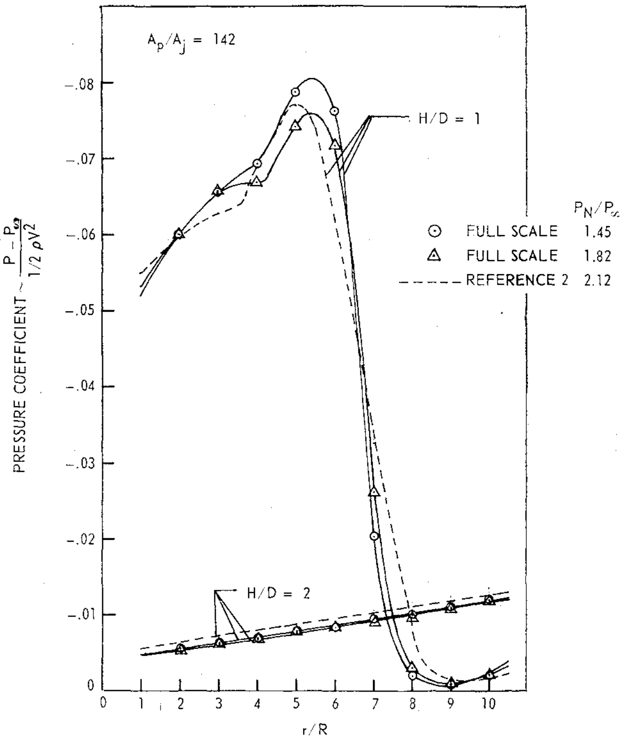

Fig. 4 Plate pressure distribution.

The value of 2% for the base loss was obtained from the experimental data of Ref. 1 for $A_p/A_j = 142$.

From Fig. 2 it is seen that the thrust loss data of the full-scale test are in excellent agreement with the generalized correlation curve of Ref. 1 in the range of practical values of H/D for VTOL aircraft (say $H/D \gtrsim 2$). On the other hand, the small-scale data of Ref. 2 indicate higher values of thrust loss than those of the full-scale test. Figure 3 shows a similar relation between the data of the full-scale test, Ref. 1, and Ref. 2 in demonstrating the independence of thrust ratio with nozzle pressure ratio.

Figure 4 shows the plate pressure distributions obtained from the full-scale test and from Ref. 2. The reference for the pressure coefficient is taken as the jet dynamic pressure $\frac{1}{2}\rho V^2$ rather than $P_N - P_\infty$ as in Ref. 2. As a result, the data correlation becomes independent of pressure ratio. The pressure ratio independence when correlated with $\frac{1}{2}\rho V^2$ rather than $P_N - P_\infty$ follows from Fig. 3, which shows the invariance of thrust ratio with pressure ratio. The data of Fig. 4 show close agreement between the pressure distributions of the full-scale tests and those of Ref. 2.

In summary, it would appear that valid aerodynamic suckdown data applicable to full-scale vehicles can be obtained from small-scale tests with cold jets for single-jet (or closely spaced multiple-jet) configurations. It should be pointed out, however, that extension of the foregoing conclusion to include multiple split-jet configurations is a dangerous extrapolation due to fundamental differences in the flow phenomena between split-jet and single-jet configurations, and therefore cannot be made on the basis of the data presented in this note. Finally, it would appear that the small-scale data correlation of Ref. 1 is an excellent representation of aerodynamic suckdown for full-scale configurations of the same family evaluated in Ref. 1.

References

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Response of Bare Wire Thermocouples to Temperature Variations in a Jet Engine Intake

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Introduction

RECENT full-scale VTOL exhaust gas ingestion tests performed by Norair and others have indicated engine inlet air temperature histories of a highly transient character for many of the configurations tested. Considering the transient character of these data, highly responsive thermocouples are required to reproduce the actual temperature transients experienced within the inlets. In general, however, thermocouples of a small enough thermal mass to follow the actual temperature transients are costly to fabricate and may not withstand the hostile vibration and acoustic environment within an engine inlet. Considering these practical factors, along with the generally large number of thermocouples required to define the inlet temperature fields for multijet configurations, it may be necessary to accept a temperature pickup which compromises the desired thermal response.

