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Impact of Altitude on Vertical Bunsen Burner Testing

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16. Abstract

A series of tests was conducted to determine the effect of altitude on FAA Bunsen burner testing. The standard 12-second vertical Bunsen burner test procedure from the FAA Aircraft Materials Fire Test Handbook was used for all testing, but the ambient air pressure was varied to represent altitudes ranging from sea level to 8000 feet. The first tests completed were initially with the Bunsen burner flame by itself. The mass flow rate of the methane fuel was decreased as the altitude increased to keep the flame height constant, which was expected because the mass of oxygen in the surrounding air also decreased. The flame temperature dropped slightly as altitude increased, but remained well above the 1550°F minimum. The flame was stable at all altitudes and no visual differences were noted as the air pressure decreased. Four different materials were tested as well, but only two were used across all the altitudes because they were the only materials that produced consistently long burn times, which was necessary to provide a basis for comparison. These two materials were a 1/32″ thick glass epoxy and a 1/32″ thick woven carbon fiber. The decreased ambient air pressure of the higher altitudes did not significantly affect the flame times or burn lengths of the two materials tested.

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LIST OF ACRONYMS

psia	Pounds per square inch absolute
psig	pounds per square inch gauge

EXECUTIVE SUMMARY

A possible problem was identified by aircraft material testing labs located in high-altitude locations. It was brought to the attention of the FAA that the lower ambient air pressure may have an effect on the various test apparatuses and the rate of material burning during testing. Therefore, testing was conducted using the FAA vertical Bunsen burner test method at varying ambient air pressures.

The vertical Bunsen burner test cabinet was set up in the FAA William J. Hughes Technical Center's environmental chamber. The test altitude was varied from sea level to 8000 feet in 2000 feet increments. This corresponds to air pressures of 14.7, 13.7, 12.7, 11.8, and 10.9 pounds per square inch absolute (psia). All testing was completed in accordance with the Vertical Bunsen Burner Test for Cabin and Cargo Compartment Materials, as described in the Aircraft Materials Fire Test Handbook. The operation of the test apparatus was automated because it had to be performed remotely from outside the environmental chamber.

The first tests were completed on the Bunsen burner flame at each altitude. To keep the required 1.5" flame height constant, the methane fuel flow rate was adjusted as the altitude increased. The mass flow rate of the fuel decreased from 0.122 g/min at sea level to 0.098 g/min at 8000 feet. The flame was stable and was visually identical throughout testing. The temperature of the flame decreased slightly from 1671°F at sea level to 1642°F at 8000 feet, but still remained well above the 1550°F minimum specified in the handbook.

Four different materials were tested, but only two were used across all the altitudes because they were the only ones that produced consistently long burn times, which were needed to provide a basis for comparison. Three samples of each material were tested at each altitude. The 1/32″ glass epoxy material produced an average flame time of 29.7 seconds and an average burn length of 1.5″. The 1/32″ woven carbon fiber material had an average flame time of 120.5 seconds and an average burn length of 9.4″. Varying the altitude had no significant effect on either set of test results.

1. INTRODUCTION

1.1 BACKGROUND

A potential problem was discovered when fire tests performed in high-altitude locations produced anomalous data for the FAA's 12-second vertical Bunsen burner test. It was hypothesized that the lower ambient air pressure and the corresponding lower mass of oxygen could have an effect on the burner flame and the burning of the test material on this and other FAA fire tests. The FAA must ensure that fire testing across all labs is as consistent and repeatable as possible, so if the altitude of a fire test lab could significantly affect the test results, limits might need to be placed on the maximum altitude at which tests could be conducted for aircraft material certification.

1.2 OBJECTIVE

The goal of this experiment was to determine how altitude affects the flame calibration and material test results for the 12-second vertical Bunsen burner test.

2. EXPERIMENTAL SETUP

2.1 TEST METHOD

All the testing in this experiment was based on the Vertical Bunsen Burner Test for Cabin and Cargo Compartment Materials section of the FAA Aircraft Materials Fire Test Handbook [1]. The only difference was that the ambient air pressure was varied to simulate altitudes from sea level up to 8000 feet. All testing was done in the FAA William J. Hughes Technical Center's environmental chamber, shown in figure 1.

