Table 3 Hydrazine material compatibility test results (decomposition rates at 275°F, 64-hr heat cycles)[a]

Capsule no.[b]	Heat cycle no.	Percent ullage at 275°F	Pressure rise rate, psi/hr	Gas evolution rate, scc/hr	Gas evolution rate/unit wetted area, scc/hr-in.^{2}
1	1	8.4	5.75	3.42	...
	2	46.5	0.64	2.72	...
	3	46.5	0.91	3.86	...
	4	46.5	1.21	5.15	...
	5	46.5	1.00	4.26	...
	6	46.5	1.11	4.72	...
2	1	...	...	...	...
	2	16.3	0.83	0.86	0.016
	3	16.3	0.56	0.58	0.011
	4	16.3	0.53	0.55	0.010
	5	16.3	0.44	0.45	0.009
	6	16.3	0.41	0.42	0.008
3	1	6.32	0.83	0.33	0.009
	2	12.4	0.33	0.26	0.008
	3	12.4	0.25	0.20	0.006
	4	12.4	0.23	0.18	0.005
	5, 6	12.4	0.20	0.16	0.005
4	1	...	...	...	...
	2	16.8	3.0[c]	3.1[c]	0.097[c]
			1.5[d]	1.55[d]	0.049[d]
5	1	11.4	4.7	3.27	0.095
6	1	11.57	1.80	1.31	0.038
	2	17.75	1.56	1.75	0.056
	3	17.75	1.65	1.85	0.059

[a] Density of hydrazine at 275°F = 0.898 g/mliter.
[b] Refer to Table 2 for capsule contents.
[c] Average rate for first 27 hr.
[d] Average rate for final 37 hr.

of the C package was not determined and, as such, a gas evolution rate per unit wetted area was not evaluated.

All aluminum samples showed evidence of corrosion; a white, powdery film was deposited on both the 1100 and 6061-T6 aluminum specimens. The 6061-T6 aluminum specimens were also slightly pitted. Hydrazine samples taken from both aluminum capsules following tests contained small quantities of white, gelatinous precipitate. The 321 stainless steel and the C package were unaffected. However, small black specks were noted in the hydrazine sample taken from the 321 stainless-steel capsule. Of particular interest was the 20% glass-filled FEP Teflon seat seal in the C package manual fill valve, which had been tested in the full-closed position. Although this seal extruded slightly into the small surrounding clearances, it retained its resistance to compression. The TFE Teflon O-rings employed in each capsule were unaffected. Both the A-70 titanium bellows sample and the 6A1-4V tensile specimens, exposed for the full test duration, were unaffected. Compared with control samples, tensile properties of the test specimens displayed very slight deviation (Table 4), and weight changes were negligible.

Conclusions

The general conclusions of this study are:

1) Shell 405 catalyst is poisoned by exposure to the ethyl-

Table 4 Tensile test results, control/test

Specimen[a]	Average yield strength, ksi	Average ultimate strength, psi	Average percent elongation
6Al-4V Ti	148/144	160/158	4.33/5.0
321 stainless steel	41.2/41.7	94.7/95.2	56.6/53.7
1100 Al	6.5/6.2	13.5/13.3	22.7/23.0
6061-T6 Al	40.9/41.4	46.9/47.7	12.0/10.7

[a] Three control and three test specimens for each material.

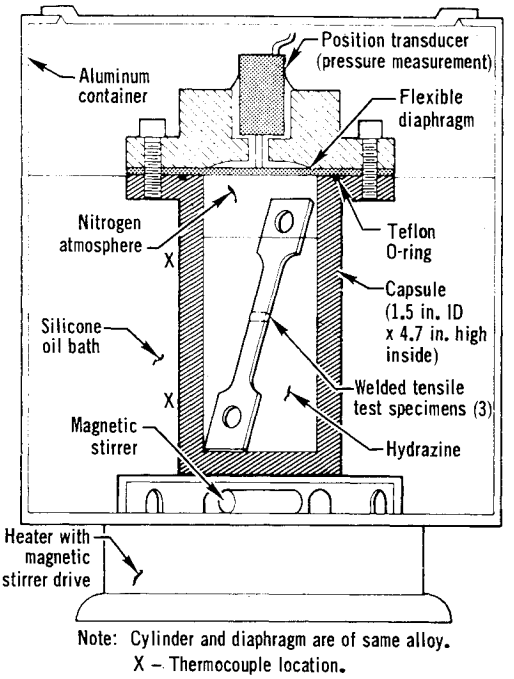

Fig. 4 Hydrazine material compatibility test setup.

ene oxide, Freon 12 chemical-decontamination agent. This catalyst should be sealed from the environment during decontamination, or additional tests should be conducted to determine whether catalyst activity can be restored following high-vacuum and ambient storage.

