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SMALL-SCALE FIRE TESTS OF HIGH-TEMPERATURE CABIN PRESSURE SEALANT AND INSULATING MATERIALS

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16. Abstract
A 2-foot-square stainless-steel panel was constructed with the same dimensions between the fuselage skin and cabin wall as those of a titanium fuselage previously exposed to an external fuel fire. The panel was subjected to a 2-gallon-per-hour kerosene burner which simulated the heat flux and temperature from a large JP-4 fuel fire, as existed during the titanium fuselage test. The purpose of the panel tests was to determine if the phenomena observed during the titanium fuselage test could be duplicated on a small scale, and also to test various sealant/insulation combinations superior to those used in the titanium fuselage in order to ascertain the degree of improvement in environmental conditions which would result. Testing of the panel utilizing the same materials found in the titanium fuselage caused phenomena and temperature distribution very similar to those observed during the full-scale test, thus giving credence to this test method as being representative of what would occur to a titanium or stainless-steel aircraft during a post-crash fire. The titanium fuselage insulation tested without any cabin pressure sealant caused a flash-fire. However, two commercially available high-temperature insulations also tested without any sealant maintained survivable conditions for at least 15 minutes. Viton,* a hydrofluorocarbon elastomer, was found not to flame or cause a flash-fire under conditions which silicone did (the titanium fuselage had a silicone cabin pressure sealant). The propensity of the formation of a flash-fire was strongly influenced by the compactness of the insulation and the presence of any voids or passageways betweeen the fuselage skin and cabin wall interface.

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PREFACE

The series of tests described herein was motivated by the results of a full-scale test (Reference 1) consisting of exposing a titanium fuselage to an external fuel fire. The titanium fuselage, as expected, remained intact and prevented fuel-flame penetration; however, the silicone cabin pressure sealant and silicone-bonded insulation auto-ignited and burned, causing early cabin heating, significant smoke and toxic gases, and a flash-fire.

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Purpose

The purpose of this phase of the project was (1) to determine if the phenomena observed during the full-scale fire test of a titanium fuselage could be duplicated on a small scale using a 2-foot-square panel of similar construction; and (2) to ascertain the degree of improvement in environmental conditions that would result from various sealant/insulation combinations for use in titanium fuselage construction.

Background

In April 1970, a full-scale fire test was performed at the National Aviation Facilities Experimental Center (NAFEC), which consisted of exposing a 28-foot titanium fuselage to an adjacent 20-foot-square JP-4 fire located on one side of the fuselage (Reference 1). The purpose of this test was to verify the added protection, compared to an aluminum-constructed aircraft, which would be provided by the nonmelting titanium skin. Theoretical calculations based on heat transfer considerations alone predicted a mere 40°F cabin temperature increase after a 5-minute exposure to a severe external fuel fire. However, these calculations neglected the burning of combustible gases produced by heating of materials immediately adjacent to the hot titanium skin; viz., the cabin pressure sealant and insulation.

The test results were quite unexpected. Conditions within the cabin remained virtually unchanged for only about 1 minute after ignition, at which time there occurred significant increases in smoke, temperature, carbon monoxide, carbon dioxide and decreases in oxygen. A flash-fire occurred at 1 minute 55 seconds after ignition. Extinguishment of the fuel fire was ordered at about 2 1/2 minutes after ignition. As expected, the titanium skin and structure withstood the fuel fire and prevented any flame penetration directly into the cabin for the duration of the test. However, examination of the test article clearly showed that the sealant and insulation were responsible for the premature attainment of fatal conditions within the cabin. A white powder-like residue, characteristic of silicone thermal decomposition, was prevalent throughout the cabin and adjacent to the seams on the surface of the outer titanium skin. Also, burn marks were observed on the interior panels adjacent to the panel interfaces. These observations provided evidence for the following explanation as to the cause of the early appearance of combustible gases and cabin heating, and the resulting flash-fire.

Combustible gases were produced by the thermal decomposition of the silicone sealant. The sealant applied to faying surfaces produced gases which escaped outward through the fuselage seams and were ignited by the fuel flames; thus, the white residue along the seams. Pyrolysis of sealant applied to filleting and doubler sections, however, produced gases which filtered inward through the insulation and panel interfaces into the cabin. At the same time, self-ignition of these gases in the space between the titanium skin and cabin wall eventually resulted in localized flaming from the panel interfaces into the cabin environment, where the air necessary for combustion was available. This flaming caused the observed burn marks along the panel interfaces.

Removal of the panels confirmed the preceding explanation, but also indicated that the insulation was partially responsible for the flaming. The sealant was completely disintegrated from the surfaces that experienced the most severe heating during the test. However, the insulation was burned, sometimes completely, in these same areas. The relative contribution of sealant and insulation could not be determined, mainly because the original quantity of sealant was unknown. Thus, it was decided to perform small-scale tests which might shed some light on the relative contribution of sealant and insulation, and allow for the testing of new sealant/insulation combinations which, ideally, would not produce hazardous gases when heated.

DISCUSSION

Test Procedure

The test article was designed to simulate the cross section of the titanium fuselage used in the full-scale test (Figure 1). Important dimensions such as the skin and cabin wall thickness, stringer depth and separation, and distance from the fuselage skin to the cabin wall were duplicated. However, it was decided to use a stainless-steel fuselage skin since, when compared with titanium, this metal can be worked more easily. Moreover, it was expected that the temperature of the two metals during heating would not vary

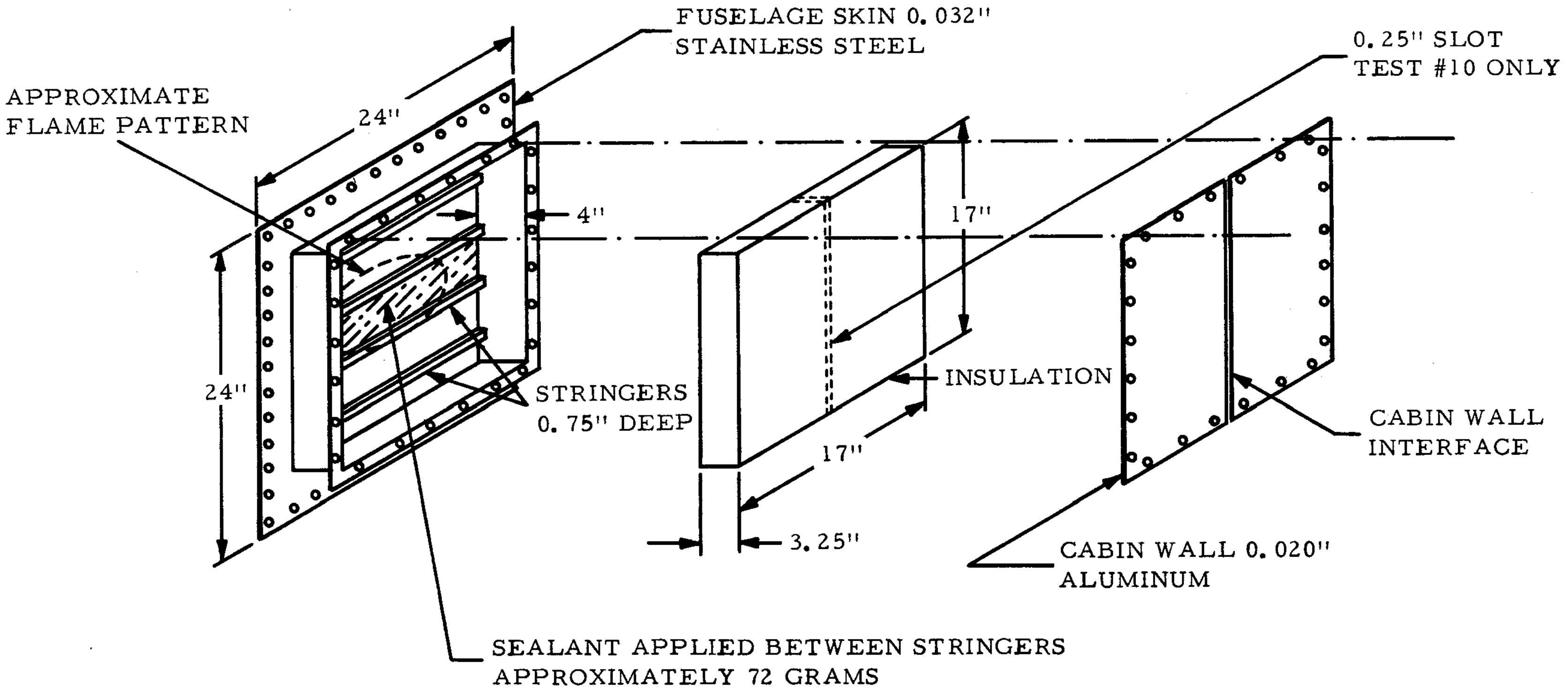

FIGURE 1 - TEST ARTICLE SIMULATING TITANIUM FUSELAGE CROSS SECTION

significantly, and, similarly to titanium, the stainless steel would not melt. The aluminum cabin wall (no decorative material was used) had a vertical slit about 1/4-inch wide, which was meant to simulate the interface between two interior panels. This feature was felt to be important in view of the burn marks discovered around the interior panel interfaces of the titanium fuselage. Since the combustible gases produced by heating of the sealant and insulation would egress from the interface, it was expected that flaming might be observed here. The sealant was applied to the fuselage skin area between two adjacent stringers and was meant to duplicate the extensive amount of sealant applied to doubler sections on the titanium fuselage.