Figure 1. The FAA technical center's environmental chamber

The handbook states that a Bunsen burner with a 3/8″ inside diameter barrel with methane at 2.5 pounds per square inch gauge (psig) should be used as the fuel source and there should be no premixing of the fuel with air. This produces a pure diffusion flame. The only adjustment that can be made to the burner is the flow rate of the methane gas with a needle valve. The flow rate of the fuel needs to be adjusted so the height of the flame is 1.5″. The flame needs to have a minimum temperature of 1550°F to be compliant.

For the 12-second vertical Bunsen burner test, the burner is lit prior to testing and then moved into position 3/4″ below the material sample for 12 seconds before being removed. The data that are to be collected from this test are the flame time, drip flame time, and burn length. The flame time is the amount of time the test sample continues to burn after the burner is removed from beneath the specimen. The drip flame time is the time that any flaming material continues to burn after falling from the specimen to the floor of the chamber. The burn length is the distance from the original edge of the sample to the furthest point of flame damage on the specimen. The material sample to be tested must be at least 3″ by 12″.

Three samples of each material must be tested. The test is considered a failure if the average flame time for all the specimens exceeds 15 seconds, the average drip flame time exceeds 5 seconds, or the average burn length exceeds 8″.

For this experiment, the Bunsen burner chamber was placed inside the environmental chamber, which meant that the tests had to be operated remotely. Therefore, the fuel flow was operated with an electronic solenoid valve, the burner was ignited with an electric spark plug, the burner was moved in and out of position under the sample with a linear actuator, and the tests were viewed with a video camera and monitor. The fuel pressure regulator was located inside the chamber so the fuel pressure would remain constant at 2.5 psig relative to the ambient pressure used during each test. The needle valve used to adjust the flame height was a manual valve located outside the chamber downstream of the fuel pressure regulator. Figure 2 shows the setup of the Bunsen burner test cabinet inside the environmental chamber.

