Evaluation of the 12-Second Vertical Bunsen Burner Test Used to Determine the Fireworthiness of Aircraft Duct Materials

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16. Abstract

This technical note provides the technical approach and test results of the evaluation of the currently used Federal Aviation Administration certification test, known as the 12-second vertical Bunsen burner test, to certify aircraft ducts and conduits.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

CFR	Code of Federal Regulations
FAA	Federal Aviation Administration
NBS	National Bureau of Standards
OSU	Ohio State University

EXECUTIVE SUMMARY

Because of the desire to improve in-flight fire safety, the Federal Aviation Administration (FAA) is examining the adequacy of the fire test requirements for inaccessible area materials, including electrical wiring and air conditioning ducts. This activity is a continuation of prior work that resulted in the development and adoption of improved fire test criteria for thermal acoustic insulation. The current test requirement for air conditioning ducts is the 12-second vertical Bunsen burner test (Title 14 Code of Federal Regulations Part 25, Appendix F Part I (a)(4)). The FAA goal is to elevate the in-flight fire performance of all major inaccessible materials to the same level as now required for thermal acoustic insulation.

The technical approach selected was to conduct intermediate-scale fire tests on ducting that meets the Bunsen burner test criteria, subjected to a standard intense fire source. An equivalent level of fire performance with the behavior of improved thermal acoustic insulation will be exhibited if the air conditioning duct does not propagate a flame when subjected to the standard fire. The ducting was removed from a surplus test aircraft and was a composite comprised of epoxy/fiberglass facings and a urethane foam core.

Additional fire tests were conducted on the duct material, although not required by federal regulations. The fire tests were the Ohio State University (OSU) rate of heat release test, the National Bureau of Standards (NBS) smoke test, radiant panel test, and the microscale combustion calorimeter test. These tests characterized the overall fireworthiness of the material and provided some indication of the adequacy of the current vertical Bunsen burner test method.

The duct material passed the 12-second vertical Bunsen burner test even after 25 years of service and possibly containing some unknown level of contamination. The burn length on the samples was between 6.99 and 7.62 cm; the regulation allows a maximum burn length of 20.32 cm. The material did not drip, and the flame-extinguishing time was zero (no flames after removing the burner) in two of the three tests. During the third test, the flames self-extinguished in 8 seconds. The regulation allows a maximum flame-extinguishing time of 15 seconds. During the intermediate-scale fire test, large quantities of flames and smoke were observed exiting the forward and aft upper sections of the fuselage. Posttest observations revealed that the fire completely consumed the duct material. The maximum temperature on the ceiling was 835°C, and the maximum heat flux was 63.2 kW/m^2. It was clear that the vertical Bunsen burner test does not ensure the same level of fire performance as exhibited by improved thermal acoustic insulation meeting recently adopted stringent fire test criteria.

During the OSU heat release tests, flames were immediately observed on the exposed face of the specimen, and a large quantity a smoke was emitting through the exhaust stack. The recorded data showed that the peak heat release exceeded the federal regulation-allowed value. The regulation allows a maximum heat release of 65 kW/m^2; the results ranged from 74.34 kW/m^2 to 87.86 kW/m^2. The microscale combustion calorimeter test results indicated that the sample fiberglass and epoxy laminate had a heat release capacity of 123.0 J/g-K, a total heat release of 13.4 KJ/g, and a char of only 12.6%. The urethane foam had a very high heat release capacity of 436.0 J/g-K, a total heat release of 24.7 KJ/g, and a char of only 2.9%. The results of the NBS smoke test indicated that this material passed. The radiant panel test is the new stringent test

requirement for thermal acoustic insulation. The results showed that the duct material performed poorly. Only seconds after exposing the material specimen to the radiant heat and torch flame, the entire sample was engulfed in flames. The test was immediately terminated to prevent fire damage to the radiant panel. Two additional specimens were tested and both performed similarly.

Based on the test results, especially the intermediate-scale test where a raging fire was experienced, it was concluded that the current FAA-required 12-second vertical Bunsen burner test is not an adequate test discriminator method to achieve the FAA's fire performance goal for ducting material and that an improved fire test method and criteria for ducting materials should be developed.

1. INTRODUCTION.

The objective of this evaluation program was to determine the adequacy of the current Federal Aviation Administration (FAA) fire test requirement for air conditioning ducts and electrical conduits. The current test is specified in Title 14 Code of Federal Regulations (CFR) Part 25, Appendix F Part I (a)(4) and is commonly referred to as the 12-second vertical Bunsen burner test. The overall FAA goal is to improve airplane standards such that fires in inaccessible areas do not spread and create catastrophic conditions. The goal is being addressed, in part, by examining the fire test standards for interior materials located in inaccessible areas, including air conditioning ducts.

2. TECHNICAL APPROACH.

The technical approach was to conduct intermediate-scale fire tests in a mockup of the area above the cabin ceiling (attic) on ducting compliant with the current flammability test requirement. This was the approach taken during the development of improved fire test criteria for thermal acoustic insulation. During this prior testing, a standard severe fire source was employed, consisting of a block of urethane foam saturated with heptane. Improved fire test criteria for insulation were developed from this earlier study, based on a requirement that a fire would not propagate when subjected to the standard foam ignition source in the intermediate-scale test article. The FAA's goal is to upgrade the fire performance of the remaining major inaccessible materials, including ducting, conduit, and electrical wirings to the same level as now required for insulation. Thus, the adequacy of the current flammability test requirement for ducting is based on the intermediate-scale performance of ducting compliant with the vertical Bunsen burner test requirement when subjected to the standard foam fire source. If compliant ducting prevents fire spread for a representative sampling of ducting materials, then the test requirement could be judged to be adequate; however, if fire spread occurs on any sample, then the test requirement is judged to be inadequate.

The current federal aviation regulation related to the subject dictates that any duct installed onboard an aircraft after 1967 must meet, as a means of compliance, the 12-second vertical Bunsen burner fire test. To pass this test, any flames present on the 75- by 305-mm material sample after the fire source has been removed must self-extinguish within 15 seconds, and the burn length shall not exceed 203.2 mm. In addition, any material that melted and fell to the base of the cabinet shall not burn for more than 5 seconds (see section 2.1 for details).

An overhead duct, which had been in a narrow-body cargo aircraft since 1980, was used for the test. The duct was a composite made of fiberglass and epoxy facings and urethane foam core. The entire duct section was fire tested in the intermediate-scale attic fire test article after it was determined that samples obtained from the duct were found to be compliant with the vertical Bunsen burner test requirement (figure 1).

In addition, this duct material was evaluated using other FAA tests such as the Ohio State University (OSU) rate of heat release apparatus, the National Bureau of Standards (NBS) smoke chamber, cone calorimeter, and the microscale combustion calorimeter. These fire tests were expected to help characterize the overall fireworthiness of the material. The temperature and heat flux profiles of the ignition sources were recorded for each test to determine their severity.

Examples of the instrumentation used to measure temperature and heat flux of various ignition sources are shown in figures 2 and 3. The following references the test procedures that are used.

- The Vertical Bunsen Burner Test for Cabin and Cargo Compartment Materials test was conducted according to FAA report DOT/FAA/CT-89/15, "Aircraft Material Fire Test Handbook," September 1990, see chapter 1 for more details. Also, see Title 14 Code of Federal Regulations (CFR) Part 25, Appendix F, Part I.