The test setup is shown in Figure 2. The test article was bolted to the open end of a 16-cubic-foot closed rectangular housing. A glass window at the rear of the housing allowed for observation of the cabin wall and interface (until obscuration resulted from the accumulation of smoke). An outlet for the pressure buildup, which accompanies a flash-fire, was provided by a blowout panel at the top of the housing. The environment of a JP-4 fuel fire was simulated by the funneled flames from a 2-gallon-per-hour kerosene burner. The flame pattern upon the fuselage skin approximated a 6- by 11-inch ellipse with a total heat flux of 16.3 Btu per square foot-second (Reference 2).

Instrumentation was provided for the measurement of temperature, smoke, oxygen, and combustible gases. The measurement locations are shown in Figure 2. The flame and fuselage skin temperatures were measured with 22 AWG chromel-alumel thermocouples, while the remaining temperatures were measured with 30 AWG chromel-alumel thermocouples. An indication of the smoke density within the housing was provided by a smoke meter utilizing a photocell/light-source arrangement which measured the percentage of light transmission across a distance of 1 foot. The oxygen and combustible gases concentrations were continuously measured by a single gas analyzer which employed the paramagnetic and catalytic combustion techniques, respectively.

Each material was also tested in the Setchkin Apparatus (ASTM test method D 1929-62T) used for determining the flash-ignition and self-ignition temperatures of a solid. This apparatus was recently modified at NAFEC with a force transducer, thus giving it the capability of also continuously measuring the weight of the specimen during the test. The

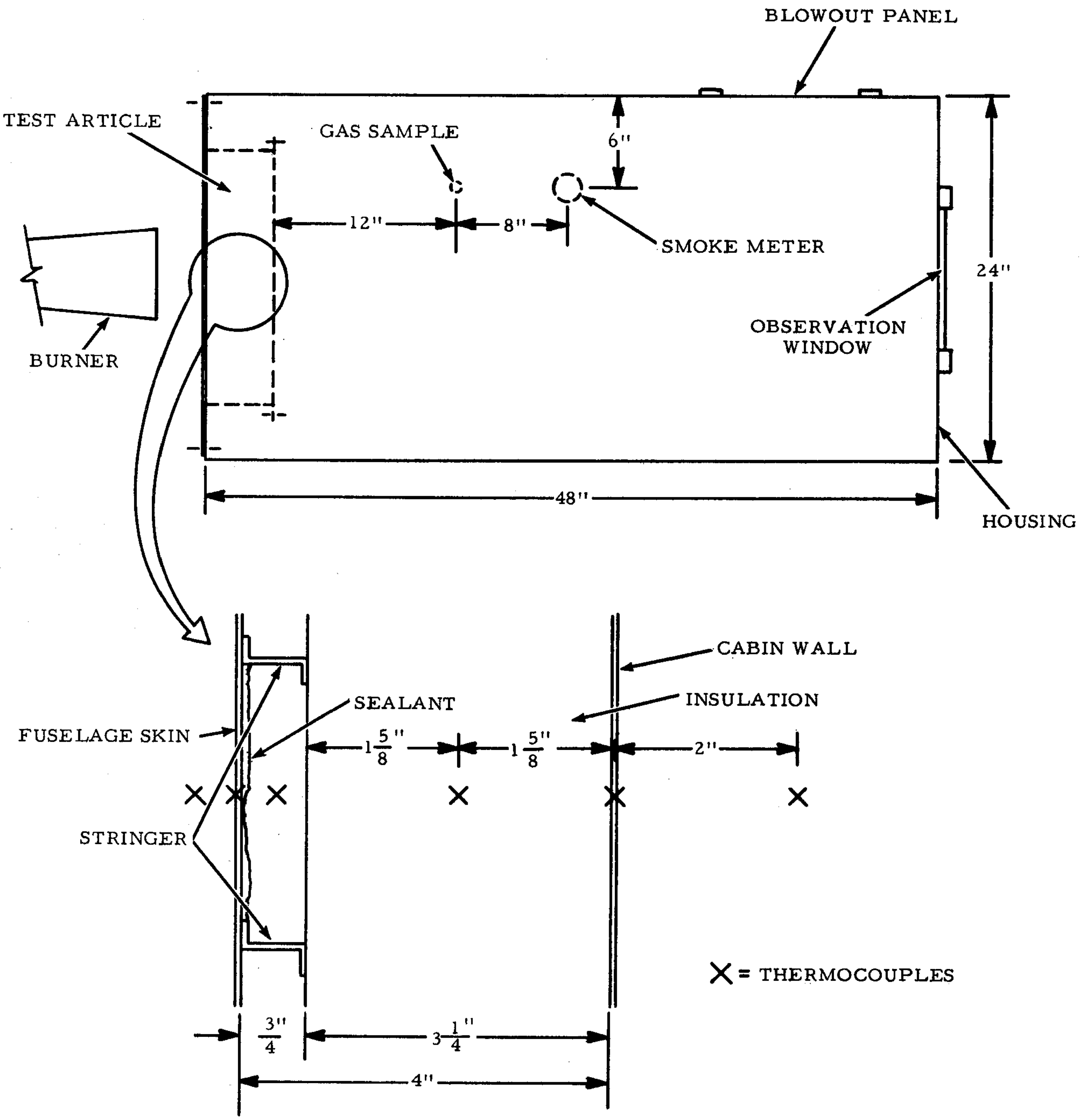

FIGURE 2 - LOCATION OF INSTRUMENTATION

rate at which a material decomposes will be largely dependent upon the ambient temperature increase and oxygen concentration. Unless otherwise stated, an ambient temperature increase of 18°F per minute and an airflow rate of 6.5 cubic feet per hour was used. All specimens weighed about 3 grams and were conditioned at a relative humidity of 50 percent and a temperature of 70°F for at least 24 hours.

Test Results

Modified Setchkin Apparatus: The results of these tests are shown in Table 1. Although the maximum test temperature did not nearly approach what the fuselage skin would attain during a fuel fire (maximum about 1800°F), a comparison of the test results gave some indication of the relative and potential fire and smoke hazards from each material. The room temperature vulcanizing (RTV) silicone was the most reactive of the materials tested, self-igniting at 940°F and losing 74 percent of its weight by 1100°F. All three Viton compounds failed to flame during heating, but did experience considerable weight loss which, at the lower temperatures, was even higher than that of the silicone. The greatest hazard from the pyrolysis of Viton is the resulting toxic gases, especially hydrogen fluoride (HF) which was expected to be the dominant gas (Reference 3). With silicone, the greatest hazard is the combustibility of the pyrolysis gases. Viton C-328 did not produce any smoke, Viton 238-99-1 produced only a small amount between 720° and 750°F, and Viton 238-97-1 produced a large amount of smoke at 780°F. Silicone, on the other hand, produced large quantities of smoke from 590° to 1050°F. The Microlite "AA" fiber glass insulation was surprisingly flammable because of its silicone binder. Constant temperature tests indicated self-ignition at 1140°F and self-heating, with accompanying loss of insulating properties, beginning at 980°F. The Dyna-Flex and Micro-Quartz insulations lost only 2.2 and 6.4 percent of their weights, respectively, by 1200°F, both without any changes in appearance.

Test Article Simulating Titanium Fuselage Cross Section: A series of tests was run with various combinations of the sealants and insulations discussed above. The different combinations are listed in Table 2 along with the important test results. The following is a more detailed analysis and interpretation of some of the test results:

The first test utilized the same sealant (RTV 106) and insulation (Microlite "AA") used in the titanium fuselage. The purpose of this test was to determine if the phenomena

TABLE 1. - PERCENTAGE WEIGHT LOSS OF MATERIALS DETERMINED BY MODIFIED SETCHKIN APPARATUS

Material	Weight Loss Percent			Maximum Test Temperature (°F)	Remarks
	600°F	800°F	1100°F		
RTV 106[1]	0.6	6.8	73.9	1100	Flames from 940° to 1040°F. Smoke from 590° to 1050°F. Weight loss constant from 1050° to 1100°F.
Viton C-328[2]	22.2	45.1	64.9	1100	No flames or smoke for test duration. Cracking sounds at 400°F.
Viton 238-99-1[3]	3.3	20.6	24.0	1100	Smoke from 720° to 750°F. No flames for test duration (1100°F). Rate of weight loss at 1100°F very small.
Micro-lite[4] "AA"	0.2	0.6	3.6	1300	Weight loss of 4.3 percent constant from 1250° to 1300°F. Tests at constant temperatures indicated (1) self-ignition at 1140°F and (2) self-heating begins at 980°F.
Dyna-Flex[4]	1.0	1.5	2.2	1200	Weight loss of 2.2 percent constant from 900° to 1200°F. No discoloration of material.
Viton 238-97-1[3]	3.2	60.0	65.6	1100	Rapid and severe weight loss (42 percent) at 780°F. Heavy smoke first observed during severe weight loss, but no flames were evident; no smoke thereafter. Weight loss constant from 1000° to 1100°F.
Micro-Quartz[4]	4.8	5.4	6.4	1200	No discoloration of material.

