# NASA-STD-6001B Test 1 Upward Flame Propagation; Sample Length Impact on MOC Investigation

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Understanding the combustion behavior of materials in the elevated oxygen environments of habitable spacecraft is of utmost importance to crew safety and mission success. Currently, certification for unrestricted flight usage of a material with respect to flammability involves passing the Upward Flame Propagation Test of NASA-STD-6001B (Test 1). This test evaluates materials in a standardized test configuration for two failure criteria: self-extinguishment within 15 cm (6 in.) and the propensity of flame propagation by means of flaming material transfer. By the NASA standard, full-length samples are 30 cm (12 in.) in length; however, factors independent of the test method such as limited material availability or various nonstandard test configurations limit the full pretest sample lengths available for test. This paper characterizes the dependence, if any, of pretest sample length on NASA-STD-6001B Test 1 results. Testing was performed using the Maximum Oxygen Concentration (MOC) Threshold Method to obtain a data set for each sample length tested. In addition, various material types, including cloth (Nomex), foam (TA-301) and solids (Ultem), were tested to investigate potential effects of test specimen types. Though additional data needs to be generated to provide statistical confidence, preliminary findings are that use of variable sample lengths has minimal impact on NASA-STD-6001B flammability performance and MOC determination.

## Nomenclature

| | | |
|---|---|---|
| *JSC* | = | NASA Johnson Space Center |
| *MOC* | = | Maximum Oxygen Concentration |
| *NASA* | = | National Aeronautics and Space Administration |
| *ULOI* | = | Upward Limiting Oxygen Index |
| *WSTF* | = | White Sands Test Facility |

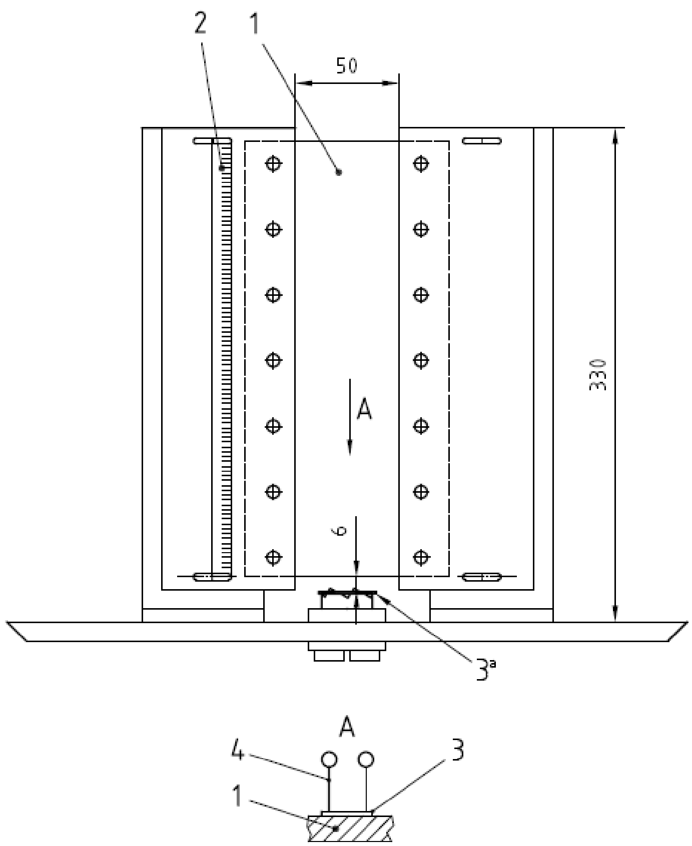
## I. Introduction

NASA uses NASA-STD-6001B[1], *Flammability, Offgassing, and Compatibility Requirements and Test Procedures, Test 1 Flammability*, primarily as a screening test for evaluating materials flammability in cabin environments. This test method evaluates the material's ability to self-extinguish as well as to its potential for propagation. The NASA White Sands Test Facility (WSTF) Materials Flight Acceptance Standard Testing section has performed flammability testing for several decades using standard length samples. Heat transfer as a result of a change in sample geometry can influence material performance in this test as longer samples could potentially conduct heat away from the combustion zone more efficiently than shorter samples. Increased length may allow sufficient time for flow to become laminar, which may affect flammability characteristics. A decrease in sample length forces the trailing edge closer to the failure criteria zone, increasing the significance of the interaction between the two. This paper's goal is to evaluate sample length as a variable and how it may impact self-extinguishment data.