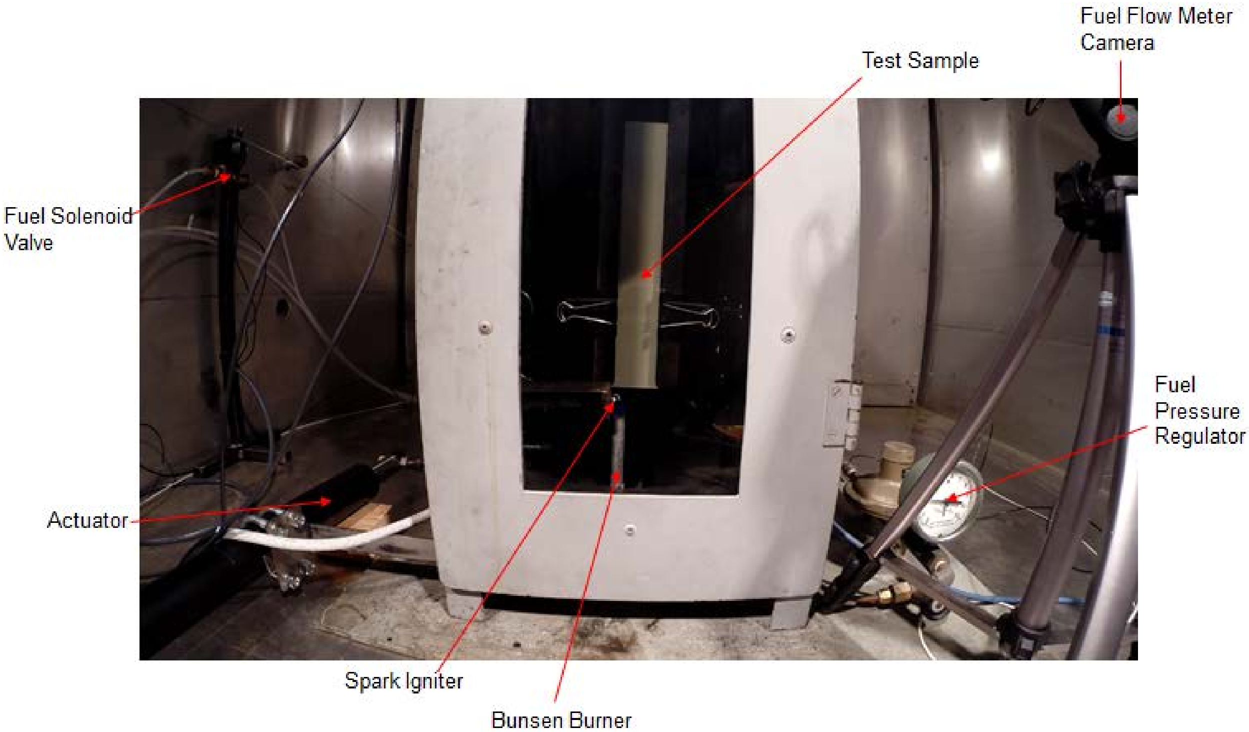

Figure 2. Automated vertical Bunsen burner test setup inside the environmental chamber

2.2 TEST PROCEDURE

For all of the tests conducted, the air pressure was varied in 2000 feet increments from sea level to 8000 feet. This corresponds with air pressures of 14.7, 13.7, 12.7, 11.8, and 10.9 pounds per square inch absolute (psia). First, tests were conducted on the Bunsen burner flame at each altitude. The height of the flame was set to the required 1.5″. The flame height was verified using a ruler placed next to the Bunsen burner and viewing the flame through the video screen. Then the volumetric fuel flow rate was recorded. This fuel flow rate was set for the test at each corresponding altitude to ensure that the flame height remained constant for the duration of testing. The temperature of the flame at each altitude was then measured using a 1/16″ Type K thermocouple placed 3/4″ above the top of the Bunsen burner tube. This distance was chosen because it is the same distance away that the material sample is placed.

After these tests were completed, material tests were conducted. Two different materials were tested, and three samples of each material were tested at each altitude. These were samples of a 1/32″ thick glass epoxy material and a 1/32″ thick woven carbon fiber material. Two other materials were used in preliminary tests, but there was a lack of burning in the polypropylene material and a lack of repeatability in the test results, even at the same altitude with the seat cover material. The flame time, drip flame time, and burn length were all measured. The flame time was measured while watching the video of the test, and the burn length was measured after removing the sample from the chamber, using the same procedure outlined in the vertical Bunsen burner handbook chapter.

3. RESULTS

3.1 FLAME TESTS

The first test completed was setting the flame height to 1.5″ at each altitude and recording the volumetric flow rate of the methane fuel. The handbook states that the total flame height should be 1.5″, which puts the height of the inner cone of the flame at 7/8″. The picture on the left of figure 3 shows the size and position of the inner cone of the Bunsen burner flame. The outer glow of the flame on the right is the height of the outer cone. Unfortunately, because the camera these tests had to be viewed through was not able to focus on the inner and outer cone at the same time, a compromise had to be made for measuring the flame height.

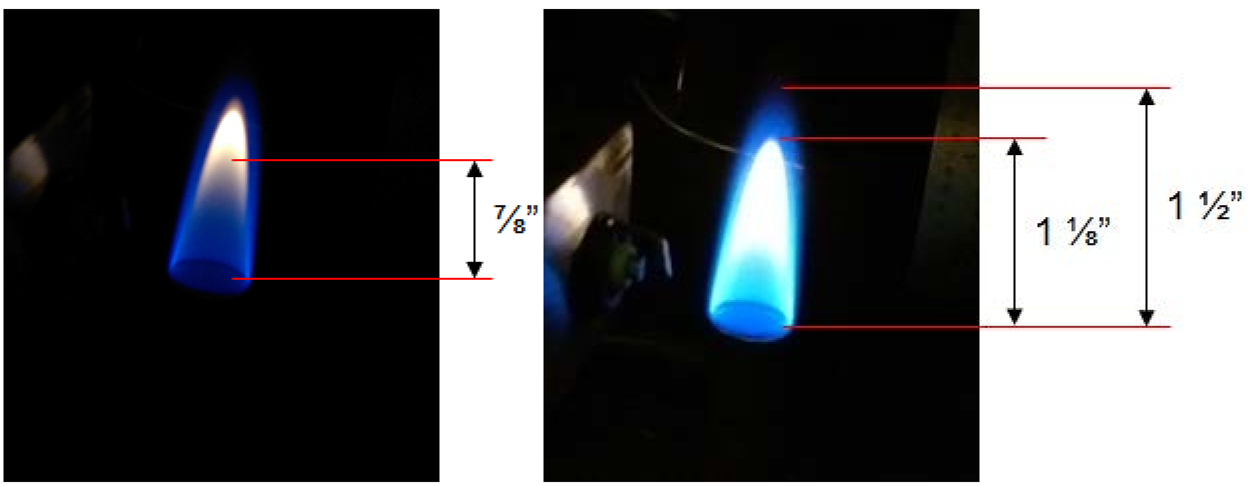

Figure 3. Bunsen burner flame inner cone (left) and outer cone (right)