[1] Manufactured by General Electric (GE)
[2] Manufactured by the Connecticut Hard Rubber Co. (CHR)
[3] Fire retardant Viton developed by Du Pont
[4] Registered trademark of Johns-Manville

TABLE 2. SUMMARY OF TEST RESULTS WITH TEST ARTICLE SIMULATING TITANIUM FUSELAGE CROSS SECTION

Test No.	Insulation			Sealant			Test Duration (min)
	Name	Manufacturer	Description	Name	Manufacturer	Description	
1	Insulation: Microlite "AA" Enclosing Film: Kapton	Insulation: Johns-Manville Film: DuPont	Insulation: Borosilicate Glass Fibers with Silicone Binder, 1.0 lb/cu ft Density. Film: Polymide, 1/2-MIL Thick.	RTV-106	GE	Silicone Rubber, Specific Gravity = 1.07.	8.5
2	Same as Test No. 1			None			12.6
3	Dyna-Flex	Johns-Manville	Alumina-Silica-Chromia Fibers, 3.0 lb/cu ft Density.	None			25.0
4	None			Same as Test No. 1			6.0
5	Same as Test No. 1			Viton C-328 RTV	CHR	Hydrofluorocarbon Cement. Low Solids Content (35 percent). Metal Primer Required.	10.6
6	None			Viton 238-99-1	DuPont	Hydrofluorocarbon Caulking Compound with Reinforcing Fibers, Measured Solids Content of 44 percent.	10.0
7	Micro-Quartz	Johns-Manville	98.5+ Percent Pure Silica Fibers, 3.5 lb/cu ft Density	None			20.0
8	Same as Test No. 7			Viton 238-97-1	DuPont	Flexible and Elastomeric Coating. Solids Content of 32 Percent.	20.0
9	Same as Test No. 7			Same as Test No. 1			20.0
10	Same as Test No. 7 (See Remarks)			Same as Test No. 1			7.0

Time to 50% ke Obscuration Per Foot (min)	Flash-Fire		Maximum Combustible Gases		Minimum O_2		Remarks
	Time (min)	Temp. Increase (°F)	Equivalent CO %	Time (min)	Percent	Time (min)	
2.3	6.7	1350	6.3 (Full-Scale Reading)	4.5 - 6.7	17.0	6.9	Flames at interface first observed after flash-fire. Flames persisted until 10.6 minutes (after burner removal) and then appeared intermittently until 12.9 minutes. Most of insulation reduced to char-like substance. White, powder-like residue on insulation and aluminum wall.
3.1	4.2	360	No Data	-	No Data	-	Flames at interface first observed right after flash-fire and persisted until 6.5 minutes. Severity of damage to insulation similar to that in first test.
See Remarks	None	-	0.5	25.0	20.4	25.0	No significant damage to insulation except for some blackening which was greatest near the fuselage skin. Combustibles first detected at 13 minutes. Maximum smoke obscuration per foot was 21 percent at 25 minutes.
1.0	0.9 - 4.0	20 - 200	0.0	-	13.0	6.0	Flaming first observed between stainless steel and aluminum skins at 0.7 minutes. Intermittent explosions of varying severity from 0.9 to 4.0 minutes. Combustible gases burned immediately upon formation. Housing interior completely covered with white powder giving "winter wonderland" effect.
1.6	5.7	40	4.3	5.7	13.6	10.6	Large pieces of Viton found at bottom of "box." Damage to insulation fairly similar to that in Tests No. 1 and 2.
1.0	None	-	0.25	5.5 - 7.5	19.2	10.0	Viton remained attached to skin, losing about 34 grams out of initial weight of 84 grams. Moisture deposited on inside of observation window.
No Data	None	-	0.0	-	21.0 (No Reduction)	-	Smoke meter malfunctioned. No observed smoke for 15 minutes; at end of test, the cabin wall was still barely visible. Very little discoloration of insulation (much less than Test No. 3).
No Data	None	-	2.0	20.0	20.3	20.0	Smoke meter malfunctioned. Observations of smoke level similar to Test No. 7. Insulation severely discolored while filtering Viton's decomposition products.
17.8	None	-	11.2	20.0	20.0	20.0	Rapid formation of combustible gases beginning at 3 minutes; lack of flash-fire probably because of absence of ignition source. Insulation discoloration similar to Test No. 8. Observed smoke slightly greater than Tests No. 7 and 8.
1.1	None (See Remarks)	-	0.1	2.4	10.0	2.4	A 1/4-inch wide vertical slot was cut through the insulation at the cabin wall interface (See Figure 1). Ignition within gap at 0.6 minutes; large flames from interface from 0.8 to 2.4 minutes consumed most combustible gases. Insulation unaffected by flames.

exhibited during the full-scale test could be duplicated on a small scale and thus give credence to this test method as being representative of what would happen to an actual titanium aircraft exposed to an external fuel fire. Figure 3 shows the temperature profile from the first test. The temperature between the fuselage skin and insulation, or "gap" temperature, showed steep excursions apparently indicating self-ignition of the silicone sealant's pyrolysis gases. Once the oxygen was depleted within this space, additional production of combustible gases did not result in ignition, and these gases eventually diffused into and accumulated within the test housing. Shortly after 2 minutes, the mid-insulation temperature began to increase sharply. This thermocouple was then detecting the oxygen-controlled or, perhaps, anaerobic decomposition of the insulation which was completed at this depth by about 4 minutes. A violent flash-fire occurred at 6 3/4 minutes and probably coincided with the burn-through of the insulation at the cabin wall interface. The time prior to flash-fire was significantly longer than in the full-scale test where it was only 1 minute 55 seconds (this time difference will be discussed later in greater detail). Oxygen, combustible gases, and smoke data are shown in Figure 4. Noteworthy is the rapid increase in combustible gases concentration starting at 3 minutes and going off-scale (6.25 percent) at about 4.4 minutes. All the combustible gases were consumed by the flash-fire. Their high values were misleading because the gas analyzer recorded in terms of equivalent CO percent. Actually, it was suspected that the greatest percentage of the combustible gases was H_2 (vacuum pyrolysis of silicone at 800°C produced more than 90 percent concentration of H_2, see page 4-13 in Reference 4). A calibration curve supplied by the manufacturer of the gas analyzer indicated that the analyzer will read 2.8 times the actual H_2 concentration. Thus, when the analyzer read 6.25 percent, the actual combustible gases concentration was probably about 2.2 percent of H_2. Except for the elapsed time until flash-fire, many of the characteristics and surmised phenomena exhibited during the titanium fuselage test were duplicated and verified by these small-scale tests; i.e., self-ignition of the sealant's pyrolysis gases within the gap, the flash-fire itself and associated pressure buildup, early and rapid accumulation of smoke, flaming at the cabin wall interface (see remarks in Table 2), disintegration and charring of the insulation, and the appearance of abundant amounts of white residue (oxidized silicone) on the insulation and cabin wall.