NASA-STD-6001B Flammability Test 1 evaluates materials in a standardized test configuration. Materials first are ignited using a standardized chemical igniter as an overwhelming ignition source to ensure any further propagation analysis can be evaluated independent of ignition. Due to the chemical ignition method, the minimum igniter affected length is ~2 in. As a result, the minimum burn length for easily ignitable materials is ~2 in. Materials are then evaluated for flammability potential via two separate failure criteria: evaluation of material self-extinguishment within 15 cm (6 in.) and the propensity of the flame to propagate to other materials by means of flaming material transfer, via K-10 paper below the burning material test fixture. Tests are performed at the worst-case anticipated environmental conditions consisting of the highest anticipated pressure and oxygen concentration, commonly 30 percent oxygen and

70.3 kpa (10.2 psia). To pass NASA-STD-6001B Test 1, five replicates must not fail either of the two failure criteria. By the NASA standard, full-length pretest samples are 30 cm (12 in.) in length; however, standard-length test samples are not always feasible due to limited availability of test material or test article configuration. In addition, constraints associated with flight experiments could limit the size of samples requiring altered sample geometries in 1g tests to bridge the gap from flight to existing and future ground experiments.

The upward limiting oxygen index (ULOI) is the oxygen concentration where there is ~50 percent probability for a material to extinguish. The ULOI is a variation of American Society for Testing And Materials (ASTM) D2863[2] Limiting Oxygen Index (LOI) utilizing the NASA-STD-6001B test fixture and orientation (Figure 1). For this method samples are ignited at the base and exposed to a concurrent buoyant flow. The Maximum Oxygen Concentration (MOC) Threshold Method[3] is an elaboration of the NASA-STD-6001B Flammability Test 1. The MOC of a material is the maximum oxygen concentration in which a material does not fail either of the Test 1 failure criteria for a minimum of five replicate tests. Because the MOC Threshold Method established a threshold by which data sets can be compared, it is a useful tool for evaluating the impact of test variables.




**Key**

1 specimen
2 scale
3 ignitor
4 nickel-chrome wire

a The ignitor is placed inside the coil.

**Figure 1**: ISO14624-1/NASA-STD-6001B Test 1 Standard Specimen Holder [4]

## II. Sample Length Study

NASA-STD-6001B Test 1 specifies full-length samples of 30 cm (12 in.) in length; however, standard-length test samples are not always feasible due to limited availability of test material or test article configuration. A sample length study was pursued to evaluate the effects of sample length NASA-STD-6001B/MOC test results. Sample length effect on MOC was evaluated for initial sample lengths of 15, 18, 20 and 30 cm (6, 7, 8, and 12 in.). Although pretest sample length was varied, failure criteria remained constant requiring either a burn length of greater than 15 cm (6 in.) or ignition of the K-10 paper located below the test sample fixture. A decrease in sample length forces the trailing edge closer to the failure criteria zone, increasing the significance of the interaction between the two. Various material types were examined, including fabric, foam, and plastic solids, to investigate whether sample length effect varied with material type. Materials used in this evaluation (Table 1) were Solimide TA-301, Ultem, Nomex HT 90-40 (hemmed, double-rolled applied to leading and trailing edges using Nomex thread; unhemmed edges were shielded in the test configuration), Nomex HT 90-40 (unhemmed), and NX2245.