These two pictures are actually of the same flame, but with a different focus of the camera. Because the 1.5″ flame height measurement is the most important, the camera was set up to produce a picture like the right side of figure 3. The flame at each altitude was set at a height of 1.5″ and the inner cone at 1.125″ was used to verify that the flame remained consistent as the pressure decreased. The burner flame was easily adjusted to the correct flame height at each altitude, appeared exactly the same each time, and was stable throughout testing.

As the simulated altitude was increased, the burner required an increased volumetric flow of fuel to keep the flame height constant. The volumetric flow rate is shown in figure 4. It increased from approximately 183 cm^3/min of methane at sea level to 199 cm^3/min at 8000 feet. However, when accounting for the decreased ambient pressure at high altitudes, the mass flow rate of the methane fuel decreased. Because there is a lower mass of oxygen to react with the methane at high altitudes, it is expected that less methane would be needed to maintain a constant air-to-fuel ratio. The mass flow rate is shown in figure 5. It was 0.122 g/min at sea level and decreased to 0.098 g/min at 8000 feet.

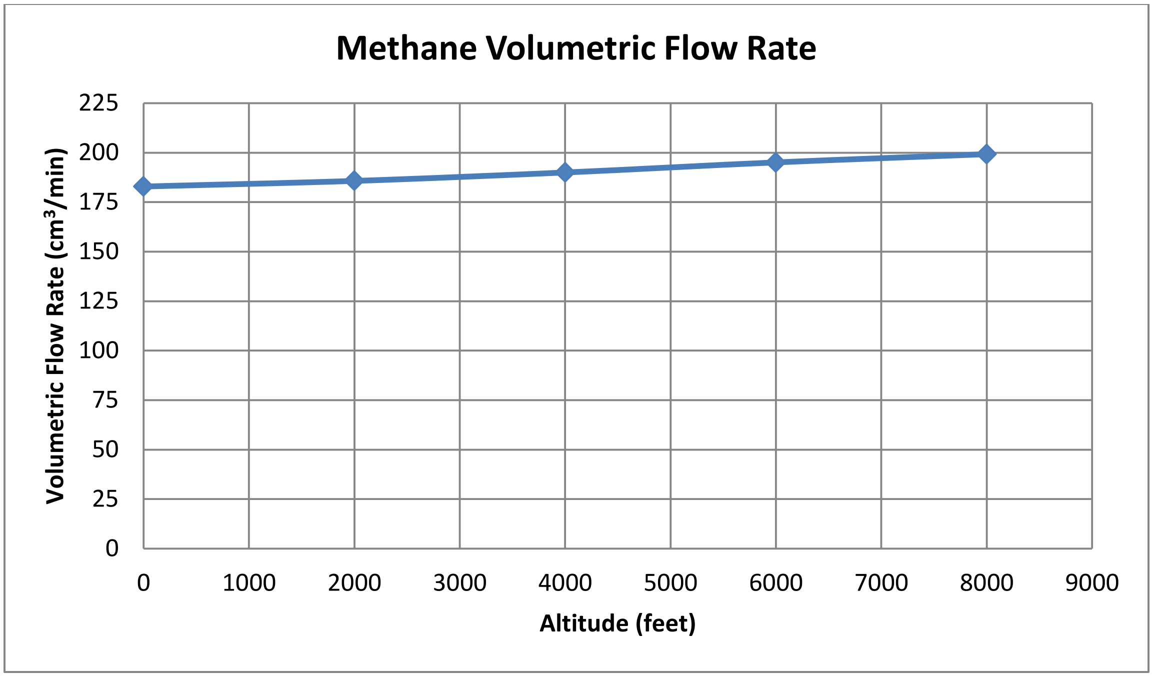

Figure 4. Volumetric flow rate of methane to the Bunsen burner with a 1.5″ flame height as a function of altitude