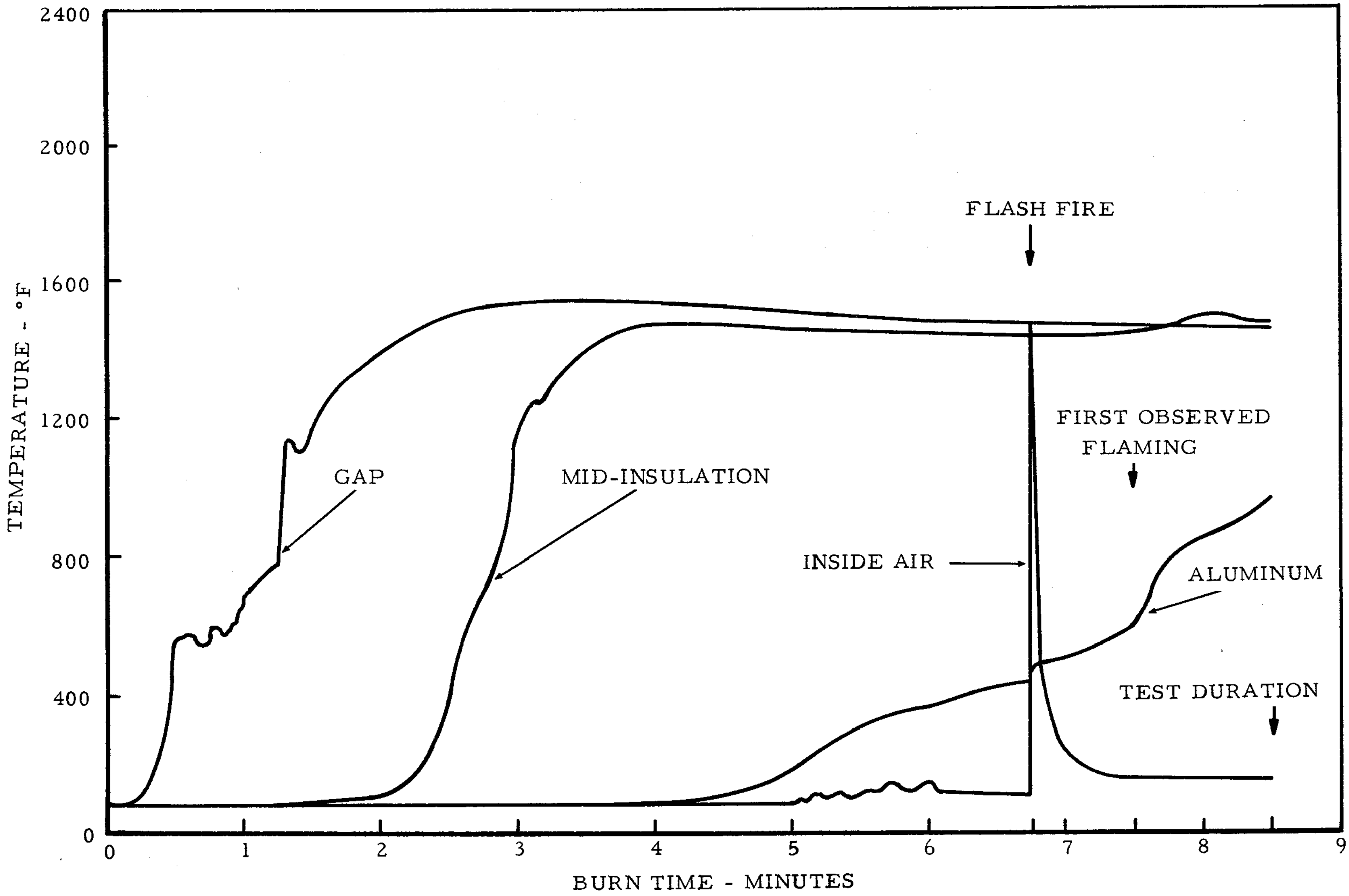

FIGURE 3 - TEMPERATURE DATA FOR TEST PANEL WITH MICROLITE INSULATION AND RTV-106 SILICONE SEALANT (TEST #1)

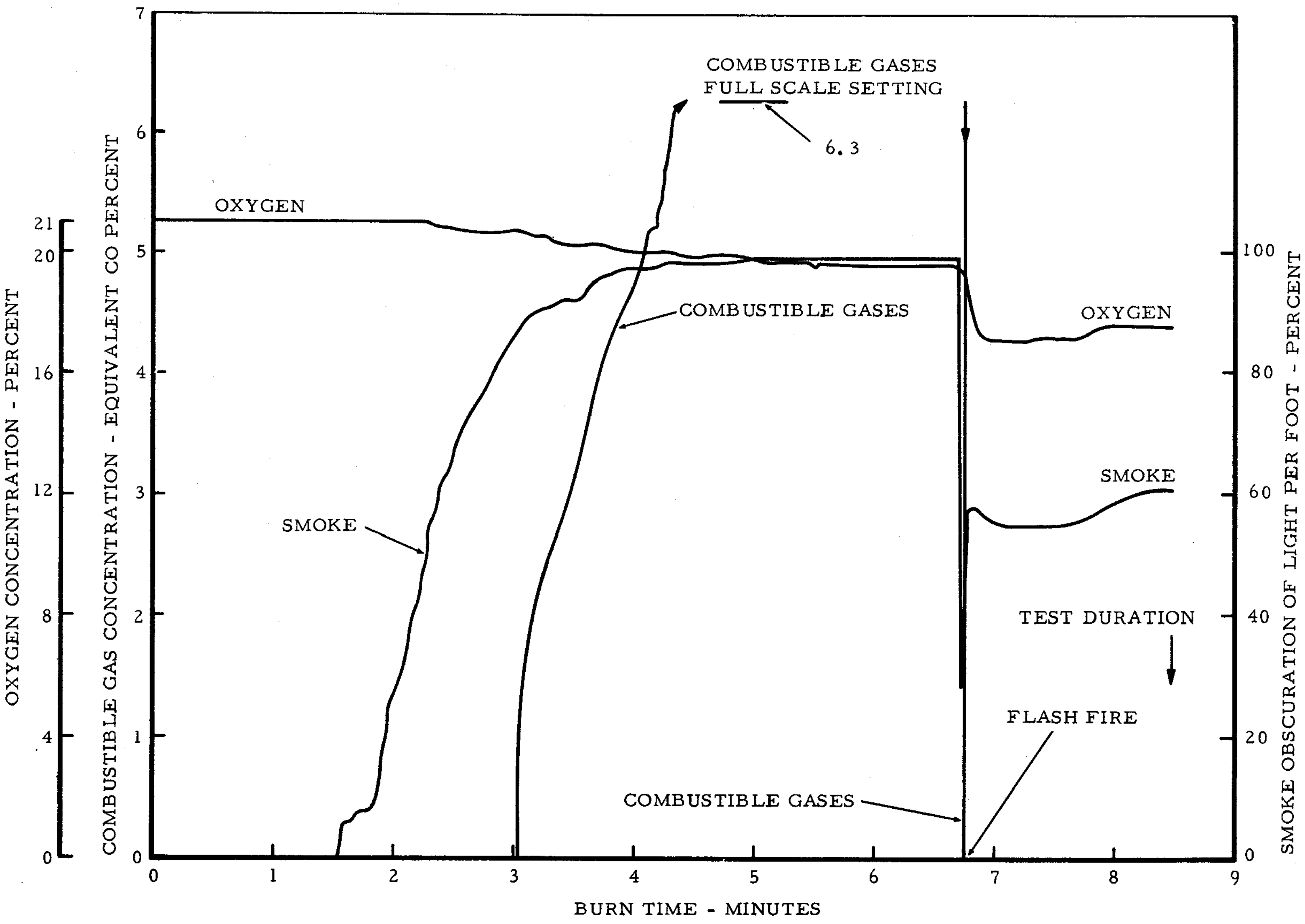

FIGURE 4 - SMOKE AND GAS DATA FOR TEST PANEL WITH MICROLITE INSULATION AND RTV-106 SILICONE SEALANT (TEST #1)

The second test also had the Microlite insulation, but without any sealant. Even the absence of a sealant did not prevent the occurrence of a flash-fire, since sufficient combustibles were formed from the decomposition of the insulation's silicone binder, only 4.3 percent of the insulation's weight, or 10.6 grams. This test best reproduced the heating of this insulation during the full-scale test. Figure 5 compares the temperature profile of Test No. 2 with that recorded by the aft section, lower group of thermocouples on the titanium fuselage (this area experienced the greatest heating of the nine instrumented sections). Compensating for the 10 to 15 seconds it took for the fire to reach maximum intensity in the full-scale test, and noting that the increments of the abscissa in Figure 5 are seconds, the agreement between the two tests is reasonable. This agreement was better for the second test than for the first, because the instrumented sections on the titanium fuselage were not adjacent to silicone-covered doubler sections. (The heating of the insulation during the first test was delayed because the sealant covered most of the flame imprint area upon the fuselage skin, Figure 1, and thus acted like an additional insulation.) Another effect of the sealant was to cause the earlier appearance of smoke (Table 2). This trend and the delayed occurrence of a flash-fire (relative to Test No. 2) were also evident in Test No. 5, which used the Microlite insulation and Viton sealant. A comparison of the gap and insulation temperatures for the three tests using Microlite is shown in Figure 6. The time prior to flash-fire correlated with the heating of the insulation and implied that the ignition source was provided once the insulation burned through at the cabin wall interface. Whether the ignition source was the flaming insulation or the radiant heat from the fuselage skin could not be determined. This interpretation of the data also appeared to be consistent with a comparison of the flash-fire intensity during each test (Table 2). The temperature increase was greatest for the test with the Microlite and silicone sealant, second with the Microlite alone, and lowest with the Microlite and Viton sealant. Assuming that the flash-fire occurred when the insulation burned through also implied that the contribution of combustible gases from the insulation's silicone binder by the time of flash-fire was probably the same for all three tests. Therefore, it was not surprising that the flash-fire from the silicone sealant and Microlite insulation was more severe than from the Microlite alone, since the potential concentration of