- The Intermediate-Scale Narrow-Body Mock-Up Test was conducted according to FAA report DOT/FAA/AR-99/44, "Development of Improved Flammability Criteria for Aircraft Thermal Acoustic Insulation."

- The Heat Release Rate Test For Cabin Materials test was conducted according to FAA report DOT/FAA/CT-89/15, "Aircraft Material Fire Test Handbook," September 1990, see chapter 5 for more details. Also, see 14 CFR Part 25, Appendix F, Part IV.

- The Microscale Combustion Calorimeter test was conducted as discussed in FAA report DOT/FAA/AR-01/117, "A Microscale Combustion Calorimeter," January 2002.

- The Smoke Test For Cabin Materials test was conducted according to FAA report DOT/FAA/CT-89/15, "Aircraft Material Fire Test Handbook," September 1990, see chapter 6 for more details. Also, see 14 CFR Part 25, Appendix F, Part V.

- The Test Method to Determine the Flammability and Flame Propagation Characteristics of Thermal/Acoustic Insulation Materials test was conducted according to FAA report DOT/FAA/AR-89/15, "Aircraft Material Fire Test Handbook," September 1990, see chapter 23 for more details. Also, see 14 CFR Part 25, Appendix F, Part VI.

The upper half of a narrow-body fuselage section was used to conduct the intermediate-scale tests, as shown in figures 4 and 5. This section was insulated with thermal-acoustic insulation blankets fabricated with metallized Tedlar® (Orcon AN54W) and fiberglass (Johns Manville 0.34 PCF Fiberglass). To simulate the cabin ceiling and create the attic space, a steel frame was installed to hold the composite ceiling panels in place. The ceiling panels, constructed of fiberglass/phenolic faces and a Nomex honeycomb core, were installed 330.2 mm below the crown of the fuselage section, and were compliant with the FAA-required heat release rate and smoke emissions standards. The attic space, formed by the ceiling panels and fuselage crown, was instrumented with thermocouples and calorimeters to measure the temperature and heat flux above the ignition source and at each end of the fuselage section. The thermocouples and calorimeters were connected to a portable data acquisition system, and their signal outputs were collected at a rate of 1 Hz. At least two cameras were set up to record the fire event. Photographs were also taken before and after each test to record the event and damage.

Prior to installing the duct (see figure 6) in the narrow-body fuselage test rig (see figure 7), a baseline test was conducted to measure the ignition source temperature and heat flux (see figure 4). The ignition source for the intermediate-scale tests was a 101.6- by 101.6- by 228.6-mm urethane foam block spiked with 10 cc of heptane. This foam block was placed in the middle of the fuselage section, but offset 215.9 mm (face of foam block) to the starboard side of the fuselage centerline. The test was initiated by starting the data acquisition system and activating the video cameras. Thirty seconds after collecting the ambient temperature data, the foam block was ignited and allowed to burn until the foam was consumed and the flames were out. The same test procedure was used when the air conditioning duct was mounted on the fuselage rig (see figure 8), but the fire was allowed to burn until the flames were out, or close to it, without damaging the test fixture (fuselage). The temperature and heat flux for all the tests were determined using the collected data. After each test, photographs of the test specimen were taken and the fire damage was recorded and measured. This test was conducted only once because of the severity of the results.

3. TEST RESULTS.

All the results from the various tests were tabulated and are shown in table 1. Table 1 includes the results and comments of the 12-second vertical Bunsen burner tests, intermediate-scale tests, OSU heat release rate tests, microscale combustion calorimeter tests, NBS smoke tests, and radiant panel heat tests. The heat source profiles of the different tests conducted were tabulated and are shown in table 2.

3.1 TWELVE-SECOND VERTICAL BUNSEN BURNER TEST.

Prior to testing the sample with this standard test, the flame temperature and heat flux of the test apparatus were measured, as shown in figure 2. The flame temperature was 925°C, and the heat flux was 40.6 kW/m^2. The test results indicated that the duct material met the current federal aviation regulation, even though the material had been in service since 1980 and unknown contaminants were present. The burn length was between 6.99 and 7.62 cm; the regulation allows a maximum burn length of 20.32 cm (see figure 9). The material did not drip and flame-extinguishing time was zero (no flames after removing the burner) in two of the three tests. During the third test, the flames self-extinguished in 8 seconds. The regulation allows a maximum flame extinguishing time of 15 seconds.

3.2 INTERMEDIATE-SCALE NARROW-BODY FIRE TEST.

The duct started to burn about 15 seconds after the foam block (ignition source) was ignited. After the fire penetrated the duct wall, the fire intensified and spread rapidly, apparently due to a chimney-like effect. Within a short period of time after penetration, the fire had spread to both ends of the test article with large flames and copious amounts of smoke rising into the air, as shown in figure 10. The maximum temperature recorded on the ceiling was 835°C, and the maximum heat flux recorded was 63.2 kW/m^2, as shown in figures 11 and 12. The fire burned intensely for over 6 minutes before it was extinguished. The severity of the duct fire was greater than observed previously with various grades of thermal acoustic insulation. Posttest observations revealed that the fire completely consumed the duct material, as shown in figure 13.

3.3 THE OSU HEAT RELEASE RATE TEST.

This test was repeated three times in the OSU apparatus. During the tests, flames were immediately observed on the exposed face of the specimen and a large quantity of smoke was emitted through the exhaust stack. Figures 14 through 16 show the heat release rate histories. The double peaks appear to correspond to the burning facing initially, followed by the involvement of the urethane core. The peak heat release rate exceeded the allowable value of 65 kW/m^2. The peak heat release rates ranged from 74.34 kW/m^2 to 87.86 kW/m^2.

3.4 MICROSCALE COMBUSTION CALORIMETER.

The fiberglass and epoxy laminate (facing) sample had a heat release capacity of 123.0 J/g-K, a total heat release of 13.4 KJ/g, and a char of 12.6%. The urethane foam core sample had a heat release capacity of 436.0 J/g-K, a total heat release of 24.7 KJ/g, and a char of 2.9%. The urethane foam is particularly flammable, as evidenced by the relatively high heat release capacity and low char yield.

3.5 THE NBS SMOKE TEST.

The duct sample was relatively smokey, although the maximum specific optical density did not exceed the allowable 200 value. As shown in figures 17 through 20, D_m values ranged from 120 to 145.

3.6 RADIANT PANEL TEST.

The duct sample exhibited extreme flammability behavior in the radiant panel test. Only seconds after exposing the material specimen to the radiant heat and torch flame, its upper layer ignited quickly, engulfing the whole panel in flames. The test was not allowed to continue for the required duration of the test to prevent fire damage to the radiant panel. Two material specimens were tested and both performed similarly, as shown in figures 21 and 22.

4. CONCLUSION.

The evaluation test results showed that the current flammability test method and criteria to certify aircraft ducts, i.e., the 12-second vertical Bunsen burner test, is not adequate to predict the behavior of ducts under realistic fire conditions. Therefore, an improved fire test method and criteria should be developed and assessed in the overall consideration of improved in-flight fire safety.