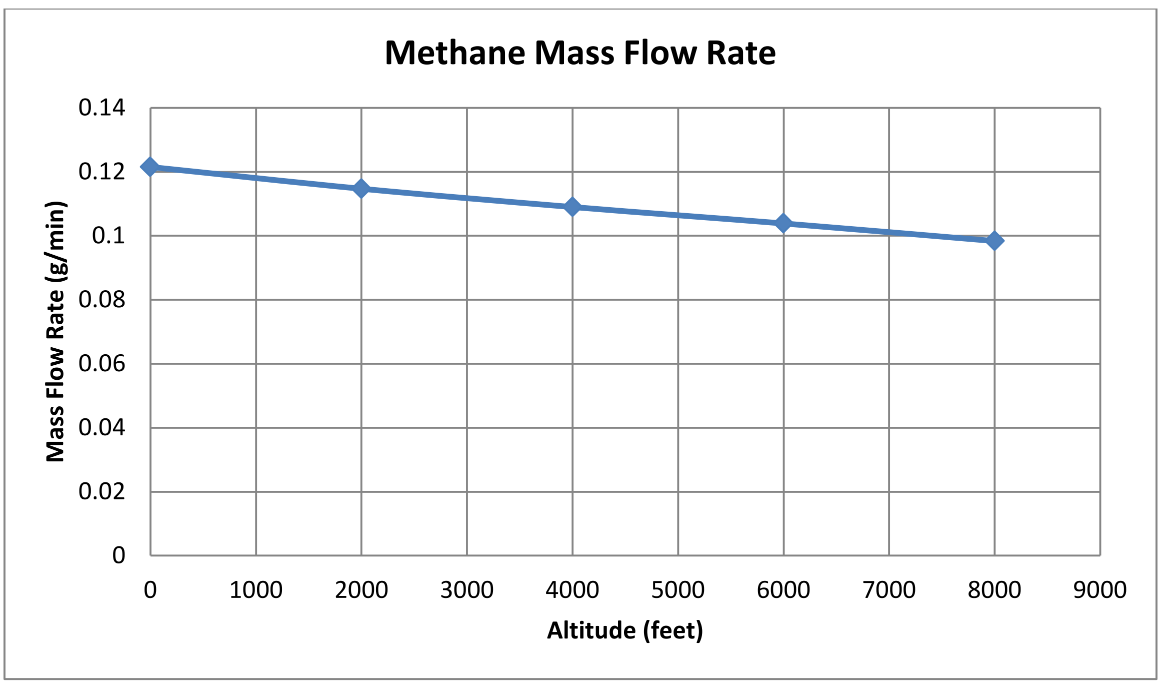

Figure 5. Mass flow rate of methane to the Bunsen burner with a 1.5″ flame height as a function of altitude

The temperature of the Bunsen burner flame was also measured at each altitude. The thermocouple was placed 3/4″ above the top of the burner tube because that is where the bottom edge of the sample is placed during material tests. Figure 6 shows that the temperature dropped slightly as the altitude increased, but it always stayed well above the 1550°F minimum temperature stated in the handbook. The measured temperature was 1671°F at sea level and dropped to 1642°F at 8000 feet.