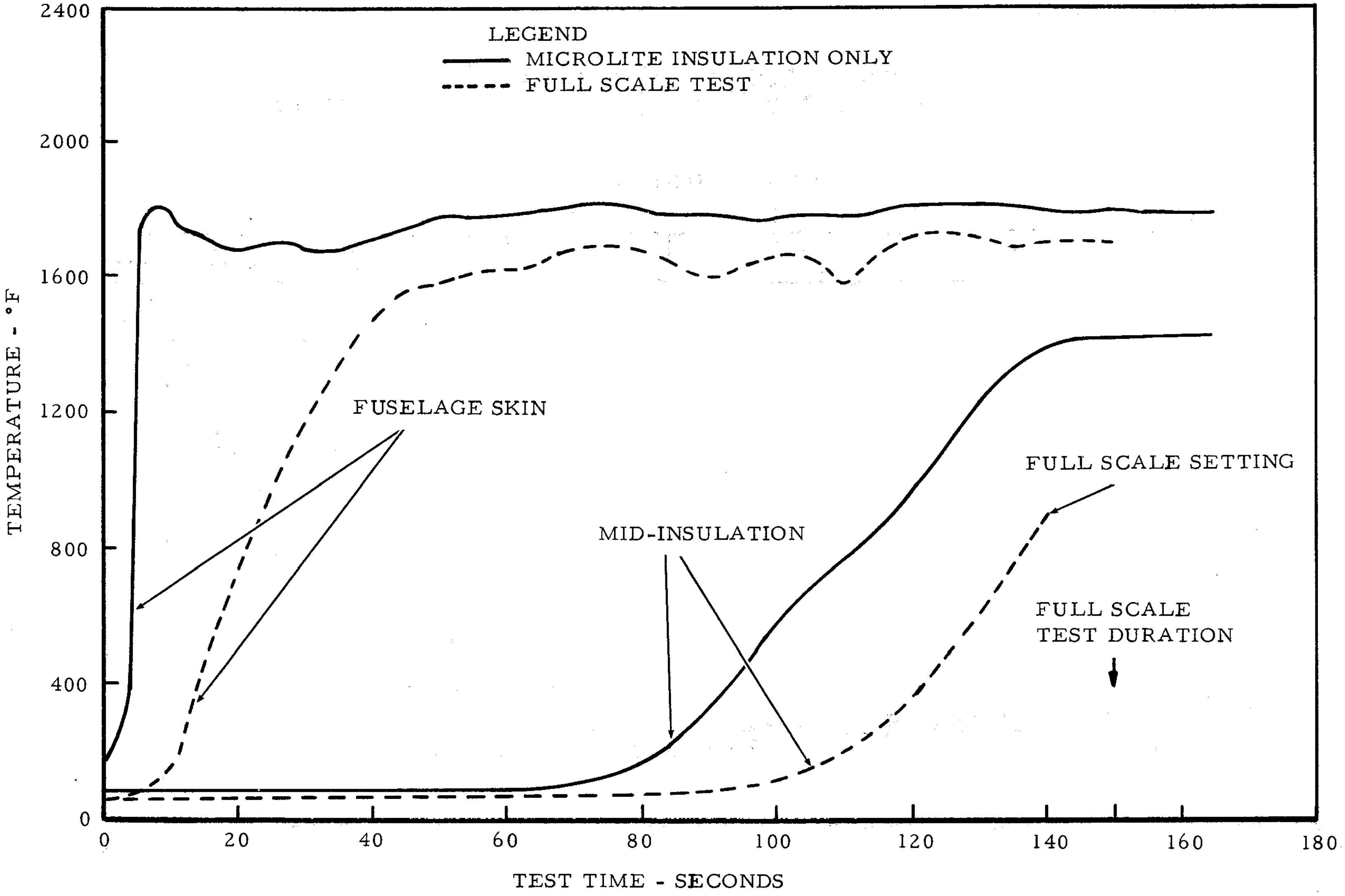

FIGURE 5 - TEMPERATURE DATA FOR TEST PANEL WITH MICROLITE INSULATION (TEST #2) COMPARED WITH FULL-SCALE TEST

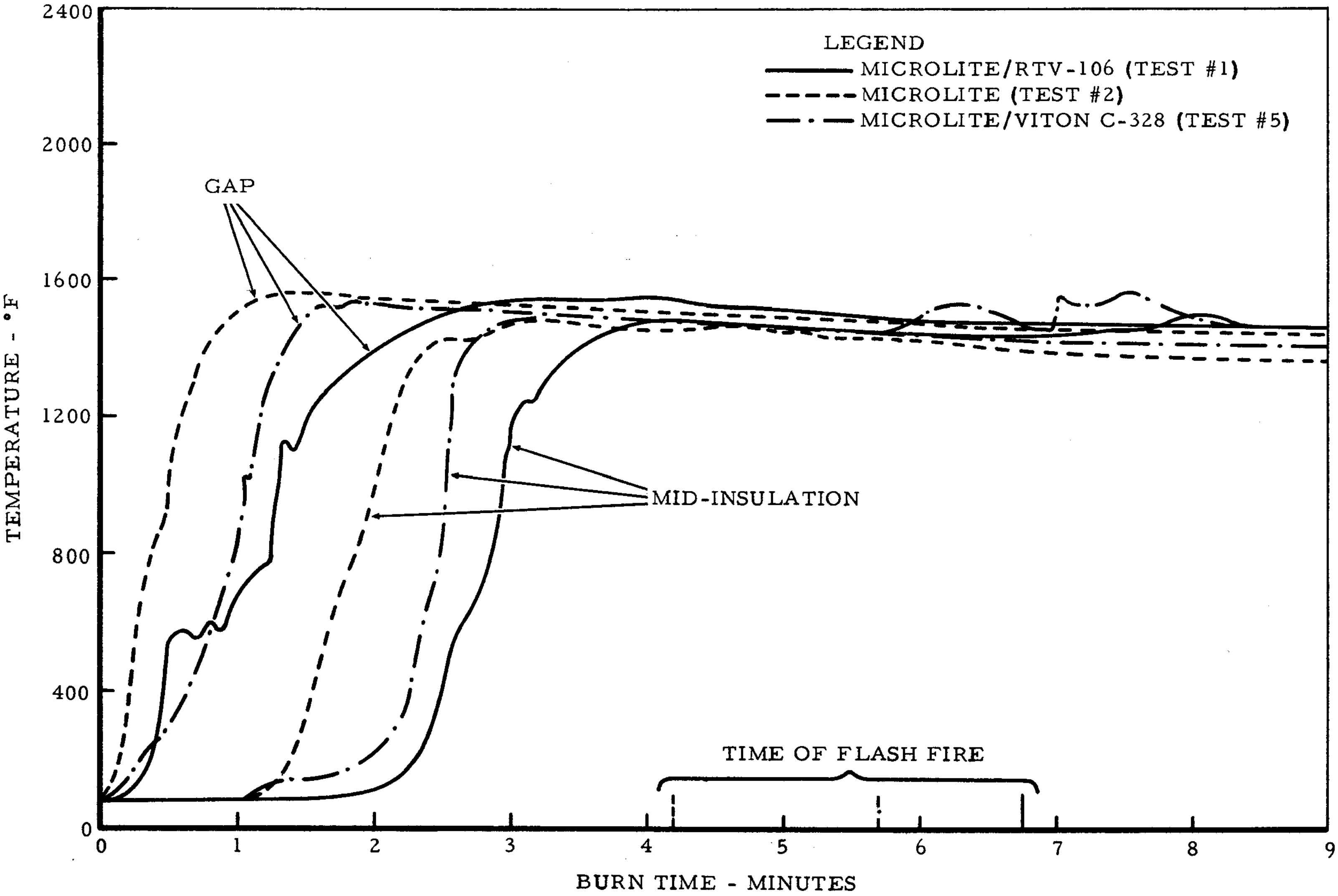

FIGURE 6 - COMPARISON OF TEMPERATURE DATA FROM TEST PANELS WITH MICROLITE INSULATION

combustible gases from the sealant far exceeded that from the insulation. (The sealant weighed 72 grams, while the amount of binder within the insulation was only 10.6 grams.) The intensity of the flash-fire from the Viton/Microlite test article was even less, since the Viton's decomposition gases probably acted primarily like an inert gas, thus reducing the effective concentration of combustible gases.

There were two reasons that the time prior to flash-fire was not reproduced by the small-scale tests. The first reason was that the small-scale test probably did not simulate the compactness of the insulation between the titanium fuselage skin and cabin wall. In the small-scale tests, the insulation was packed much tighter, delaying the egress of combustibles (and smoke) from the cabin wall interface. The second reason was that, in the packing of insulation between formers in the titanium fuselage, a small space existed between adjacent insulation batts. This space also allowed for the earlier accumulation of combustibles (and smoke) within the titanium fuselage and, more important, the formation of flames at the cabin wall interface before the insulation burned through. Thus, these flames could have provided the ignition source necessary to trigger the flash-fire in the titanium fuselage at a time much earlier than the insulation burn-through during the small-scale test. Actually, the most likely ignition source in the titanium fuselage test (Reference 1) was the rupture of the cabin wall near the aft end, which was apparently caused by a pressure buildup, between the titanium skin and cabin walls, associated with the vaporization and rapid combustion of the silicone sealant. This was another phenomenon which could not be duplicated on a small scale.

The extreme hazard caused by the absence of any insulation was accentuated by the results of Test No. 4. This test configuration incorporated the silicone sealant without any insulation. Flaming was observed as early as 0.7 minute and intermittent explosions persisted from 0.9 to 4.0 minutes (Figure 7). After 4.0 minutes, all the volatiles from the decomposing silicone had been burned and a steady-state condition was attained. The intermittent explosions were caused by the absence of any insulation, thus allowing for the relatively