2) Titanium is the best known tank material for heat sterilization of hydrazine propellant.

3) Additional testing is required for nonmetallic materials, with particular emphasis on Teflon. FEP Teflon with 20% glass filler was durable under the hydrazine sterilization environment, and TFE Teflon O-ring seals used in the test vessels performed satisfactorily.

4) Irregular shapes and rough surface finishes require additional investigation to determine their effect on hydrazine-decomposition rate.

References

[1] "Environmental Specification," Doc. VOL-50503-ETS, Jan. 1967, Jet Propulsion Lab., Pasadena, Calif.

[2] "Status Report—1967: Monopropellant Hydrazine Rocket Technology," Rept. RRC-67-R-88, 1967, Rocket Research Corp.

Experimental Evidence of Thermal Resistance at Soldered Joints

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Introduction

In order to make a rational correlation of heat-transfer data for a system consisting of different metals soldered together, it is necessary to have some idea of the magnitude of the thermal resistance presented by soldered joints. A

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survey of some of the leading heat-transfer texts[1-3] leads one to suspect that a soldered joint presents negligible resistance and, therefore, can be ignored in all calculations of the overall thermal resistance. This Note reports the results of an experimental investigation on the thermal resistance of soldered joints.

Description of Thermal System and Its Operation

The thermal system studied consisted of two right-circular brass cylinders (36 mm diam × 40 mm long) soldered with pure tin to form a rigid cylinder 80 mm long, Fig. 1. Each cylinder was lapped and polished to produce nominally flat surfaces having a surface roughness of 0.3 μ. Each cylinder had four holes drilled to the centerline with spacings shown in Fig. 1. After soldering, the rigid cylinder was placed in a rig[4] similar to ones used by most investigators of contact resistance. One end of the rigid cylinder was heated with a steady flow of hot water while the other end was cooled with a steady flow of cold water. After the steady-state heat flow along the cylinder had been established, readings from the thermocouples placed in the drilled holes were taken and plotted against their position. These temperature readings were extrapolated to determine the pseudotemperature drop at the joint. This was taken to be the temperature drop necessary to overcome the joint resistance which was defined as

$$R_j = \Delta T_j/(Q/A) \qquad (1)$$

where Q is steady heat flow along the length of the cylinder as determined by the thermocouple readings, their spacing, and the thermal conductivity of the cylinders, and A is the nominal area of the joint.

The lateral surfaces of the cylinders were well insulated so that little or no heat escaped the thermal system. The cylinders were placed under a mechanical load (10–100 kg/cm²) to see whether there would be any contact pressure effect. All the derived test results are shown in Fig. 2, where the resistance is plotted against the nominal pressure.

Description of Surfaces and Method of Soldering

E1(P): Both surfaces were lapped and polished to 0.3 μ roughness. Both were heated to just slightly above the melting temperature of pure tin and lightly brushed with a solution of zinc chloride. Pure tin was liberally applied to each to form a thin liquid layer and, while still liquid, the two surfaces were brought into contact and rubbed together. While held together with a nominal pressure of 0.5 kg/cm², the cylinders were allowed to cool to ambient temperature. Surfaces E3(P), E5(P) were prepared and soldered exactly as surfaces E1(P).

E2(P/1): These two surfaces were lapped as previously noted. One surface was polished to a roughness of 0.3 μ while the other was turned on a lathe such that the depth of cut was 0.05 mm and the advance of the tool was 0.50 mm. The turning produced a spiral pattern on the surface. These surfaces were soldered exactly in the manner previously described.

E4(P): These two surfaces were prepared exactly as surfaces E1(P). Here the zinc chloride solution was omitted prior to the application of the pure tin.

E6(P): These surfaces were prepared exactly as surfaces E1(P). They were heated to about the melting temperature

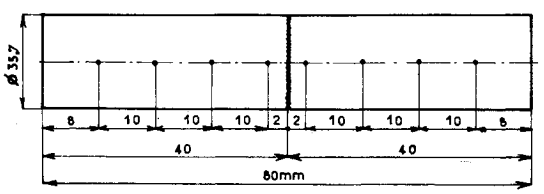

Fig. 1 Sketch of thermal system.