FIGURE 1. VERTICAL BUNSEN BURNER TEST

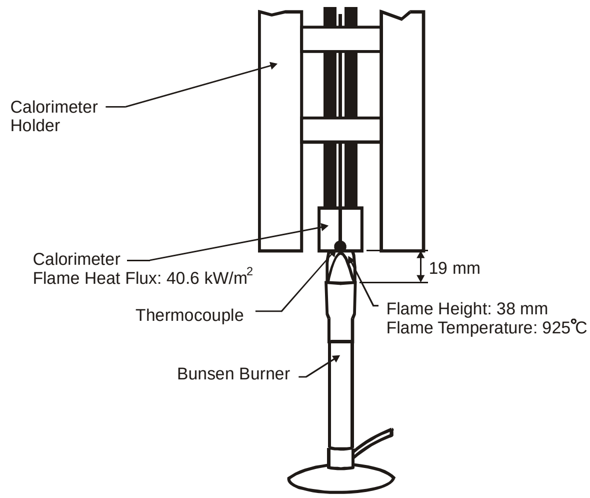

FIGURE 2. BUNSEN BURNER HEAT PROFILE INSTRUMENTATION SETUP

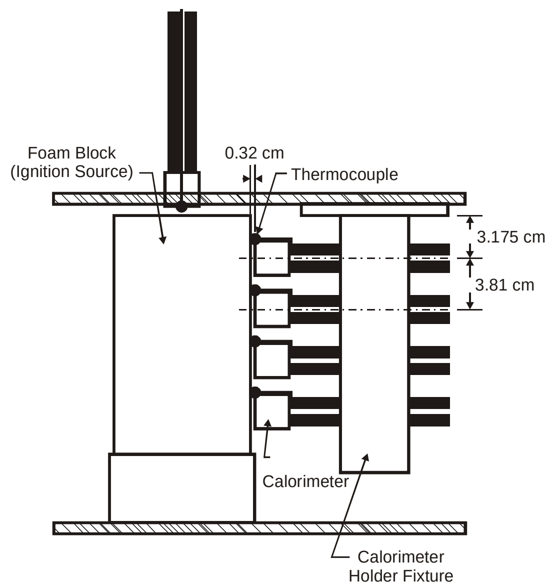

FIGURE 3. URETHANE FOAM HEAT PROFILE INSTRUMENTATION SETUP

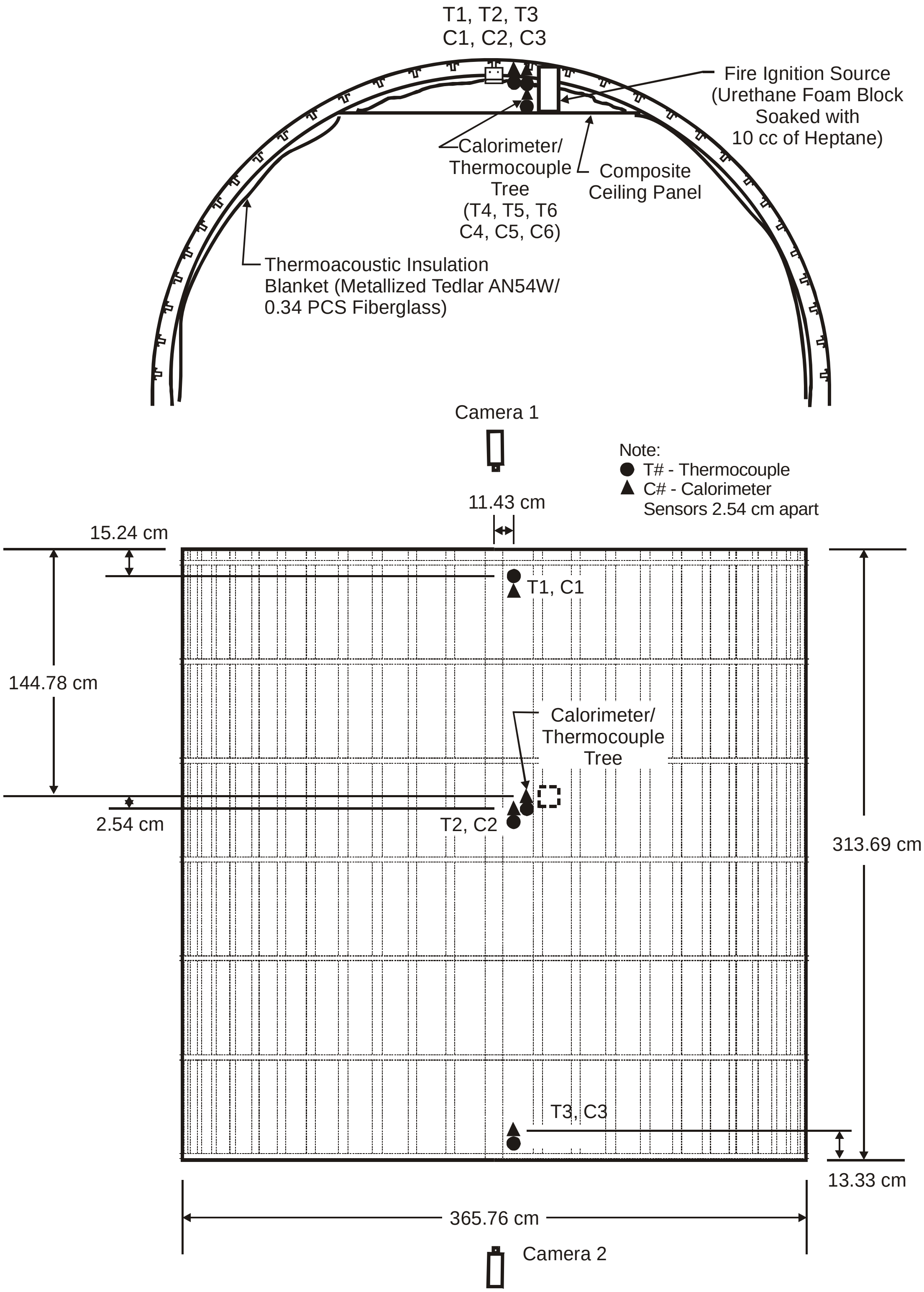

FIGURE 4. INTERMEDIATE-SCALE SETUP WITH IGNITION SOURCE ONLY

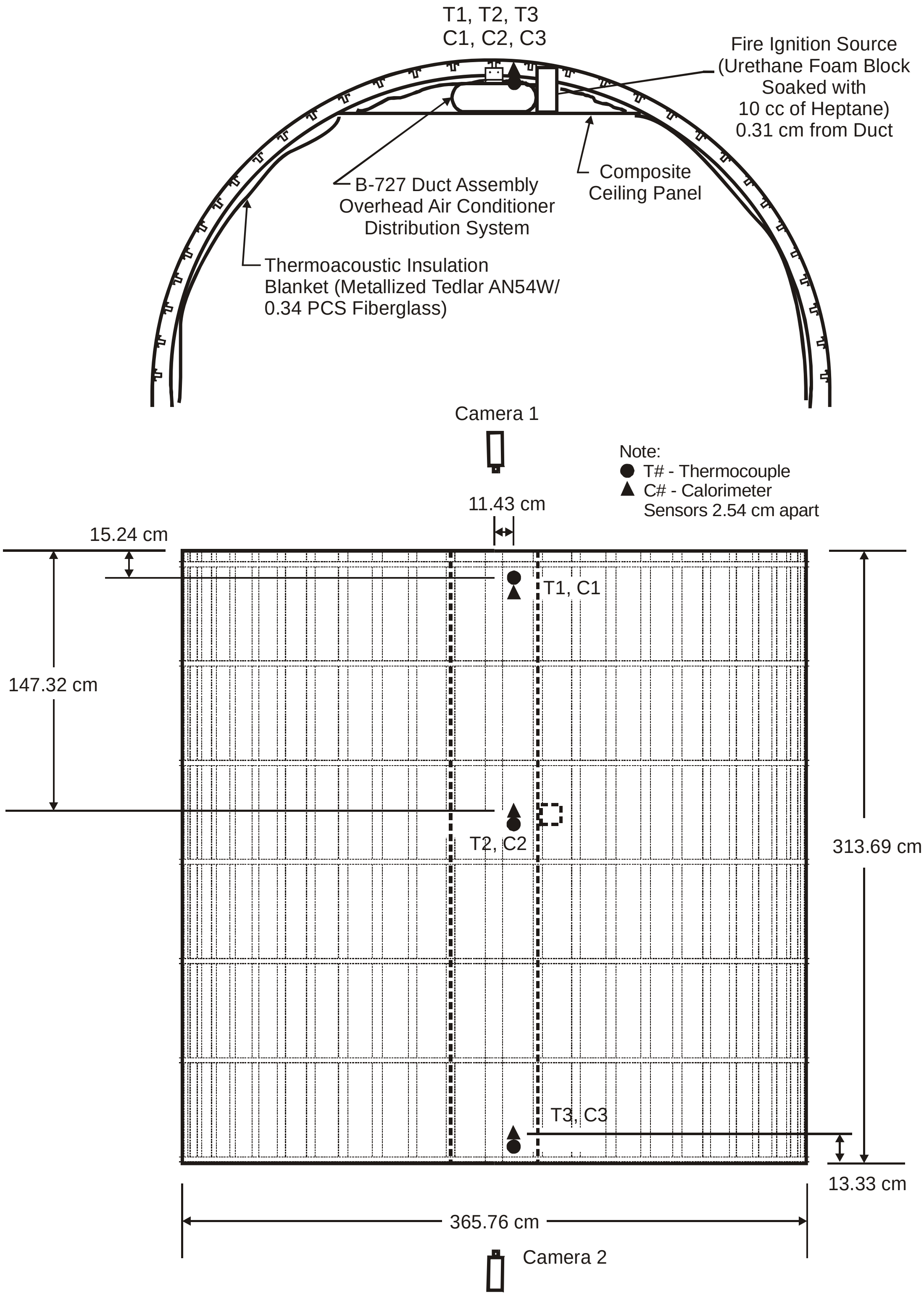

FIGURE 5. INTERMEDIATE-SCALE SETUP WITH AIR CONDITIONING DUCT

FIGURE 6. NARROW-BODY AIRCRAFT AIR CONDITIONING OVERHEAD DUCT

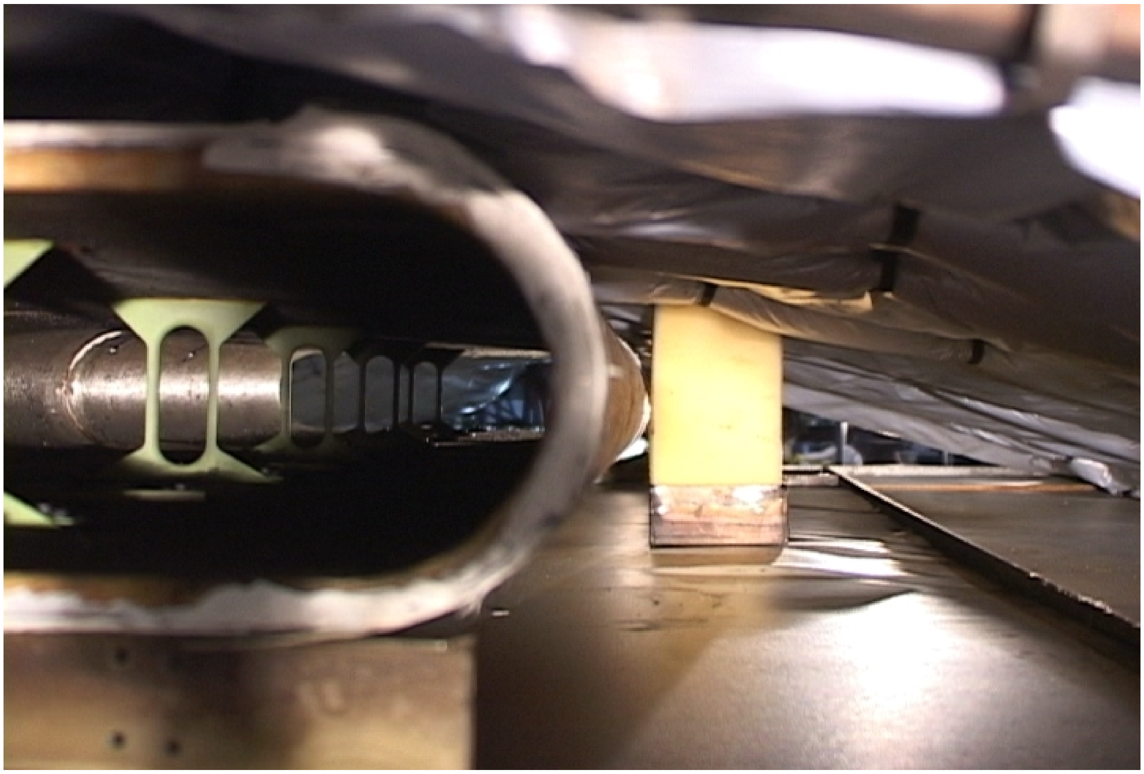

FIGURE 7. AIR CONDITIONING OVERHEAD DUCT IN AIRCRAFT ATTIC

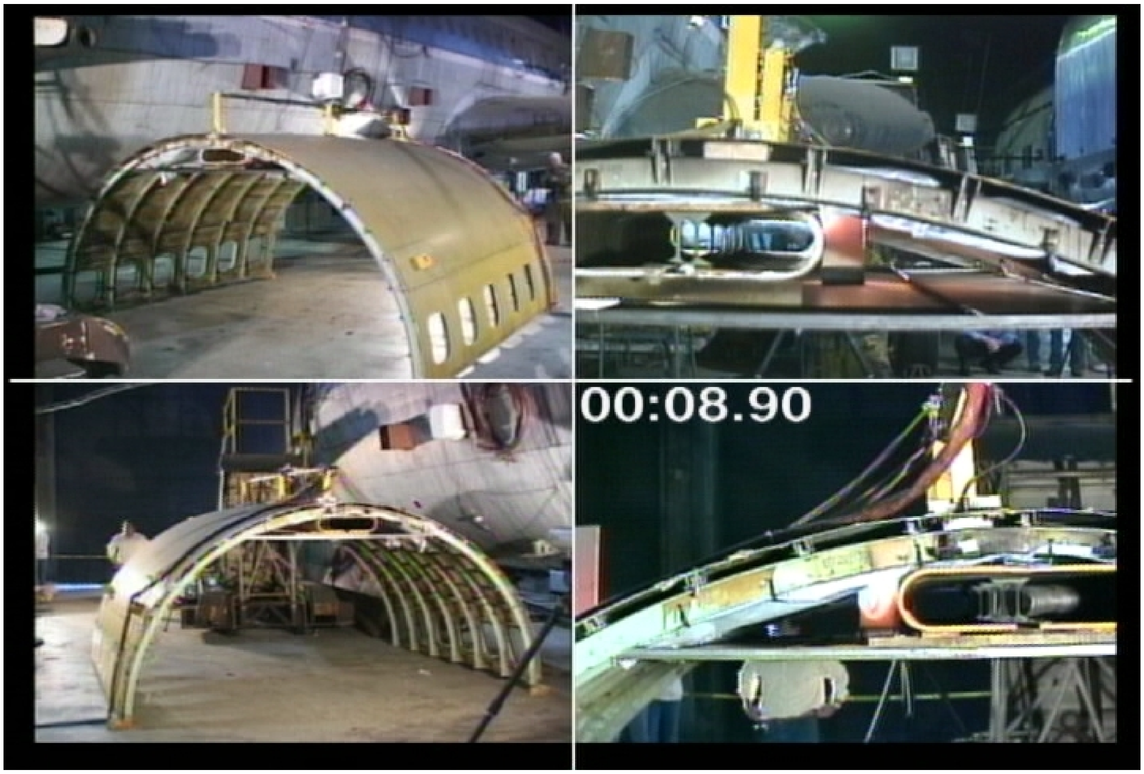

FIGURE 8. INTERMEDIATE-SCALE SETUP

FIGURE 9. VERTICAL BUNSEN BURNER POSTTEST

FIGURE 10. INTERMEDIATE-SCALE FIRE TEST

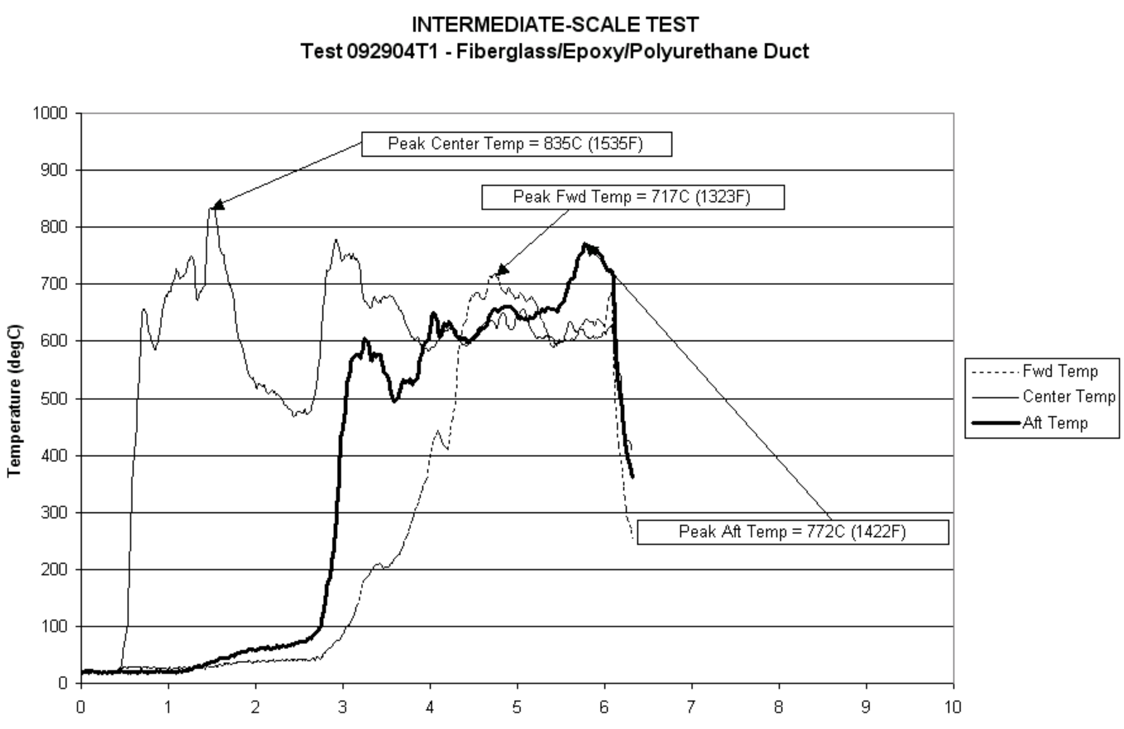