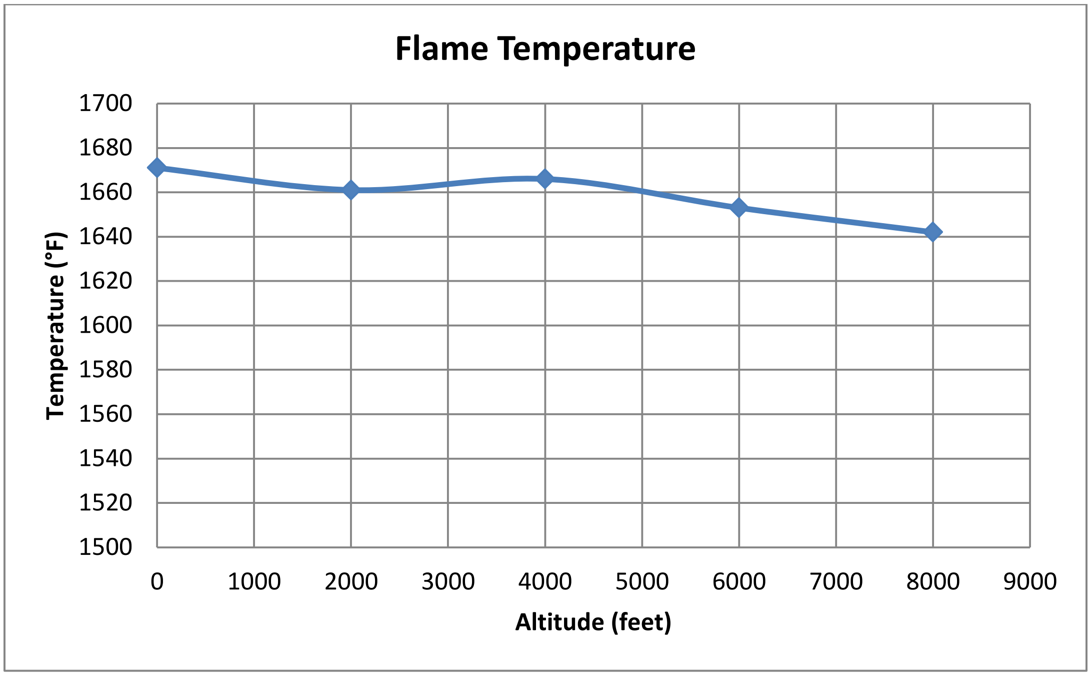

Figure 6. Bunsen burner flame temperature measured 3/4″ above the burner as a function of altitude

3.2 PRELIMINARY TESTS

Before material tests at altitude were conducted, preliminary tests were run on different materials to identify which ones would produce results that could show the effects of the change in air pressure. If the material was too flame resistant and produced little to no burning, then it would not show any difference between altitudes. Also, if a certain material's results were not repeatable at a constant altitude, then it would be impossible to determine which differences were caused by altitude and which differences were caused by the material itself.

The first material tested was a tan fabric aircraft seat cover material. Four tests were conducted at sea level. The flame times ranged from 2–11 seconds, and the burn lengths ranged from 3.25″ to 4.75″. It was difficult to get the fabric material to stay perfectly straight in the sample holder, which caused further inconsistencies in testing the material. The flame time was not repeatable enough to get good results from this material.

The second material tested was a polypropylene fiber material. It was thicker and stiffer than the seat cover material, so it fit better in the sample holder; however, it melted underneath the Bunsen burner flame and did not actually burn. Two samples were tested at sea level and two were tested at 8000 feet. Both altitudes produced the same average melt length of 4.125″ and zero flame time; therefore, this material was not a good selection to show differences caused by a change in altitude.

A 1/32″ glass epoxy material was then tested. Two samples were tested at sea level. They both had flame times of 28 seconds and the burn lengths were 1.75″ and 1.625″. This material produced consistent results and burned long enough so that the change in air pressure, if it caused the previous discrepancy, should have had an effect on the results. A 1/32″ woven carbon fiber material also produced good results. Two samples of that material were also tested at sea level. They had burn lengths of 9.25″ and 9.625″ and flame times of 116 and 121 seconds.

3.3 MATERIAL TESTS

The 1/32″ glass epoxy and 1/32″ carbon fiber materials were chosen to be tested at varying altitudes because they produced long flame times that could be affected by changes in air pressure. Three samples of each material were tested at altitudes varying from sea level to 8000 feet in 2000-foot increments; therefore, 15 tests were conducted for each material. The standard 12-second vertical Bunsen burner test procedure was used. Flame time, drip flame time, and burn length were all measured; however, drip flame time was zero for all tests conducted.

After conducting the experiment, the test results showed little to no correlation of a change in flame time or burn length with a change in altitude. Figure 7 shows the test results for the 1/32″ glass epoxy material. It compares the flame times and burn lengths at each altitude. Each dot represents the results from one test and the curved solid line is the average at each altitude. The dashed lines represent ±2 standard deviations from the mean of all the data points. These are in place to show which tests differed the most from the mean. The results were not perfectly consistent between tests, and because only three samples were tested at each altitude, one anomaly can have a large effect on the mean.