Depending upon the particular objective of the investigation, damped thermal response may or may not represent a serious compromise in the test objective. For instance, for determining the thrust degradation resulting from exhaust gas ingestion for a particular airplane configuration, measurements of short-duration temperature pulses of the order of a few msec are not required because of the relatively slow adjustment of the engine to changes in inlet temperature. For evaluations of this type, some damping of the instantaneous temperature field is acceptable; in fact, there may be some merit to matching the response of the temperature readout circuit to the response of the engines for experimental correlations of this type.

On the other hand, for configurations in which exhaust gas ingestion is severe enough to result in engine stall caused by sharp localized temperature pulses within the engine inlet, undamped measurements of these temperature pulses are obviously important. This means selection of a highly responsive temperature pickup and a recorder with response equal to or greater than that of the temperature pickup.

Although in the foregoing an example is pointed out for a case in which instantaneous temperature determination is not important and for a case in which instantaneous temperature determination is important, it is not the purpose of this note to discuss what one should be measuring, since there is no unique answer to this question. Rather, the purpose of this note is to aid one in the selection of a particular temperature pickup once the desired response is established, or, if the desired response results in wire gage too fine to withstand the environment, to provide data from which the actual response may be determined so that the data may be interpreted accordingly. If in following the latter course, one feels that the instantaneous temperature is highly important, it is still possible to reconstruct the actual input temperature history, given the output temperature history and temperature pickup response characteristics. This can be accomplished by use of compensating amplifiers either directly in the

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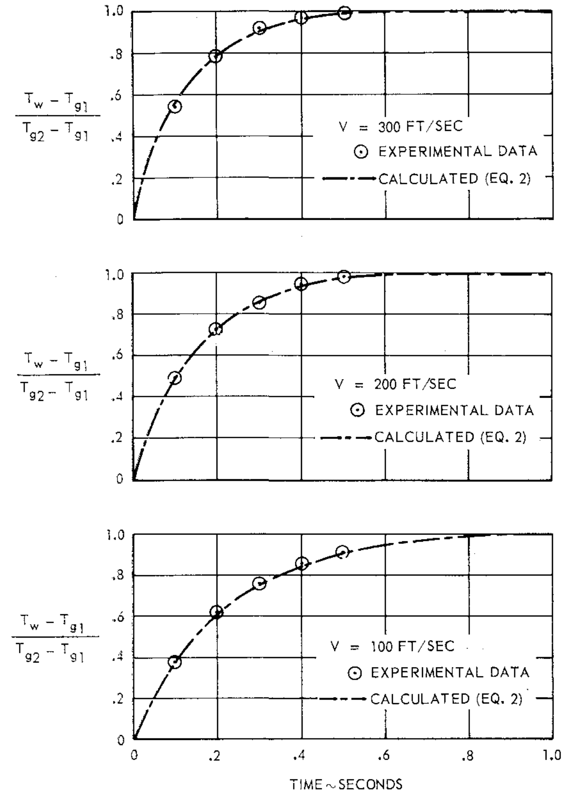

Fig. 1 Comparison of theoretical response to experimentally determined response for a step change in gas temperature from T_{g_1} to T_{g_2}.

instrumentation circuit or through various data-playback techniques.

Analysis

Consider a thermocouple wire oriented normal to an approaching airflow. Neglecting radiation and heat loss from the ends of the wire by conduction, and assuming the radial temperature gradient through the wire is negligible, the following heat balance may be written:

$$\dot{q} = hA(T_g - T_w) = wc(dT_w/dt) \quad (1)$$

where h = convection coefficient, A = wire surface area, T_g = recovery temperature of the air, T_w = wire temperature, w = weight of the wire, c = heat capacity of the wire, and t = time. For typical bare thermocouple wire sizes projected approximately $\frac{1}{8}$–$\frac{1}{4}$ in. beyond the supporting probe, and whose temperature is within a few hundred degrees of ambient temperature, the assumptions stated previously,

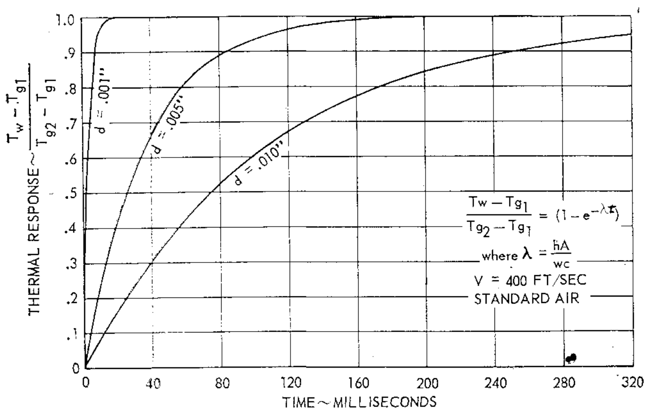

Fig. 2 Response of iron-constantan thermocouple to step change in gas temperature from T_{g_1} to T_{g_2}.