FIGURE 11. INTERMEDIATE-SCALE TEST TEMPERATURE HISTORY

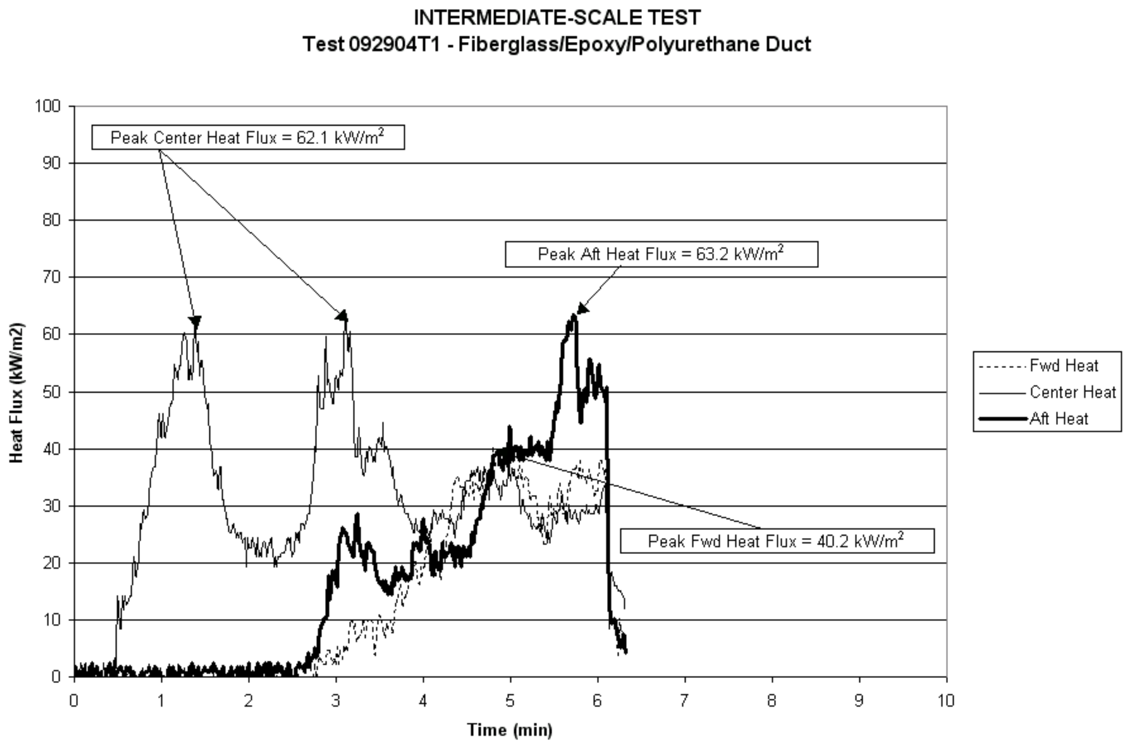

FIGURE 12. INTERMEDIATE-SCALE TEST CALORIMETER HISTORY

FIGURE 13. POSTTEST CONDITION OF AIR CONDITIONING DUCT

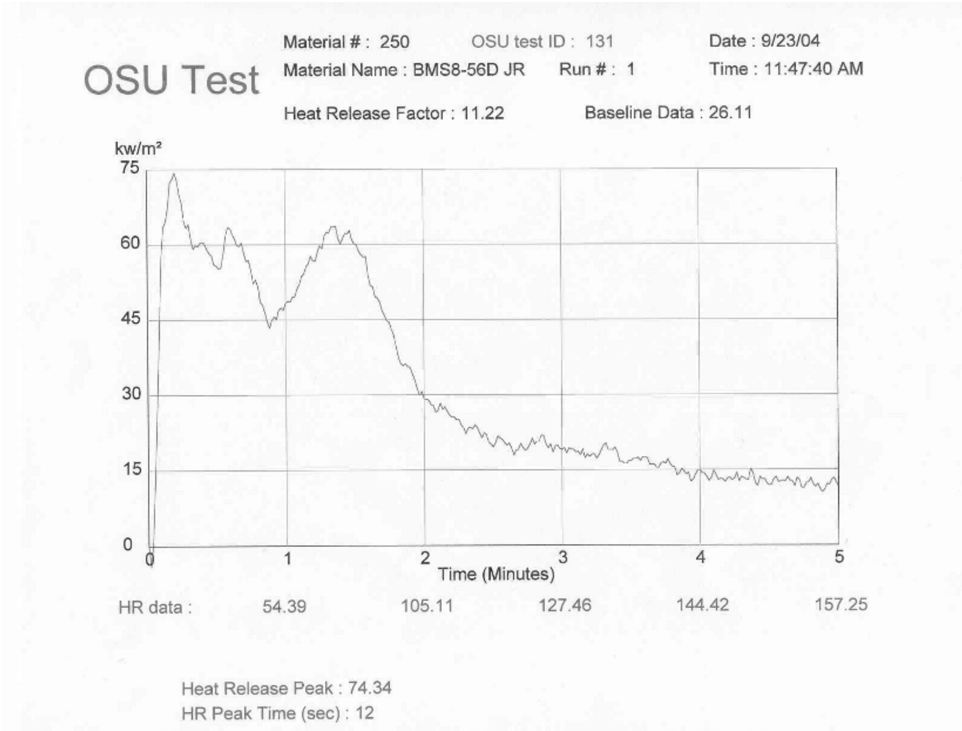

FIGURE 14. HEAT RELEASE TEST RUN 1

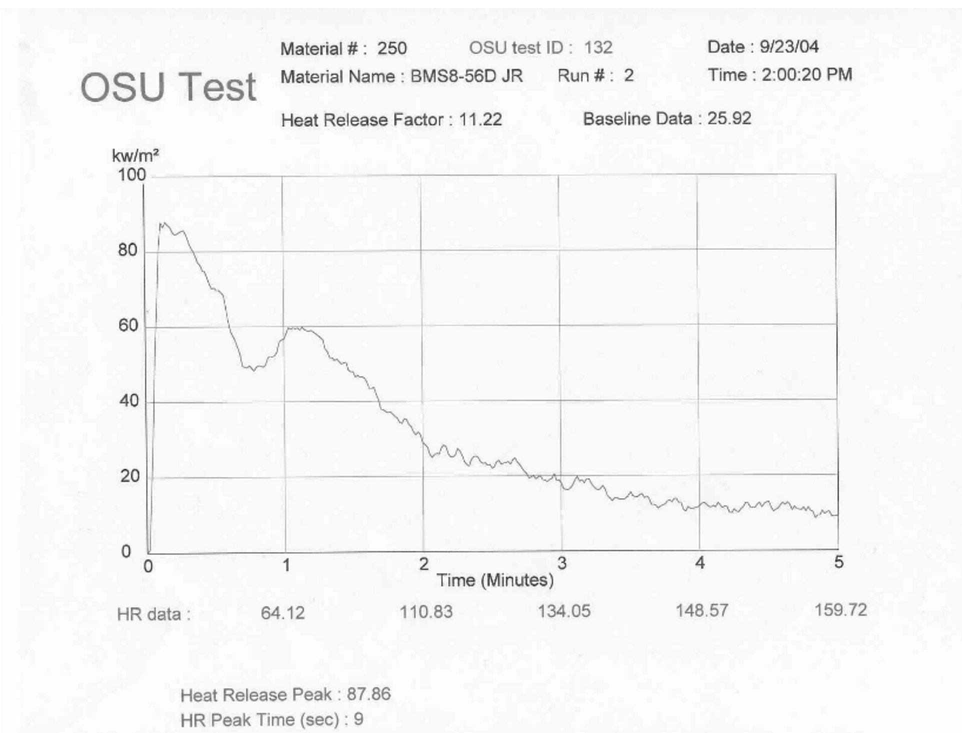

FIGURE 15. HEAT RELEASE TEST RUN 2

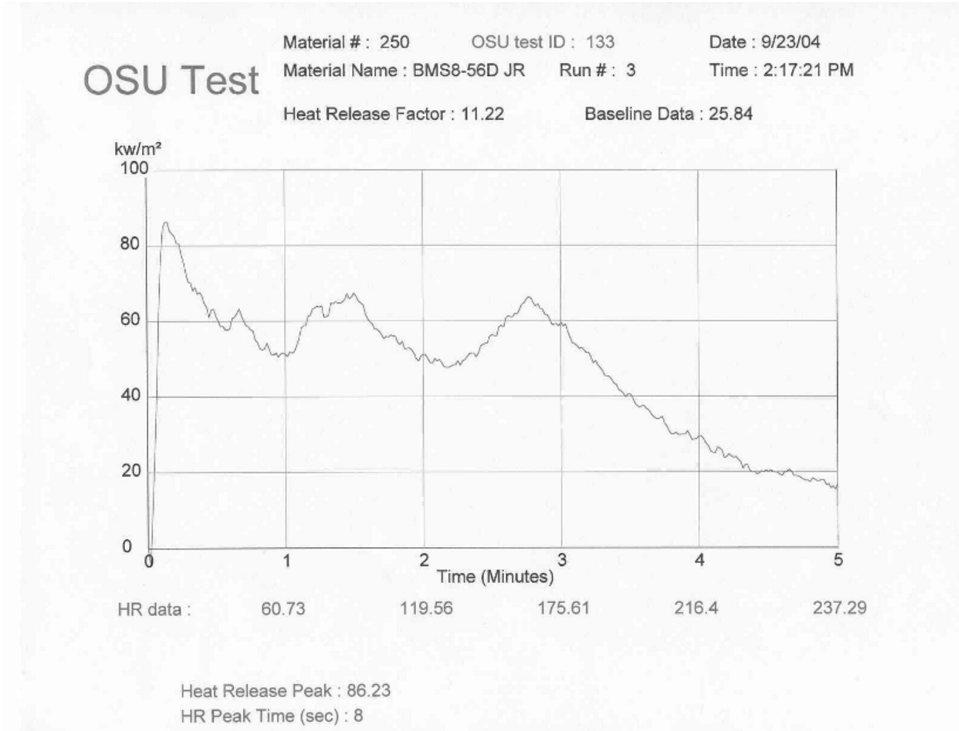

FIGURE 16. HEAT RELEASE TEST RUN 3

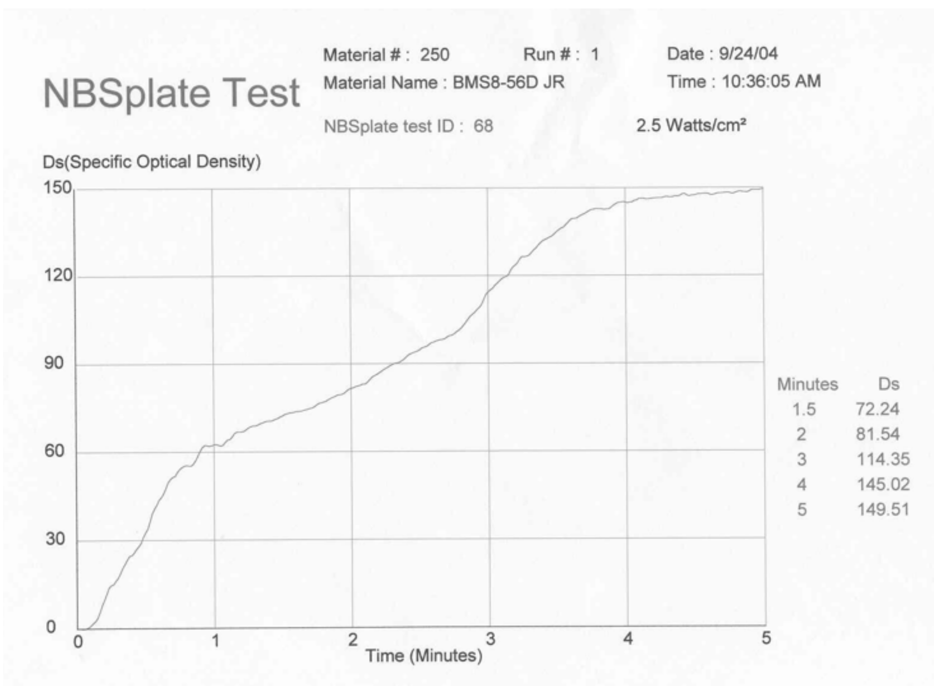

FIGURE 17. THE NBS SMOKE TEST RUN 1

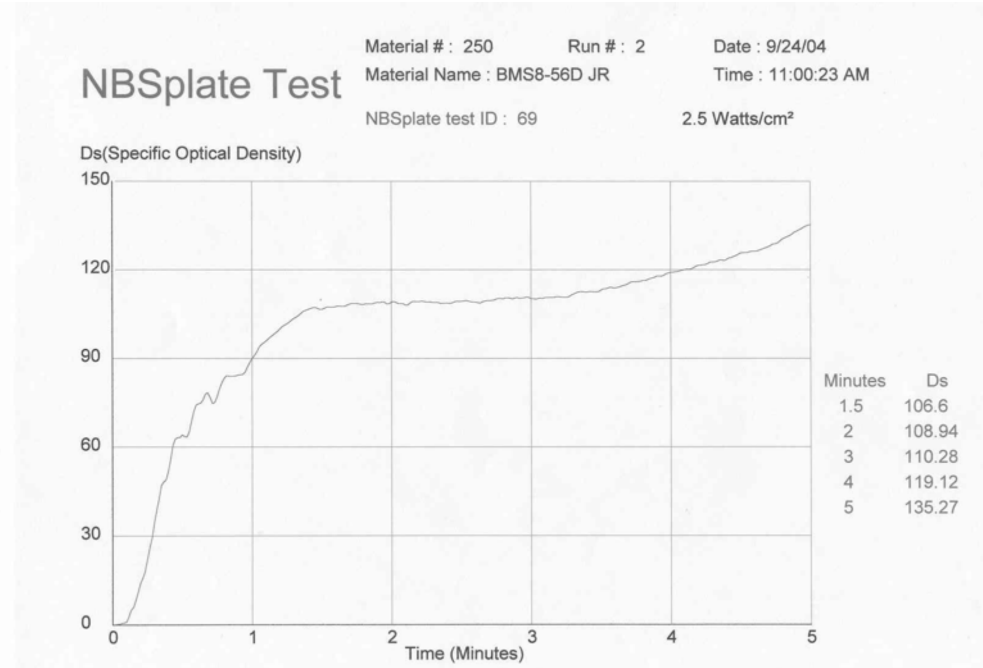

FIGURE 18. THE NBS SMOKE TEST RUN 2

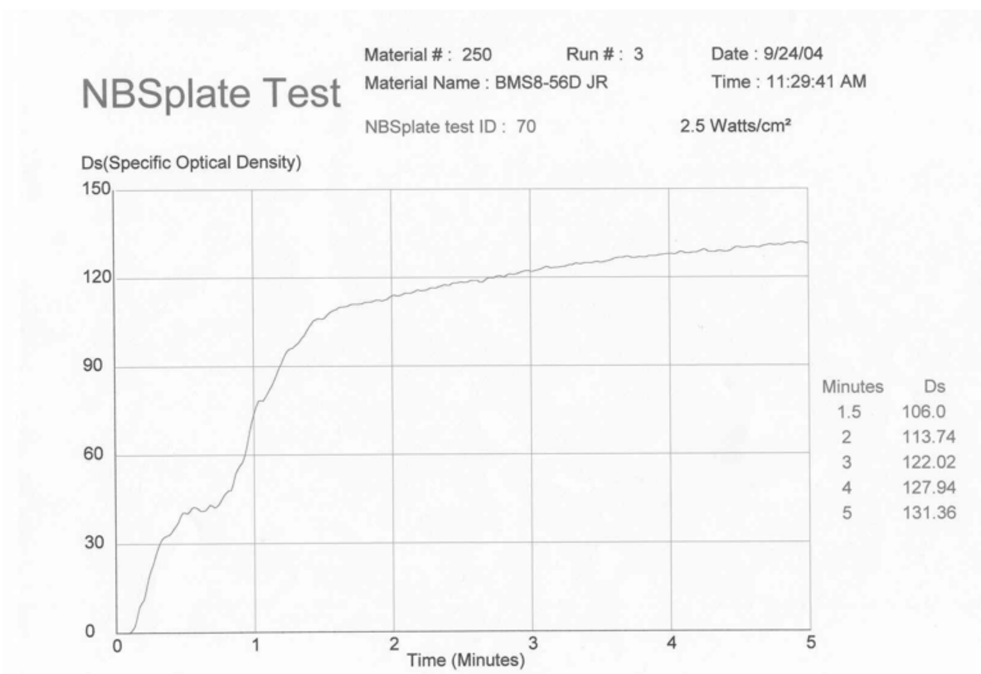

FIGURE 19. THE NBS SMOKE TEST RUN 3

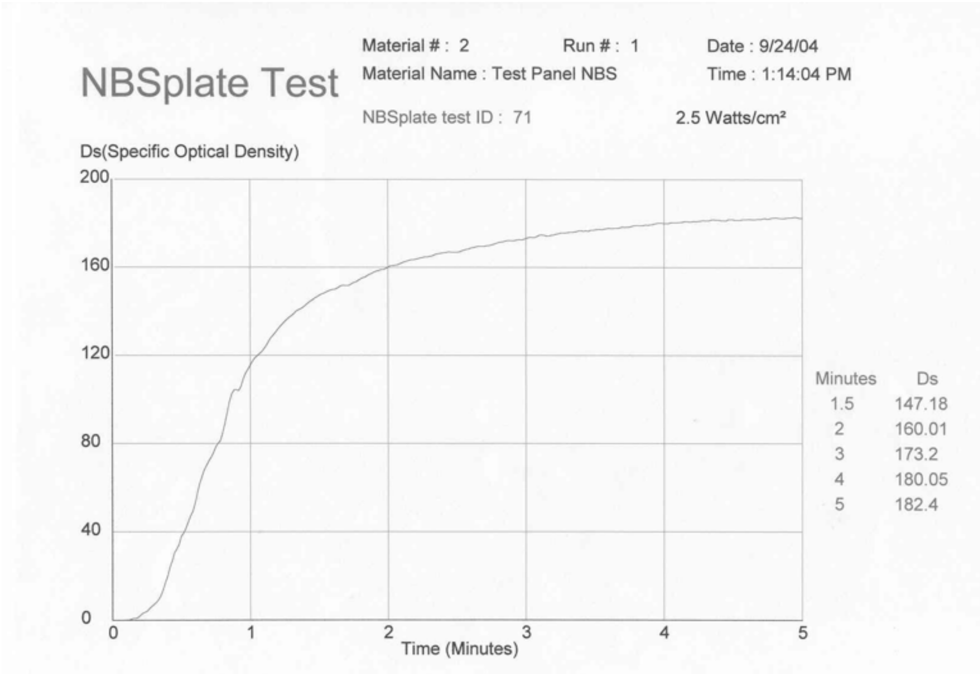

FIGURE 20. THE NBS SMOKE TEST RUN 4

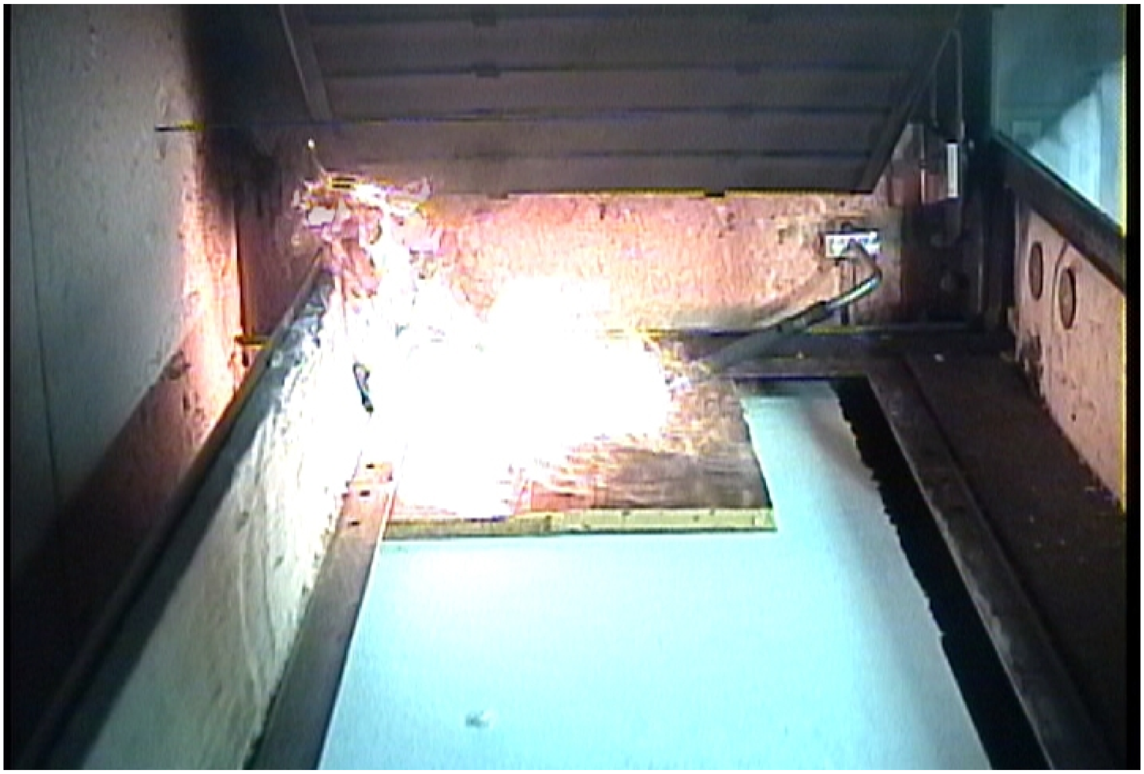