The flame time remained consistent from test to test and from altitude to altitude. There is no discernable trend to show that altitude had any effect on the flame time of the glass epoxy. There was more deviation in the burn lengths, because the average appears to decrease in the middle altitudes before the increase at 8000 feet. However, it appears that there was one low result at 4000 and 6000 feet that caused the average to decrease. The other two test results from those altitudes were consistent with the rest of the data.

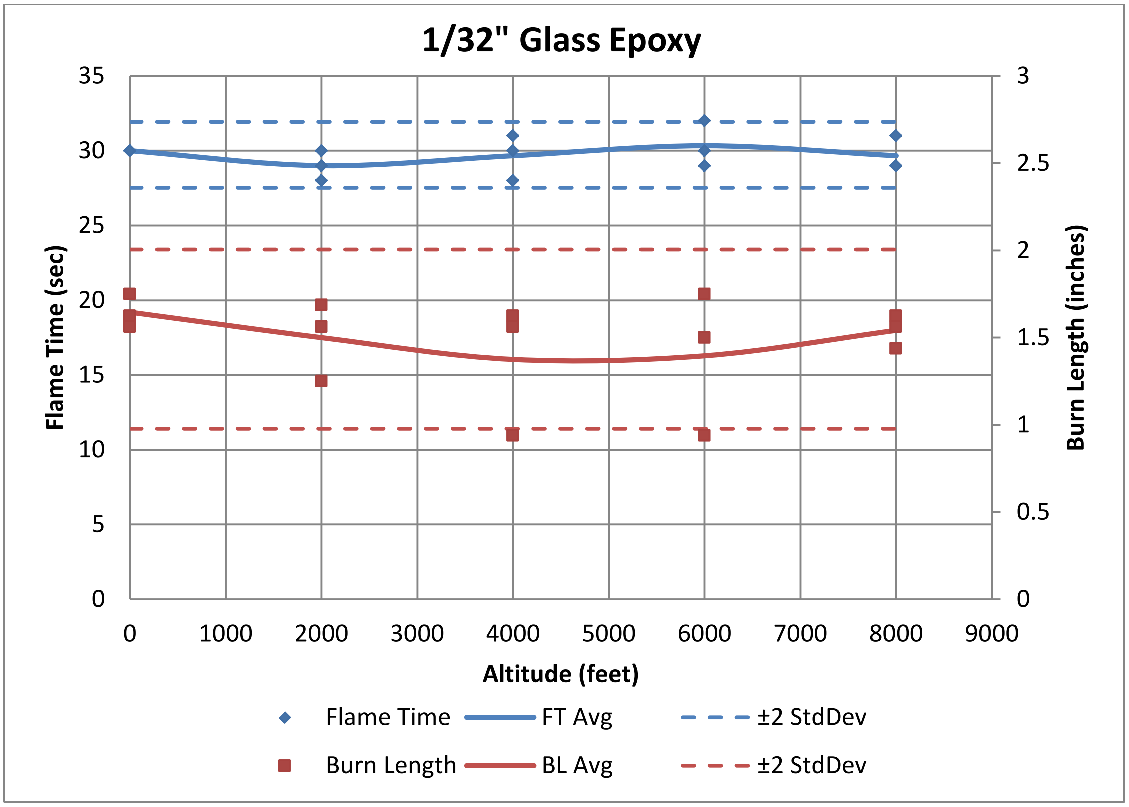

Figure 7. Material test data for 1/32″ glass epoxy material at each altitude

The 1/32″ woven carbon fiber material also showed that the change in ambient air pressure had little to no effect on the flame time and burn length. The experimental results are shown in figure 8. Similar to the graph in figure 7, the dots represent the results from each test, the solid line shows the average at each altitude, and the dashed lines shows ±2 standard deviations away from the overall mean. The altitude changes had little effect on the average for the flame time and burn length.

The biggest deviation comes from the burn length at sea level, in which one sample burned the entire 12″ length. However, this result was more than two standard deviations from the mean and was possibly an aberration. The results from the other two tests at sea level were very similar to the results at other altitudes.