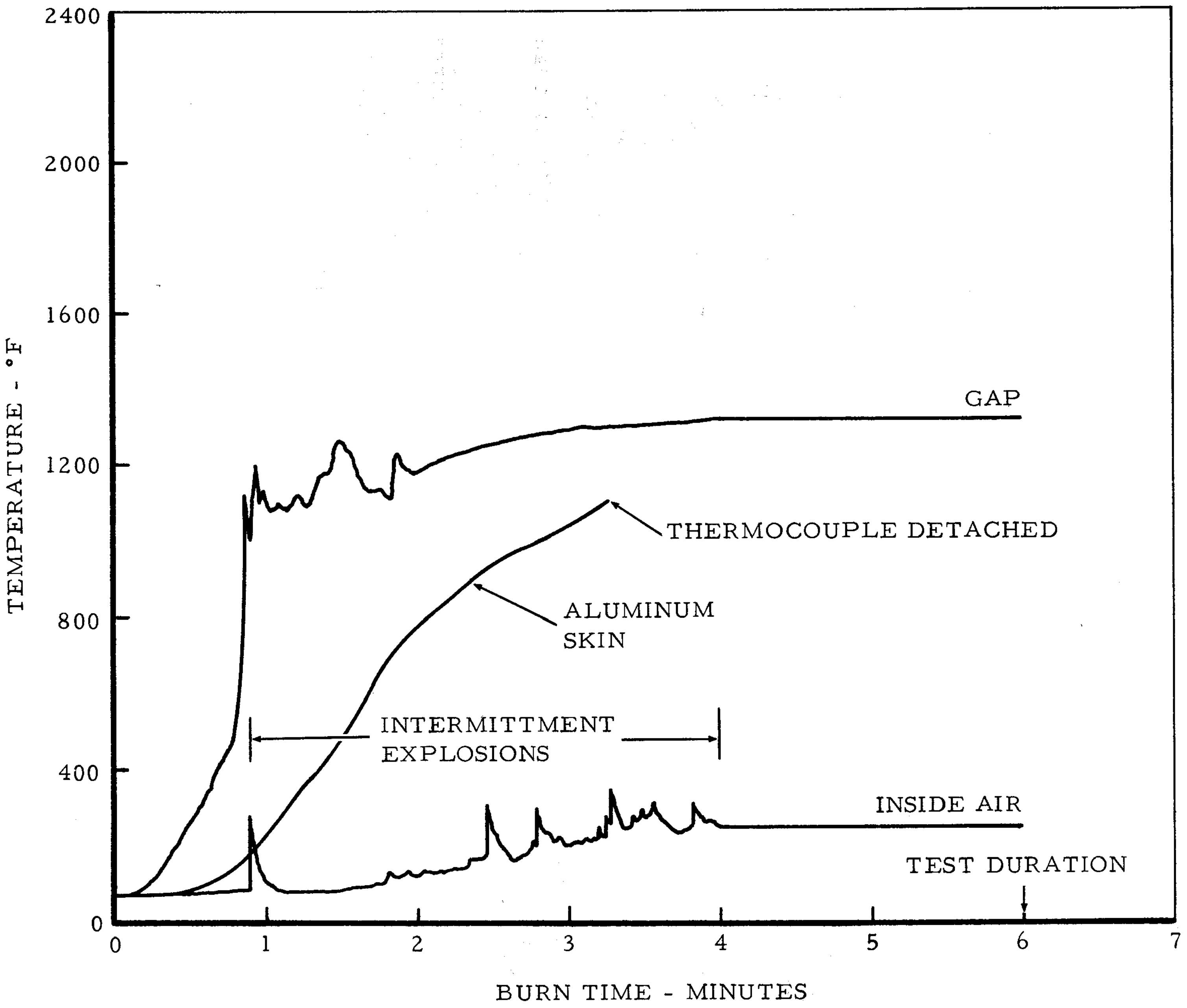

FIGURE 7 - TEMPERATURE DATA FOR TEST PANEL WITH RTV-106 SILICONE SEALANT (TEST #4)

free passage of air necessary for combustion from the test housing to the area of combustible gas formation (and eventual combustion).

Test No. 6 was similar to Test No. 4, except that a Viton caulking compound was used instead of the silicone rubber. After 10 minutes, there was no flash-fire and the Viton was still attached to the fuselage skin, having lost about 40 percent of its weight (Table 2). Some of this weight loss was realized as smoke (Figure 8). However, the rate of smoke generation is somewhat different for the Viton than for the silicone rubber. The Viton appeared to produce a large amount of smoke when it was first heated, and then very little smoke thereafter, as evidenced by the decreasing smoke concentration shown in Figure 8. This trend was also evidenced during the tests with the modified Setchkin Apparatus (Table 1). On the other hand, the silicone rubber appeared to continuously produce large quantities of smoke since the light obscuration remained at 100 percent throughout the test (Figure 8).

Two tests (Nos. 3 and 7) were performed to demonstrate that a high-temperature insulation without any cabin pressure sealant would provide a safe cabin environment against an external fuel fire for a significant time. Two commercially available insulations manufactured by Johns-Manville were tested: Dyna-Flex and Micro-Quartz. From a survivability viewpoint, both insulations performed quite satisfactorily since, in both tests, the air temperature remained habitable for the entire test duration (20 minutes) and very little smoke, combustible gases, or absence of oxygen were detected for at least 15 minutes (Table 2). A comparison of the mid-insulation temperatures (Figure 9) demonstrated that the Micro-Quartz was superior from a heat transfer viewpoint. This superiority was not due to the slightly greater density of the Micro-Quartz used in these tests, but rather to its lower inherent apparent conductivity. (At 1000°F and a density of 3.0 pounds per cubic foot, the Micro-Quartz has a 25 percent lower apparent conductivity than Dyna-Flex.) However, the lower apparent conductivity of the Micro-Quartz was not manifested as markedly by the aluminum cabin wall temperature (Figure 9). Thus, in terms of maintaining a safe cabin temperature, the Dyna-Flex was closer to the Micro-Quartz than one might expect from just comparing their mid-insulation temperatures and, for all practical purposes, would probably do the job just as well.

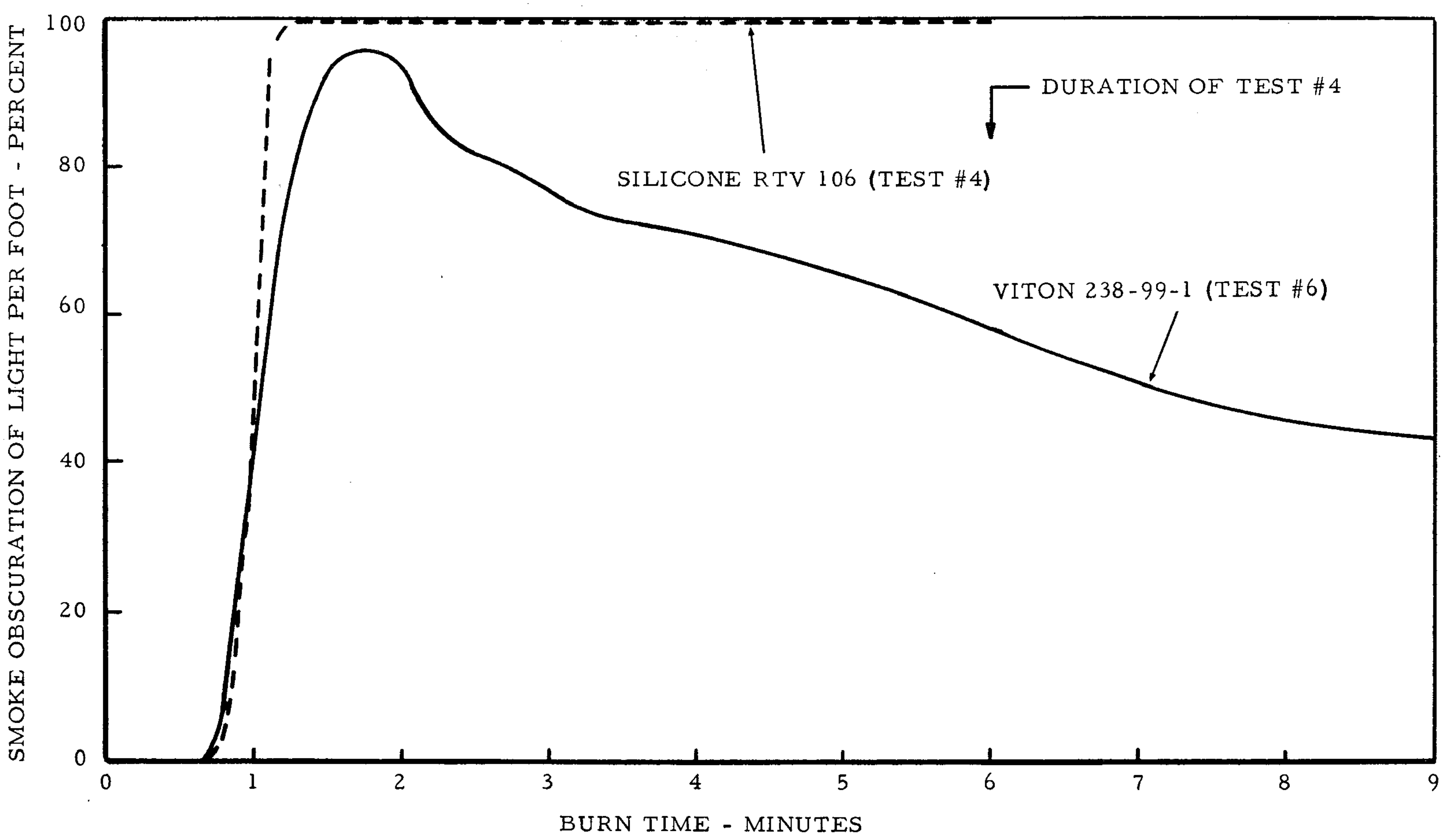

FIGURE 8 - COMPARISON OF SMOKE DATA FROM TEST PANELS WITH SILICONE (TEST #4) AND VITON (TEST #6)