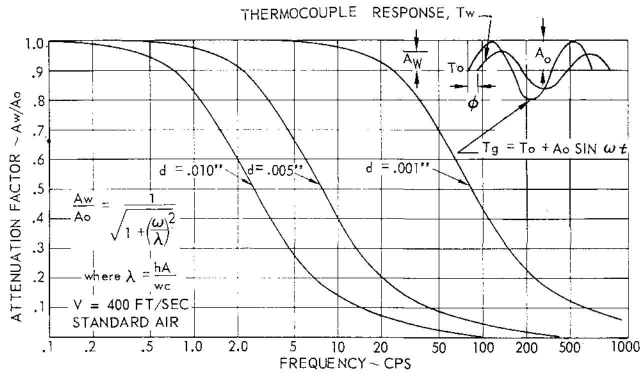

Fig. 3 Response characteristics of iron-constantan thermocouple to a sinusoidal variation of gas temperature.

namely, 1) neglecting radiation, 2) neglecting conduction heat loss from the ends of the wire, and 3) neglecting the radial thermal gradient, have been checked by numerical calculations and were found to be good engineering approximations for an analysis of the thermal response of the thermocouple junction.

Case I

Step input: consider the case for which T_w is in equilibrium with the air temperature at $t < 0 (T_w = T_{g1})$. At $t = 0$, the air temperature is suddenly changed to the value T_{g2} and remains constant for $t > 0$. The solution to Eq. (1) is then given by

$$(T_w - T_{g1})/(T_{g2} - T_{g1}) = 1 - e^{-\lambda t} \quad (2)$$

where $\lambda \equiv hA/wc$.

Case II

Sine wave input: consider the case in which the air temperature varies sinusoidally with time. That is, let T_g of Eq. (1) be given by

$$T_g = T_0 + A_0 \sin\omega t$$

For this case the particular solution to Eq. (1) may be shown to be given by

$$\frac{T_w - T_0}{A_0} = \frac{1}{[1 + (\omega/\lambda)^2]^{1/2}} \times \sin\left(\omega t + \sin^{-1}\frac{-\omega/\lambda}{[1 + (\omega/\lambda)^2]^{1/2}}\right) \quad (3)$$

The temperature attenuation factor is then given by

$$\frac{A_w}{A_0} = \frac{1}{[1 + (\omega/\lambda)^2]^{1/2}} \quad (4)$$

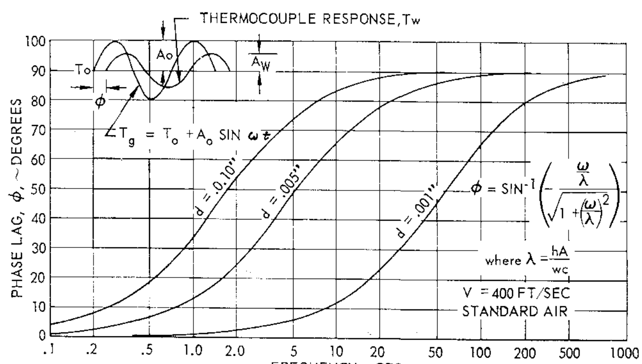

Fig. 4 Phase lag characteristics of iron-constantan thermocouple for a sinusoidal variation in gas temperature.

where $A_w \equiv (T_w - T_0)_{max}$, and the phase lag angle is

$$\varphi = \sin^{-1} \frac{-\omega/\lambda}{[1 + (\omega/\lambda)^2]^{1/2}} \tag{5}$$

For the purpose of evaluating λ in Eqs. (2–5), the convection coefficient h may be determined from experimental data of Ref. 1, which gives the Nusselt number as a function of the Reynolds number for flow across wires. For the iron-constantan thermocouple response results presented in Figs. 1–4, values of $\rho = 486$ lb/ft^3 and $c = 0.12$ Btu/lb°F were used. It is seen from Eq. (2) that the thermocouple time constant is simply the inverse of λ.

