows typical pointing accuracy determined from the analog computer. Excerpts from two runs are shown. The first includes noise inputs typical of those measured in the FOES used for air-bearing tests. The second used an essentially noise-free signal, which is more representative of that specified for the Princeton experiment.‡ The air-bearing platform simulation shows performance very close to that obtained in tests. The orbital simulation shows an order-of-magnitude improvement in performance (0.1 arc-sec) which is what is expected from the control system in orbit.

Summary

The demonstration of accuracy during the OAO air-bearing tests has not only shown the acceptability of the control system but has verified the usefulness of the air-bearing platform. In fact, the air-bearing platform has now reached a high level of importance for both qualitative and quantitative measurements for both the development cycle and the acceptance tests of each delivered system; it will prevent possible in-flight failures and will produce a far sounder control system.

‡ Different experiments will be flown on each OAO spacecraft; thus the FOES characteristics are modified accordingly. The Princeton experiment is scheduled for the third spacecraft.

Transient Characteristics of a Steam Generator

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Nomenclature

D_{ii} = i.d. of inner tube
D_{io} = o.d. of inner tube
D_{oi} = i.d. of outer tube
D_{oo} = o.d. of outer tube
L = tube length
Q = heat-transfer rate
T = exit temperature of the steam
T_E = saturation temperature
T_{GE} = temperature of the gas stream as it leaves the evaporating position of the generator
T_{GI} = temperature of the gas entering the generator
T_{GO} = exit temperature of the gas
T_{GS} = temperature of the gas as it leaves the superheating portion of the evaporator
T_S = T_E
T_W = entering water temperature
UA = over-all coefficient of heat transfer multiplied by the appropriate area

Closed cycle powerplants have the advantage of being insensitive to environmental pressures. This note considers a compact design that receives products of combustion at 2200°F and starts delivering steam when the pressure reaches 2000 psia. The time transient for this pressure ise should be quite short if this powerplant is to be competitive with other closed cycle systems. The steam generator would consist of several parallel double-pipe heat exchangers, each working as a "straight-through" boiler. The physical dimensions of the steam generator are based on a steady-state steam generating rate of 1 lb/sec at 2000 psia and 1400°F. The most recent work on the heat-transfer characteristics of this arrangement is by Rounthwaite and Clouston.[1]

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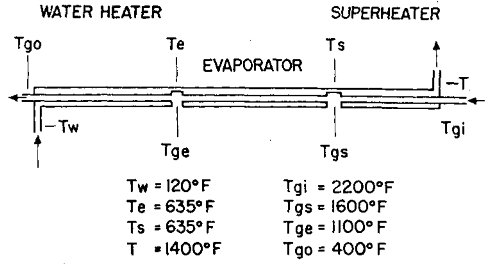

Fig. 1 Schematic of steam generator for purpose of steady-state analysis.

The critical point for the design, because of the high temperature, is the hot gas entrance. The material for the inner tube is Haynes Multimet with a design stress of 5000 psi at 1900°F. The outer tube can be sized on the basis of a design stress of 10,000 psi. After applying the appropriate heat-transfer equations, the conditions of this design are met by using ten sets of the following:

Inside Tube

$$D_{ii} = 0.495 \text{ in.}$$

$$D_{io} = 0.625\text{- or } \tfrac{5}{8}\text{-in. BWG-16}$$

Outside Tube

$$D_{oi} = 0.834 \text{ in.}$$

$$D_{oo} = 1.00\text{- or 1 in. BWG-14}$$

The necessary tube lengths and the temperature for each of the sections that are shown in Fig. 1 can be determined from the appropriate heat-transfer relations. Table 1 summarizes the results of these calculations. The total weight of the steam generator is 350 lb and the length of each of the ten sets of tubes is 29 ft.

The initial starting transient is the time from the start of hot gas flow with the system at 120°F to the opening of valves 1 and 2 shown in the equipment schematic in Fig. 2. Valves 1 and 2 open when the steam pressure is 2000 psia. The

Table 1 Steady-state results

	Water heater	Evaporator Boiling film	Evaporator Vapor film	Superheater
UA	38L	39.2L	32L	30.7L
Q, Btu/sec	586	394	70	580
L, ft	15.1	5.53	0.85	7.66

Table 2 Time transients

Case	System volume, ft³	Initial transient, sec	Time to evaporate water in void, sec	Final transient, sec	Total time, sec
Filled plus excess volume	2.4	22	6	24	52
½ filled, no excess volume	1.6	21	...	20	41

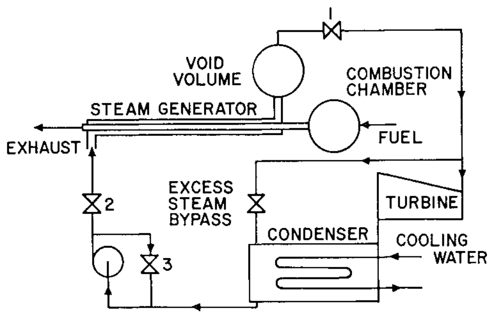

Fig. 2 Equipment schematic.

tubes will initially have some quantity of water present which will expand in addition to evaporating when heated. If the tubes are almost filled with water, a void expansion volume must be supplied as shown in Fig. 2. The energy equations are written as time derivatives and then are placed in finite difference form for computer solution. Polynomials are used to fit the steam table data necessary for the solution. A plot of the complete time transients are shown on the graph in Fig. 3.