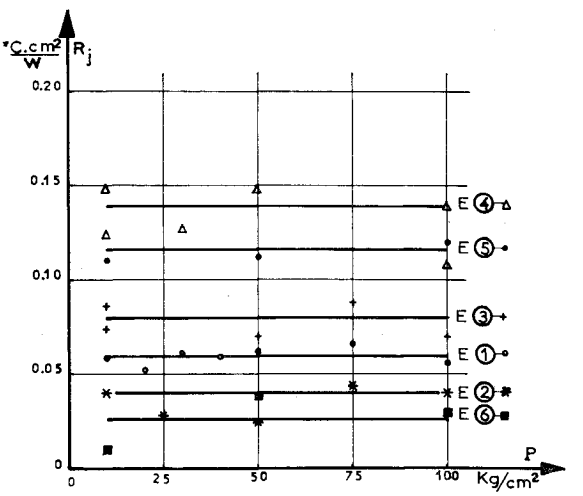

Fig. 2 Joint resistance vs nominal joint pressure.

of tin, brushed lightly with the zinc chloride solution, and applied liberally with tin. This time the two pieces were allowed to cool and it was observed that a crust formed on the tin. When completely cool, the surfaces were turned on a lathe to remove the crust, leaving a thin layer of pure tin on each surface. They were placed in contact (tin against tin) under a nominal pressure of 70 kg/cm² and heated to the melting temperature of tin. When it was apparent that fusion was complete, the pieces were allowed to cool to ambient.

Observations of Solder Joints after Test

Each joint tested was cut into small sectors and prepared for viewing under a microscope. Microphotographs, both black and white and color, were also taken to have a permanent record of the observations made by eye. The observations differed according to the manner of soldering the joints.

E1(P): A discontinuous layer of oxide was found in the midplane of the soldered joint. This consisted of long, flat regions and appeared to occupy 15% of the apparent area. The interfaces between the tin and the solid cylinders appeared to be very good. Very tiny cavities could also be observed throughout the tin, but their volume relative to the oxide volume was negligible.

E2(P/1), E3(P), and E5(P): These joints were very similar to the E1(P) soldered joint.

E4(P): This joint had no oxide layer, but had a very large number of cavities dispersed throughout the tin. These cavities varied in size (many small ones but few large ones) and shape (but mostly spheroidal). They also appeared to be bunched together. The volume of these cavities cannot be estimated but they seem to range in size from 0.20 to 2.0 μ.

For all the joints tested and examined it appears that the average thickness of solder is about 15 μ, which would theoretically present a resistance of 0.00246°C cm²/w.

Conclusions

The experimentally determined joint resistance is from 10 to 100 times greater than the theoretical value. The resistance seems to be independent of the nominal pressure on the joint. The method of soldering has a great deal to do with the magnitude of the resistance—careful preparation produces a good joint (low resistance), whereas average care produces a bad joint (high resistance); compare E2(P/1) and E6(P) with E4(P). The presence of an oxide in the solder has less influence than the presence of cavities upon the resistance.

We can conclude that a substantial resistance exists at a soldered joint which is orders of magnitude larger than theory would predict, and it depends greatly on the method of soldering. For certain thermal systems this resistance should not be neglected.

References

[1] Grober, H., Erk, S., and Grigull, U., *Fundamentals of Heat Transfer*, 3rd ed., McGraw-Hill, New York, 1961, p. 134.

[2] Jacob, M., *Heat Transfer*, 7th ed., Vol. 1, Wiley, New York, 1959, pp. 164–165.

[3] Carslaw, H. S. and Jaeger, J. C., *Conduction of Heat in Solids*, 2nd ed., Clarendon Press, Oxford, 1959, p. 23.

[4] Yovanovich, M. M., "Thermal Contact Conductance in a Vacuum," Rept 4542-39, Nov. 1965, Engineering Projects Lab., Massachusetts Institute of Technology, Cambridge, Mass.

Condensation and Probe Interference Effects on Planar Expansion-Deflection Nozzle Experiments

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Nomenclature

A = area
H = plug height
M = Mach number
P = pressure
T = temperature
X = distance measured from plug base, in.
Y = distance measured from nozzle centerline, in.