**Table 1: Test Material Summary**

| Material | Nominal Thickness [cm (in)] | Density [g/cm$^3$ ( lb/ft$^3$)] | Type | Burn Characteristic |
|---|---|---|---|---|
| Solimide®[a] TA-301 | 0.27 (0.11) | 0.006 (0.37) | Polyimide, Foam | Charring |
| Ultem®[b] | 0.03 (0.01) | 1.24 (77.41) | Polyetherimide, Film | Charring |
| Nomex®[c] HT 90-40 | 0.03 (0.01) | 0.66 (41.3) | Polyaramid Fabric | Charring |
| NX2245[d] | 0.04 (0.02) | 0.46 (28.7) | Polyaramid Fabric | Charring |

[a] Solimide® is a registered trademark of Imi-Tech Corporation, Elk Grove Village, Illinois.
[b] Ultem® is a registered trademark of SABIC Global Technologies BV, Bergen op Zoom, The Netherlands.
[c] Nomex® is a registered trademark of E. I. DuPont de Nemours and Company, Wilmington, Delaware.
[d] NX2245® is a Japanese-produced polyaramid fabric that was supplied courtesy of the Japan Aerospace Exploration Agency (JAXA).

Edge ignition testing was performed for this series to evaluate burn length and MOC to be consistent with standard requirements. Nomex is not used in flight applications with edges exposed and is commonly tested with edges hemmed. Other test configurations, such as surface ignition or multiple fabric layers, are known to exhibit elevated MOCs using the same material types.

## III. Test Data and Observations

NASA-STD-6001B sample length impact on MOC evaluation data is presented in Table 2. A summary of MOC sample length effects data for the various materials is presented in Figure 1 and ULOI summary in Figure 2.

**Table 2: NASA-STD-6001B Flammability Test 1 Maximum Oxygen Concentration Sample Length Impact**

| | Sample Length | | Pressure | ULOI[a] | MOC[b] |
|---|---|---|---|---|---|
| | cm | in. | psia | | |
| **Solimide TA-301** | 15 | 6 | 10.2 | 25.6 | 22.0 |
| | 18 | 7 | 10.2 | 25.2 | 23.0 |
| | 20 | 8 | 10.2 | 24.7 | 23.0 |
| | 30 | 12 | 10.2 | 24.3 | 23.1 |
| **Ultem** | 18 | 7 | 10.2 | 25.8 | 23.1 |
| | 20 | 8 | 10.2 | 24.0 | 23.1 |
| | 30 | 12 | 10.2 | 24.5 | 23.0 |
| **Nomex HT 90-40 (Hemmed)** | 15 | 6 | 10.2 | 28.5 | 25.0 |
| | 18 | 7 | 10.2 | 29.3 | 25.0 |
| | 20 | 8 | 10.2 | 29.8 | 25.0 |
| **Nomex HT 90-40 (Unhemmed)** | 15 | 6 | 10.2 | 25.9 | 24.1 |
| | 18 | 7 | 10.2 | 26.1 | 24.1 |
| | 20 | 8 | 10.2 | 25.4 | 24.0 |
| | 30 | 12 | 10.2 | 25.8 | 23.1 |

| | Sample Length | | Pressure | ULOI[a] | MOC[b] |
|---|---|---|---|---|---|
| | cm | in. | psia | | |
| | 15 | 6 | 10.2 | 25.6 | 22.0 |
| NX2245 | 15 | 6 | 10.2 | 26.2 | 25.0 |
| | 18 | 7 | 10.2 | 26.3 | 25.0 |
| | 20 | 8 | 10.2 | 27.6 | 25.0 |
| | 30 | 12 | 10.2 | 26.5 | 25.1 |

[a] ULOI (Upward Limiting Oxygen Index) is a variation of ASTM D28632 Limiting Oxygen Index (LOI) utilizing the NASA-STD-6001B test fixture and orientation