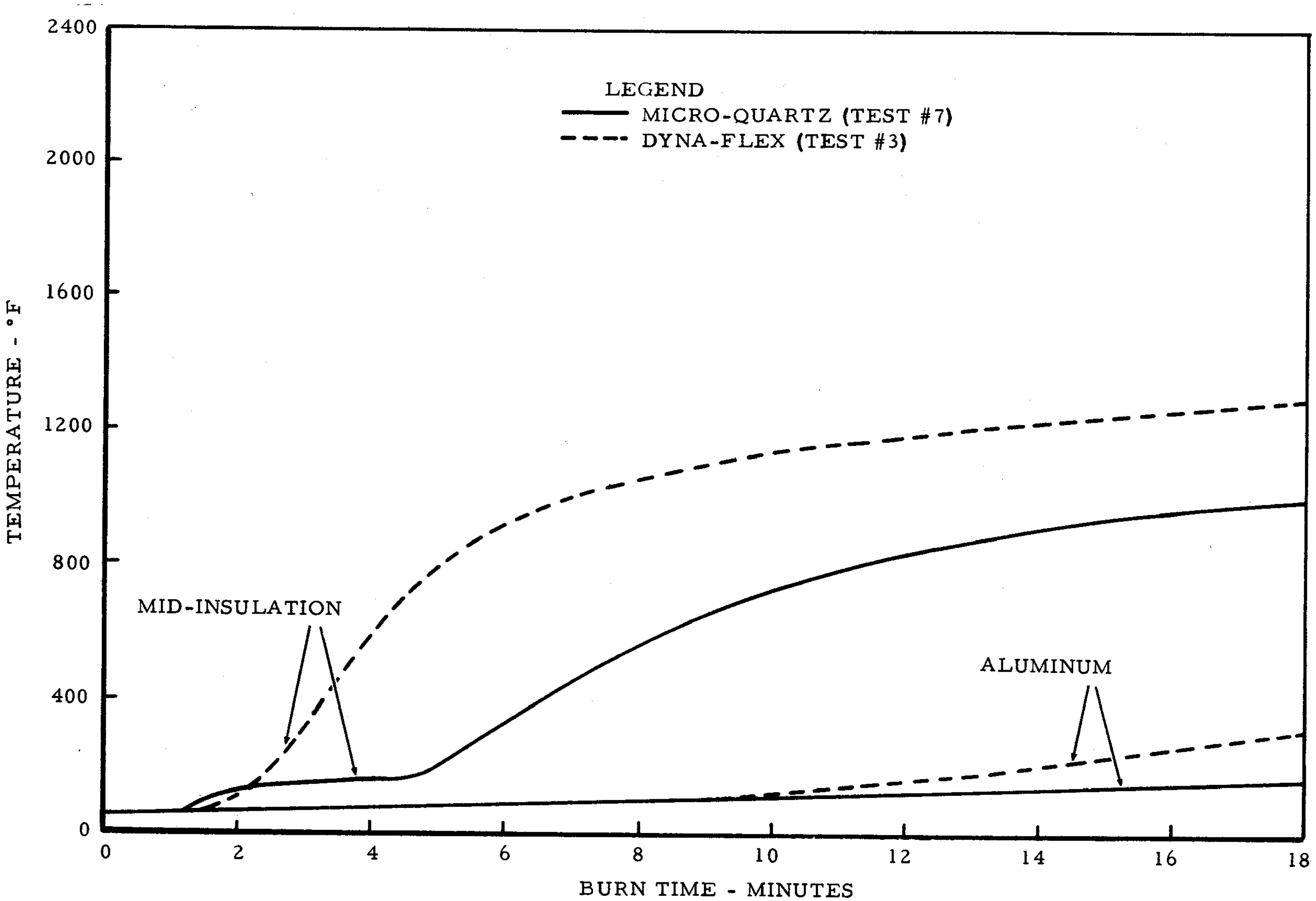

FIGURE 9 - COMPARISON OF TEMPERATURE DATA FROM TEST PANELS INSULATED WITH MICRO-QUARTZ AND DYNA-FLEX

Tests 3 and 7 both proved that an "inert" insulation without any cabin pressure sealant would significantly increase the passenger survivability time during an external fuel fire. The next step was to determine what effect the sealants would have on the degree of protection provided by the insulation. Test No. 8 incorporated a Viton sealant with the Micro-Quartz insulation. The Viton selected was DuPont's 238-97-1, a flexible and elastomeric coating, which better met the properties required of a cabin pressure sealant than the two previously tested Vitons. The temperature profile was relatively unaffected by the Viton, and the observed smoke level similar to Test No. 7. Apparently judging by its post test discoloration, the Micro-Quartz insulation filtered out the smoke particles generated by the decomposition of the Viton. Condensate, as well, was noted on the surface of the aluminum cabin wall adjacent to the insulation. Unlike Test No. 7, however, combustible gases formed from the decompositon of the Viton. These gases were first detected at 5 minutes and reached an equivalent CO concentration of 2 percent by 20 minutes (Figure 10). There was no resulting flash-fire within the test housing. Nonflammable toxic gases like HF (Reference 3) may also have been present, but they were not measured. The results of Test No. 8 indicated that the Viton sealant did not alter the degree of protection provided by the Micro-Quartz, except for the formation of combustible gases and probably toxic gases (the quantities of which require further study to determine the possible extent of their hazard.

A silicone sealant was used with the Micro-Quartz insulation in Test No. 9. The results were similar to Test No. 8, except for the significantly higher concentration of combustible gases (Figure 10) and the slightly higher observed smoke level. Even the discoloration of the insulation was roughly the same. Again, there was no flash-fire in spite of the apparently adequate amount of combustible gases (over 11 percent equivalent CO concentration at 20 minutes). The absence of a suitable ignition source precluded a flash-fire. The Micro-Quartz insulation prevented any flames from the decomposing silicone to act as an ignition source and any significant heating of the housing air which might have caused self-ignition. Thus, another important variable emerged in evaluating the capability of a fuselage skin-insulation-sealant combination to protect passengers during an external fuel fire--the compactness of the insulation. This was verified in Test No. 10.