FIGURE 21. RADIANT HEAT PANEL TEST OF AIR CONDITIONING DUCT MATERIAL

FIGURE 22. RADIANT HEAT PANEL POSTTEST DUCT CONDITION

TABLE 1. TESTS RESULTS

Test No.	Test ID	Test 1	Test 2	Test 3	Comments
1	Vertical Bunsen Burner				
	Flame Extinguishing Time (sec.)	0	0	8 sec.	Third test specimen sparked and had after flame. Allowable extinguishing time is 15 sec. according to federal aviation regulations.
	Burn Length (cm)	6.99	6.99	7.62	Allowable burn length is 20.32 according to federal aviation regulations.
	Drip Extinguishing Time (sec.)	0	0	0	No drips
	Pass or Fail Test?	Passed	Passed	Passed	
2	Intermediate-Scale Test				
	Burn Length (cm)	304.8	304.8		Duct burned completely. Duct length was 304.8 cm.
	Heat Release Peak (kW/m^2)	91	63		Ignition source peak heat flux was 62 kW/m^2.
	Time to Peak Heat Flux (sec.)	63	66		This time is from ignition to heat flux peak.
	Peak Temperature (°C)	825	835		
	Pass or Fail Test?	Failed	Failed		FAA goal for improved in-flight fire safety is no fire propagation.
3	Heat Release Test*				
	Heat Release Peak (kW/m^2)	74.34	87.86	86.23	Federal aviation regulations requires that this value does not exceed 65 kW/m^2.
	Heat Release Peak Time (sec.)	12	9	8	
	Total Heat Release ($kW*min/m^2$)	105.11	110.83	119.56	Federal aviation regulations requires that this value does not exceed 65 $kWmin/m^2$.
	Pass or Fail Test?	Failed	Failed	Failed	
4	Microscale Combustion Calorimeter*	Fiberglass/ Epoxy Laminate	Urethane Foam		
	Heat Release Capacity (j/g-K)	123.0	436.0		There is no FAA requirement for this test.
	Total Heat Release (kJ/g)	13.4	24.7		
	Char (%)	12.6	2.9		