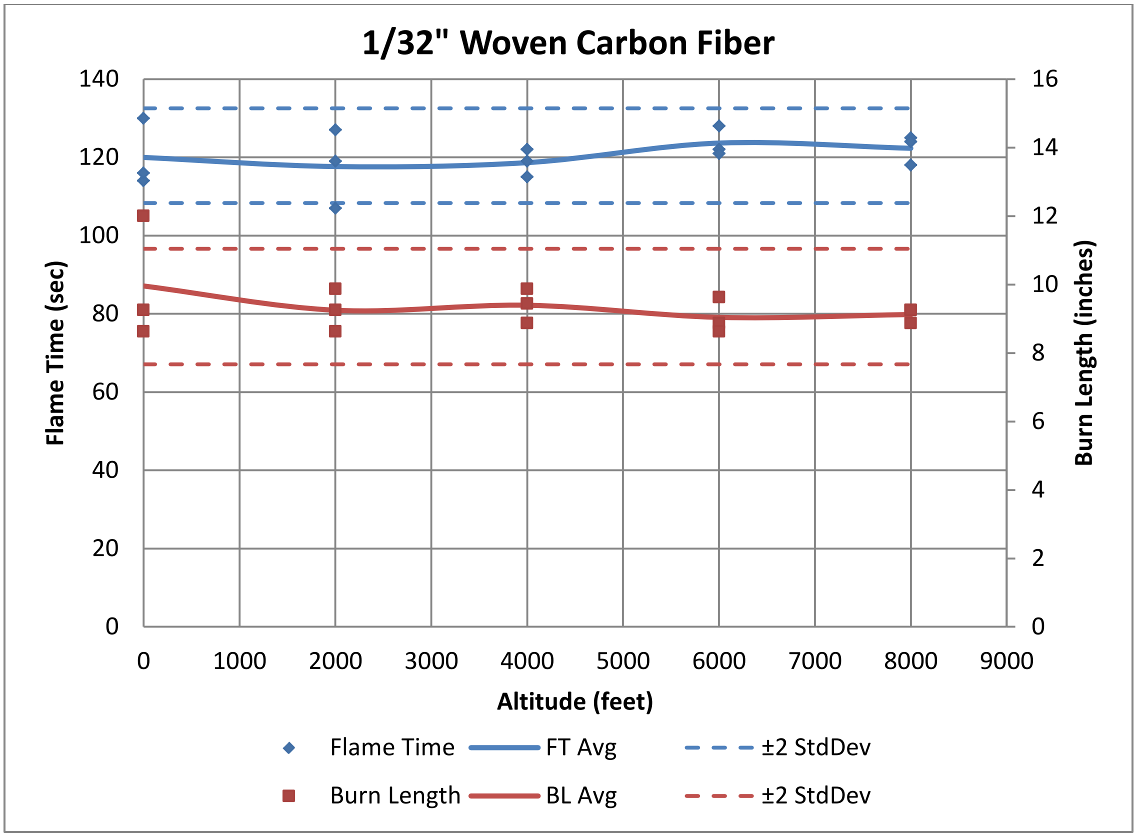

Figure 8. Material test data for 1/32″ woven carbon fiber material at each altitude

4. CONCLUSION

Several tests were conducted with the FAA's vertical Bunsen burner test apparatus at ambient air pressures ranging from sea level to 8000 feet. The Bunsen burner flame was tested by itself and was used to test materials in the 12-second vertical burner test. The flame was stable at all altitudes and appeared exactly the same visually throughout testing. The mass flow rate of the methane fuel was decreased as the altitude increased to keep the flame height constant, which was expected because the mass of oxygen in the surrounding air also decreased. The flame temperature dropped slightly as altitude increased, but still stayed well above the 1550°F minimum.

Four different materials were also tested, but only two were used across all altitudes because they were the only ones that produced consistently long burn times, which were needed as a basis for comparison. These two materials were a 1/32″ thick glass epoxy and a 1/32″ woven carbon fiber. The decreased ambient air pressure of the higher altitudes did not significantly affect the flame times or burn lengths of the two materials tested.

5. REFERENCES

1. FAA Report. (2000). Aircraft Materials Fire Test Handbook, Chapter 1: Vertical Bunsen Burner Test for Cabin and Cargo Compartment Materials (DOT/FAA/AR-00/12).