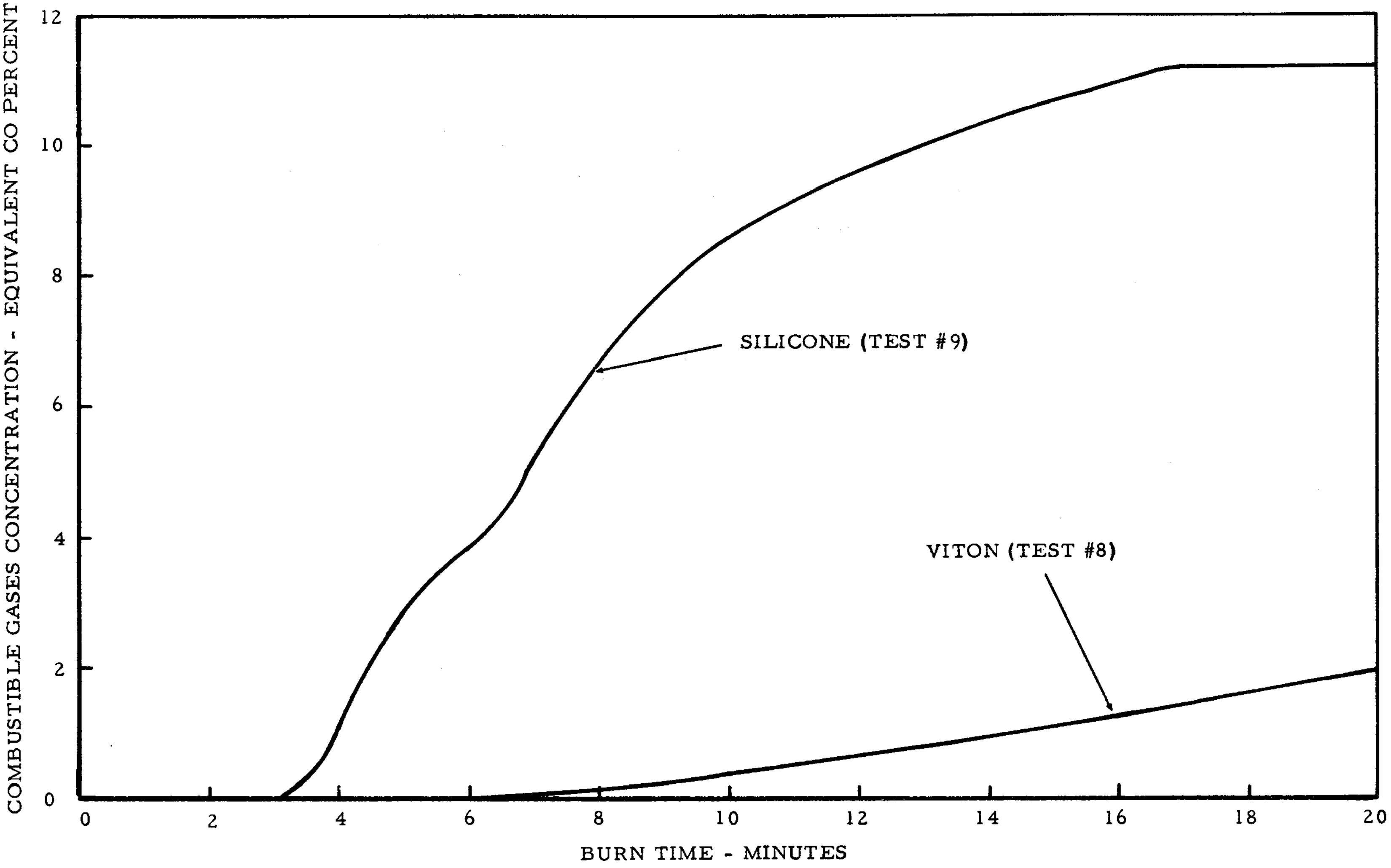

FIGURE 10 - COMPARISON OF COMBUSTIBLE GASES FROM MICRO-QUARTZ-INSULATED PANELS WITH SILICONE AND VITON

Test No. 10 also used the silicone sealant and Micro-Quartz insulation. This time a 1/4-inch wide vertical slot was cut completely through the insulation at the cabin wall interface (Figure 1) in order to simulate the spacing between adjacent insulation batts at a former. In all previous tests (1 through 9), the insulation had completly covered the cabin wall interface. The inclusion of a slot drastically altered the results from Test No. 9. A flash (ignition) was observed within the gap at 0.6 minute and large flames started licking out of the slot into the test housing at 0.8 minute. At about this time, the instrumentation began to indicate increases in air temperature, smoke level, and depletion of oxygen (Figure 11). Violent flaming persisted, although it could not always be detected because of smoke obscuration, until about 2.4 minutes. Notice the sudden increase in 0_2 and decrease in inside air temperature at 2.4 minutes shown in Figure 11. Apparently, all the volatiles generated by the decomposing silicone were burned by this time. From about 3 minutes until the end of the test, except for the gradual increase in mid-insulation temperature, there were no significant changes in measured properties. The insulation was examined after the test and showed very little discoloration except for the surface facing the fuselage skin. Even the surfaces constituting the slot showed virtually no discoloration, indicating that the observed flaming originated at the cabin wall interface and did not extend back to the silicone. Except for the initial ignition of the silicone's decomposition products, further burning in the gap and slot areas probably did not occur since the oxygen was depleted during initial flaming. Thus, the presence of voids or passageways between the silicone-covered fuselage skin and cabin air can allow flaming at the cabin wall which will have a detrimental effect upon the survivability time during an external fuel fire.

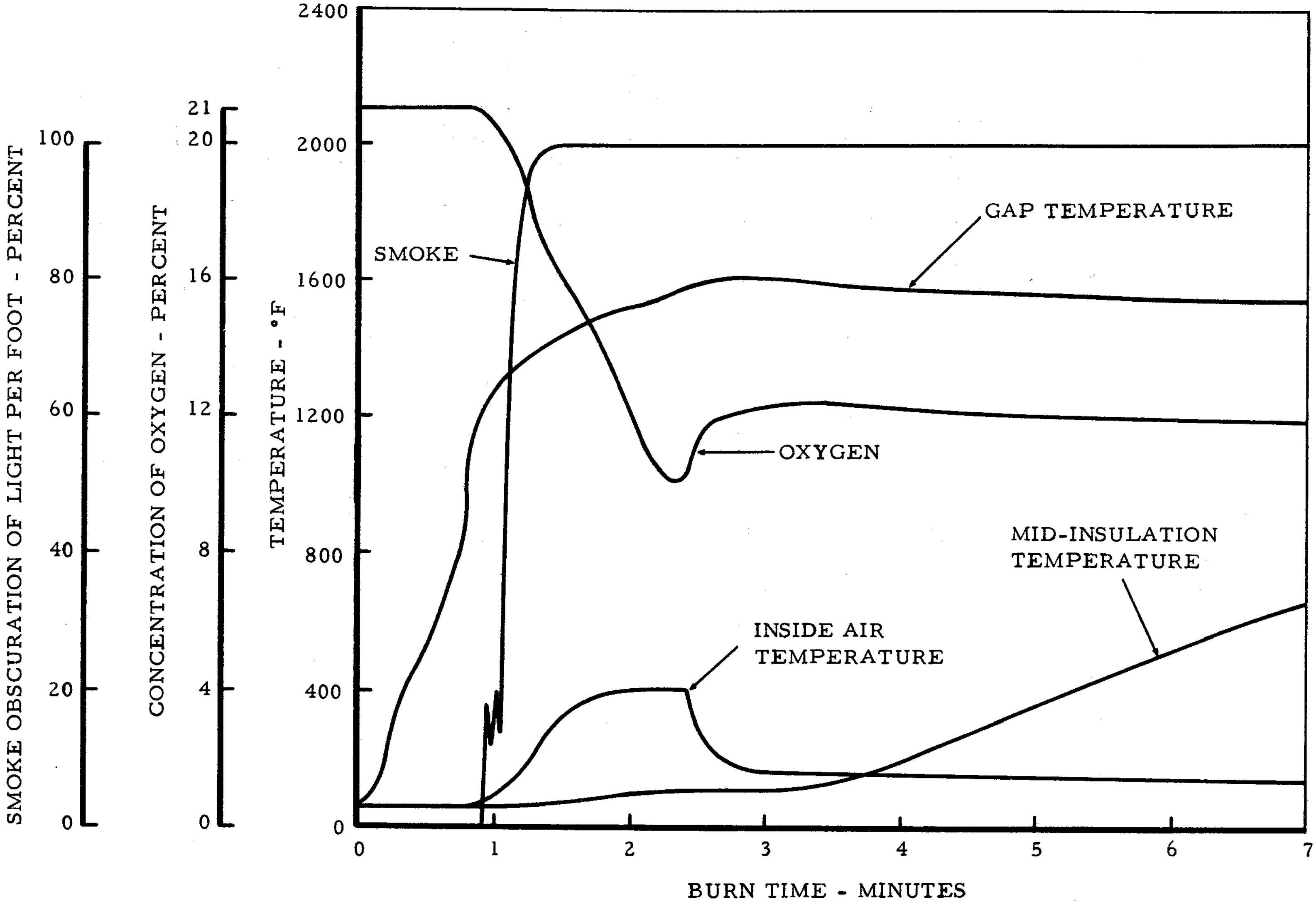

FIGURE 11 - TEMPERATURE, SMOKE AND OXYGEN DATA FOR TEST PANEL WITH SILICONE SEALANT AND MICRO-QUARTZ INSULATION WITH 1/4" SLOT (TEST # 10)

SUMMARY OF RESULTS

1. A small-scale test article duplicating the cross section of the titanium fuselage between the outer skin and cabin wall and incorporating the same insulation and sealant, when exposed to the flames from a 2 gallon per hour kerosene burner, exhibited many of the phenomena evidenced during the titanium fuselage full-scale test except, most notably, the time to flash-fire.

2. A flash-fire occurred when the Microlite insulation was tested without any sealant or with a Viton elastomer, indicating the silicone binder caused the flash-fire.

3. The test on the Microlite insulation without any sealant reasonably duplicated the heating of insulation in the titanium fuselage test.

4. In tests where the Microlite insulation completely covered the interior panel interface, flash-fire occurred immediately following insulation burn-through.

5. A test with the silicone sealant without any insulation resulted in intermittent explosions (pops) of varying severity from 0.9 to 4.0 minutes.

6. The silicone and Viton, tested separately without any insulation, exhibited a very similar increase in smoke level until the maximum obscuration was reached. However, after this time, the smoke obscuration retained its maximum value (100 percent) for the silicone-covered panel, but gradually diminished for the Viton-covered panel.

7. Two high-temperature insulations, Dyna-Flex and Micro-Quartz, were tested without any sealant. In both tests, very little smoke, combustible gases or absence of oxygen were detected for 15 minutes, at which time the cabin wall temperature had only risen to 240° and 150°F for the Dyna-Flex and Micro-Quartz-insulated panels, respectively.

8. The silicone and Viton sealants were each tested with the Micro-Quartz insulation. Both tests exhibited similar smoke levels and temperature profiles; however, after 20 minutes the Viton and silicone-covered panels produced 2.0 and 11.2 percent equivalent CO concentration, respectively. Neither test evidenced a flash-fire.

9. The silicone sealant and Micro-Quartz insulation with a 1/4-inch wide vertical slot cut completely through the insulation at the cabin wall interface was tested. Violent flaming at the interface began at 0.8 minute and lasted until 2.4 minutes; smoke caused 100 percent light obscuration by 1.5 minutes; the oxygen concentration decreased continuously from the onset of flaming and reached a minimum concentration of 10 percent at 2.4 minutes; and the housing air temperature peaked at 400°F by 2.0 minutes.

CONCLUSIONS

Based upon the results of these small-scale tests with the materials tested, it is concluded that:

1. The heating of the insulation measured during the titanium fuselage test can be duplicated on a small scale, thus giving credence to this test method as being representative of what would occur to a titanium or stainless-steel aircraft during a post-crash fire.

2. A small amount of silicone binder in the Microlite insulation (4.3 percent by weight) without any cabin pressure sealant can cause a flash-fire.

3. Two commercially available high-temperature insulations used without any cabin pressure sealant can each maintain survivable conditions within a nonmelting aircraft fuselage during a post-crash fuel fire for at least 15 minutes.

4. Viton will not flame or flash-fire under conditions in which silicone will.

5. Viton produces smoke over a relatively small temperature range; whereas, silicone produces smoke over a significantly wider temperature range.

6. A continuous Micro-Quartz insulation will filter out much of the smoke generated by a decomposing cabin pressure sealant and prevent any sealant flaming from burning through at the cabin wall interface or any significant cabin heating which might ignite the combustible gases accumulating within the housing. Unfortunately, present aircraft construction and inspection procedures do not allow for implementation of a continuous insulation system.

7. The rate at which combustible gases accumulate within the cabin and the time prior to the formation of an ignition source will be strongly influenced by the compactness of the insulation and the presence of any voids or passageways between the fuselage skin and cabin wall interface.

APPENDIX

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