Results

The results of the analysis were compared to experimental data obtained for the response of a 30-gage ($d = 0.010$-in. diameter) iron-constantan thermocouple subjected to a step change in air temperature. The step change in air temperature was achieved by thrusting the thermocouple, which was initially in thermal equilibrium with the ambient environment, into a uniform stream of hot gas at 230°F issuing from a 4- × 4-in.^{2} duct. The output of the thermocouple was monitored on an oscilloscope and the thermal response was documented with an oscilloscope camera. Data were obtained for hot air flow velocities of $V = 100$, 200, and 300 fps.

Figure 1 shows the comparison of the theoretical calculations with the experimental data for a step change in air temperature from T_{g_1} to T_{g_2} at $t = 0$. The dash curve is the theoretical calculation given by Eq. (2) with the numerical value of λ calculated as described previously for the actual conditions of the experiment. The experimental data are represented by the symbols, each of which is an average of duplicate data which were within 2% of each other for all data points measured. Although continuous traces of the experimental data were obtained, the agreement between the experimental data and the theoretical calculations is too close to allow definition of two discrete curves. As a result, points were measured from the continuous trace experimental data at 100-msec time intervals for the comparison shown in Fig. 1.

The near perfect agreement of the calculated curves and the experimental data must be considered somewhat fortuitous. In reviewing the various inputs to the analysis in detail, one may have expected disagreement between the analysis and the experimental data in the neighborhood of 10–20% if the anticipated differences between the analysis and the experiment had accumulated in a more unfavorable way. Even with an unfavorable accumulation of differences, however, the analysis must be considered as a good indication of the actual thermocouple response.

Figures 2–4 show some numerical results of the analysis which are of particular interest for the response of thermocouples within the inlet to a jet engine. The results given are for iron-constantan thermocouples of various wire gage sizes oriented normal to an airstream with a velocity of 400 fps at standard pressure and temperature. The curves are also considered indicative of the response for other wire orientations and indicative of the response for chromel-alumel thermocouples since the response depends only upon the value of λ, which for chromel-alumel thermocouples is within a few percent of the value for iron-constantan thermocouples for the same wire size and flow conditions. The data of Fig. 2, which give the response to a step change in air temperature, indicate a time constant of approximately 100 msec and a 99% rise time of approximately $\frac{1}{2}$ sec for the 30-gage ($d = 0.010$-in. diameter) thermocouple wire used in recent exhaust gas ingestion tests performed by Norair and others.

Figures 3 and 4 show, respectively, the attenuation factor A_w/A_0 [Eq. (4)] and the phase lag angle φ [Eq. (5)] as a function of frequency for a gas temperature which varies sinusoidally with time. From Fig. 3, it is seen that flat response for the 30-gage (0.010-in. wire) is limited to frequencies of less than a few tenths of a cycle/second while at 15 cps the input signal is attenuated 90%.

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Aerospace Ground Equipment Reduction by Built-In Testing

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Background and Problems

THE cost of avionics and aerospace ground equipment (AGE) for a modern military aircraft is becoming a greater percentage of the total program cost with each passing year. This is not just the original cost of the avionics and the AGE to provide the necesssary support. It is also the ownership costs, which include maintenance, spare parts, facilities, and the training of personnel to keep the aircraft on flight status.

The military normally uses AGE at three levels of maintenance: organizational (flight line), intermediate (field shop), and depot. This also represents the order of urgency for rapid turnaround of equipment to maintain a mission-ready aircraft.

In addition to the problems of space and the training of personnel, there are the problems of time and equipment. The AGE that checks a complicated avionics system must provide an accuracy and reliability that inspires confidence with the human interface. The complexity of avionics subsystems is also increasing, which has a direct effect on AGE. This complex equipment requires months of training for the technician to reach the required skill level to perform the necessary maintenance. With the more complicated systems, this means less time of the technician's enlistment is spent in the actual work for which he was trained. The reenlistment rate of these highly trained technicians is also somewhat less than desired, since the knowledge gained in this training is just what industry is looking for. Providing increased space for these men and their equipment is also of concern to the military. This is especially true on aircraft carriers, where AGE quantities, if not restricted or replaced by other functions, can cause a reduction in the quantities of aircraft that could be carried otherwise.

Present testing techniques, if continued without improvement, could completely overwhelm operations at the organizational maintenance level. Even if the properly trained technicians were available, they could be required to wait their "turn" to get the aircraft. A means must be provided to reduce or eliminate organizational and intermediate level AGE and the associated long-term technician training programs.

Approach

Microminiaturization techniques applied to advanced avionics systems now make it more feasible to employ built-in self-test and fault-isolation circuits commonly known as BIT.

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