*Note: This test is currently not required by the FAA for ducts or conduits certification.

TABLE 1. TESTS RESULTS (Continued)

Test No.	Test ID	Test 1	Test 2	Test 3	Comments
5	Smoke Test*				
	Maximum Specific Optical Density (D_m)	145.02	119.12	127.94	
	Pass or Fail?	Passed	Passed	Passed	Federal aviation regulations requires that this value does not exceed 200.
6	Radiant Panel Heat Test*				
	Flame Propagation (cm)	Material ignited very fast; test was stopped before end	Material ignited very fast; test was stopped before end	N/A	Federal aviation regulations requires that this value does not exceed 5.08 cm.
	Flame Time (sec.)	Material ignited very fast; test was stopped before end	Material ignited very fast; test was stopped before end	N/A	Federal aviation regulations requires that this value does not exceed 3 sec.
	Pass or Fail?	Failed	Failed	N/A	

*Note: This test is currently not required by the FAA for ducts or conduits certification.

TABLE 2. HEAT SOURCE PROFILE

Test	Peak Heat Flux (kW/m^2)	Peak Temperature (°C)	Comments
Vertical Bunsen Burner	40.6	9.52	Exposure time is 12 seconds
Intermediate Scale	49.5	781.1	Total heat release calculated for 10 minutes Calorimeters on the crown.
Intermediate Scale	49.5	781.1	Total heat release calculated for 10 minutes Calorimeters on the crown.
Intermediate Scale	62.0		Total heat release calculated for 2 minutes. Calorimeters in front of foam.
Radiant Heat	173.9	-	Exposure time is 15 seconds; Just radiant panel on—flame was off.
Heat Release Rate	25.0	-	Exposure time is 5 minutes
Smoke	25.0	-	Exposure time is 4 minutes
Microscale Combustion Calorimeter	-	930.0	

*FAA Minimum Temperature is 843.3°C