Subscripts

a = ambient conditions
b, c = plug base and shroud contour, respectively
cl = nozzle centerline
d = dew point
e, t = nozzle exit and nozzle throat, respectively
$0y$ = condition at the inlet of the total pressure probe
01 = stagnation conditions
sw = conditions at centerline sidewall

Introduction

RECENT interest in altitude-compensating or plug-type nozzles has focused attention on the design of test facilities to properly evaluate these systems. A problem frequently encountered in cold flow nozzle tests is the effect of the location and amount of water vapor condensation on the flowfield[1–8] and, therefore, its influence on thrust and pressure measurements. The nonuniform wakelike character of these plug nozzle flowfields raises the important question of the influence of probes on the measured performance of such a system.

This investigation[9] concerns the effect of water vapor condensation on the plug base pressure, nozzle centerline static pressure distribution and total pressure profiles perpendicular to the nozzle centerline downstream of the wake neck for a planar expansion-deflection (E-D) nozzle, and the nature and magnitude of disturbance feedback caused by a rake probe. Figure 1 shows the "closed" wake configuration which represents the design operating condition and is the flowfield used in the present investigation. (The separated flow region and the basic test setup are described in Ref. 10.) An indraft supersonic wind tunnel consisting of a contraction section (area ratio 200:1 to nozzle throat), a planar E-D nozzle test section ($A_e/A_t = 1.965$ and $A_c/A_t = 1.150$), and a diffuser leading to two 3130 ft³/min continuous vacuum pumps were used. The nozzle section was 5 in. wide, and the geometric throat height on each side of the plug was 0.92 in. The nozzle and plug were instrumented with 73 static pressure taps.

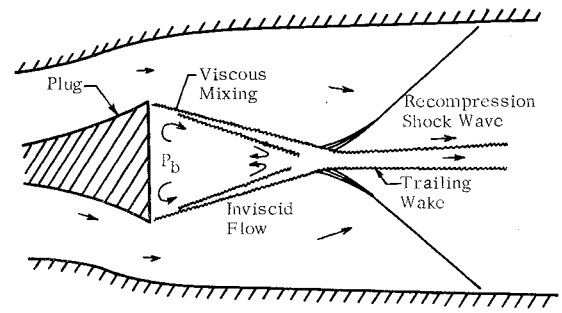
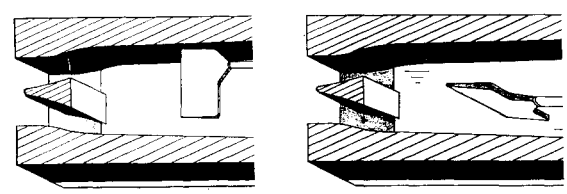


Fig. 1 Essential features of the flow behind the two-dimensional plug in the planar E-D nozzle.

Special provisions were made in the plug base for a small, variable-length, total-pressure probe in order to determine the centerline total pressure in the reversed flow region of the near wake. This probe was made from a single piece of 0.05-in. hyperdermic tubing. An adjustable rake probe was designed and constructed to measure total pressure profiles in the trailing wake. It was also used in the disturbance feedback experiments. This probe was fabricated by epoxying together 54 hypotubes of 0.05-in. diam. Of the 54 tubes, 23 were for total pressure measurement. The blockage area (0.5 in. by 2.75 in.) was 11% of the throat area and 6% of the exit area. To avoid excessive vibration, the probe was designed with the sting off-center so that the probe extended through the wake while in contact with the top of the nozzle test section (Fig. 2a). An aluminum wedge of the same dimensions was designed to check disturbance feedback from the wake to the plug base (Fig. 2b). Pressures were measured from mercury manometers read to the nearest 0.05 in. The wet and dry bulb temperatures were measured with a standard sling psychrometer. The base pressure was obtained from a mercury micrometer read to the nearest 0.0005 in.

Discussion of Results

Previous investigators,[4,5] working with nozzles of similar size and Mach number as the present facility, have shown that a supercooling of 120°F is necessary for condensation. It can be shown that, in an isotropic expansion to Mach 2, the supercooling limit would be exceeded under all operating conditions ($T_{01} \approx 70$°F, $p_{01} = 1$ atm, minimum $T_d > -5$°F, maximum $M = 2$) in the present facility. This conclusion is verified by other investigators.[5,7]



a) Rake probe vertical **b) Replica probe horizontal**

Fig. 2 Sketch of rake and replica probe orientation in nozzle section.

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