The final starting transient is the time from the start of steam flow until the steam reaches its proper superheat temperature. Two conditions were evaluated for the final starting transient, but the case of initially full tubes is the only one of practical significance. The amount of superheating will be proportional to the surface in contact with the vapor. Energy equations for this case are placed in finite-difference form and solved by iteration techniques on a digital computer. The results of these calculations are shown in Fig. 4.

The liquid volume expands during the initial transient, and this puts excess water in the void space at the start of the final transient for initially full tubes. It will take 6 sec to evaporate this water before superheating starts. A summary of the results is given in Table 2.

The size of the generator can be reduced if the average gas temperature is increased by increasing the gas flow rate, but it would increase the initial mass of fuel carried by 120 lb for each minute of operation.

The time variations in the different cases for the initial transient are primarily due to variations in the amount of heat-transfer surface in contact with the liquid, as increased contact area increases the evaporation rate. The temperature rise in the final transient for the tubes initially filled with water is very slow at first because of the small surface initially exposed to the dry steam. The steam generation rate is initially higher than required, and the steam bypass valve must open to maintain pressure. This situation disappears as steady state is approached due to a decreasing amount of liquid in contact with the surface.

The total transient is less than 1 min, and it takes about 20 sec for operation to begin. This may appear short, but

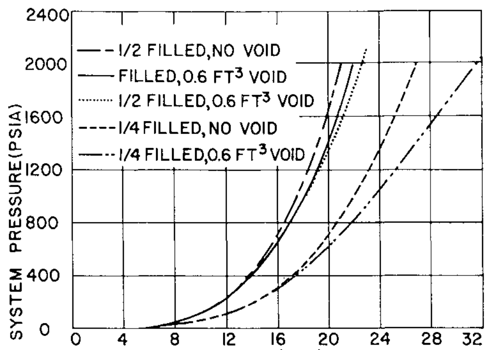

Fig. 3 Initial starting transient.

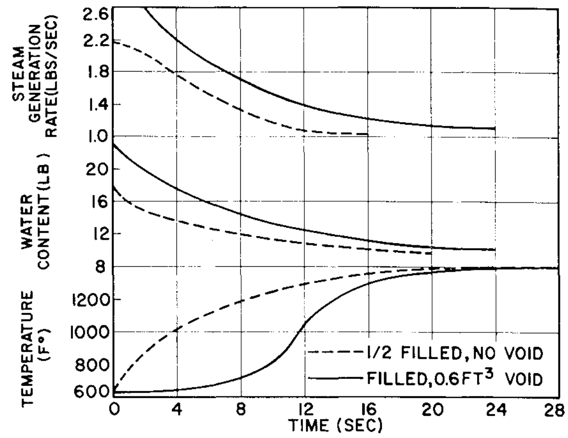

Fig. 4 Final starting transient.

some applications would require auxiliary power during the initial transient. The case of tubes $\frac{1}{2}$ full with no excess void represents the shortest total transient, but there would be considerable danger of tube burnout during the initial transient if they were not completely filled with water. The tube length can be shortened by using higher gas flow rates and gas exhaust temperatures. This, however, will require more fuel to be carried plus reduce the heat-transfer resistance on the gas side, which will raise tube wall temperature and weaken the material.

Reference

[1] Rounthwaite, C. and Clouston, M., "Heat transfer during evaporation of high quality water-steam mixtures flowing in horizontal tubes," *Modern Developments in Heat Transfer* (American Society of Mechanical Engineers, New York, 1961), Part I, pp. 200–211.

High-Temperature Inorganic Adhesives for Electromagnetic Applications

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The mission requirements and performance characteristics of current and advanced aerospace vehicles and weapons systems are continually demanding more refined and efficient detection and ranging equipment. The radomes that contain such electromagnetic devices must compromise the performance of this equipment as little as possible while still offering aerodynamic smoothness and environmental protection. Only ceramic materials, with their high-temperature stability, resistance to rain erosion, and uniform electrical properties, are presently available for the fabrication of such radomes. Unfortunately, producing a monolithic ceramic radome in the sizes and configurations required for optimum vehicle performance has proved to be difficult and sometimes impossible. Processing equipment and techniques,

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