[b] MOC (Maximum Oxygen Concentration) per NASA-STD-6001B, Test 1

All $O_2$ Concentration measurements were made to a tolerance of +0.15%/-0.0 %

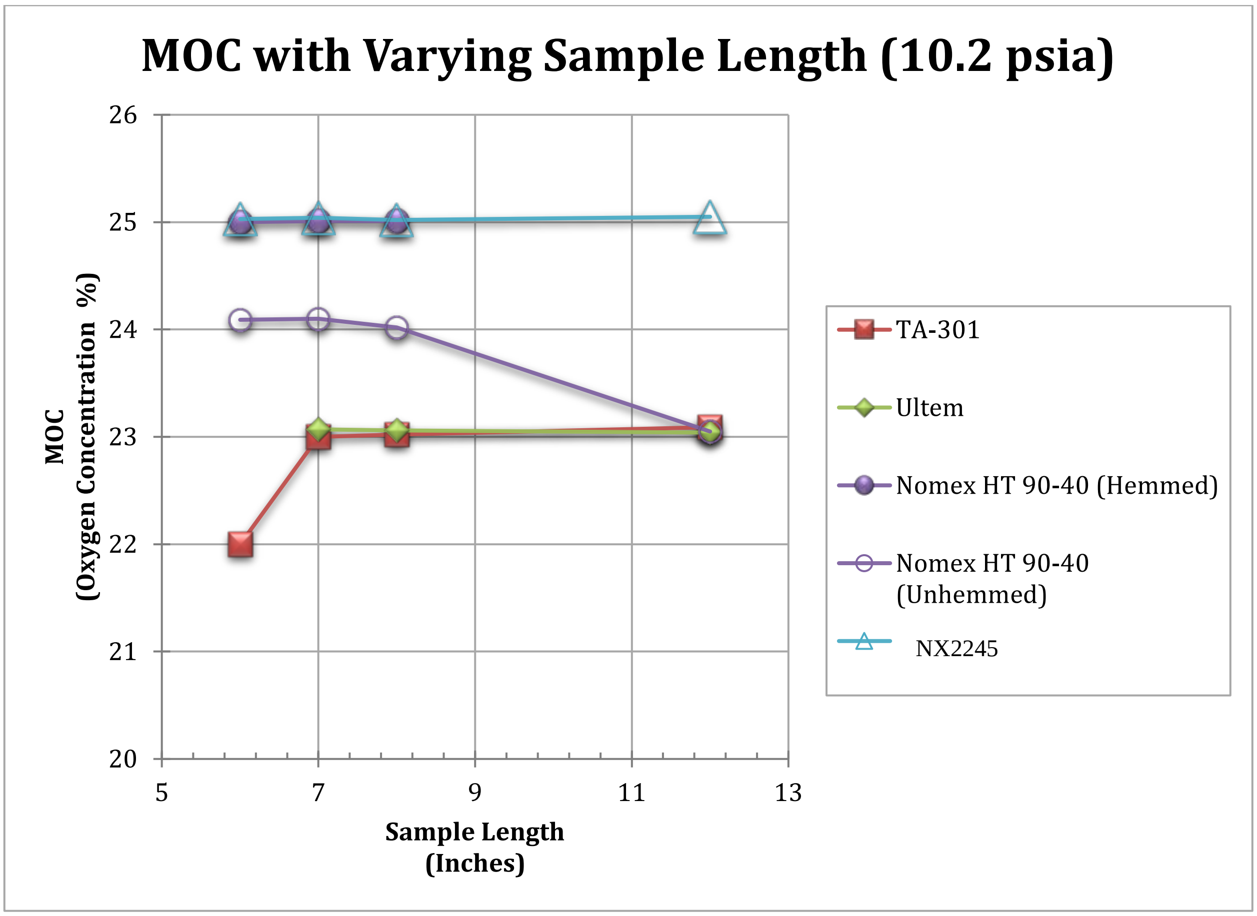



**Figure 2: NASA-STD-6001B Flammability Test 1 Maximum Oxygen Concentration (MOC) Sample Length Impact Evaluation**

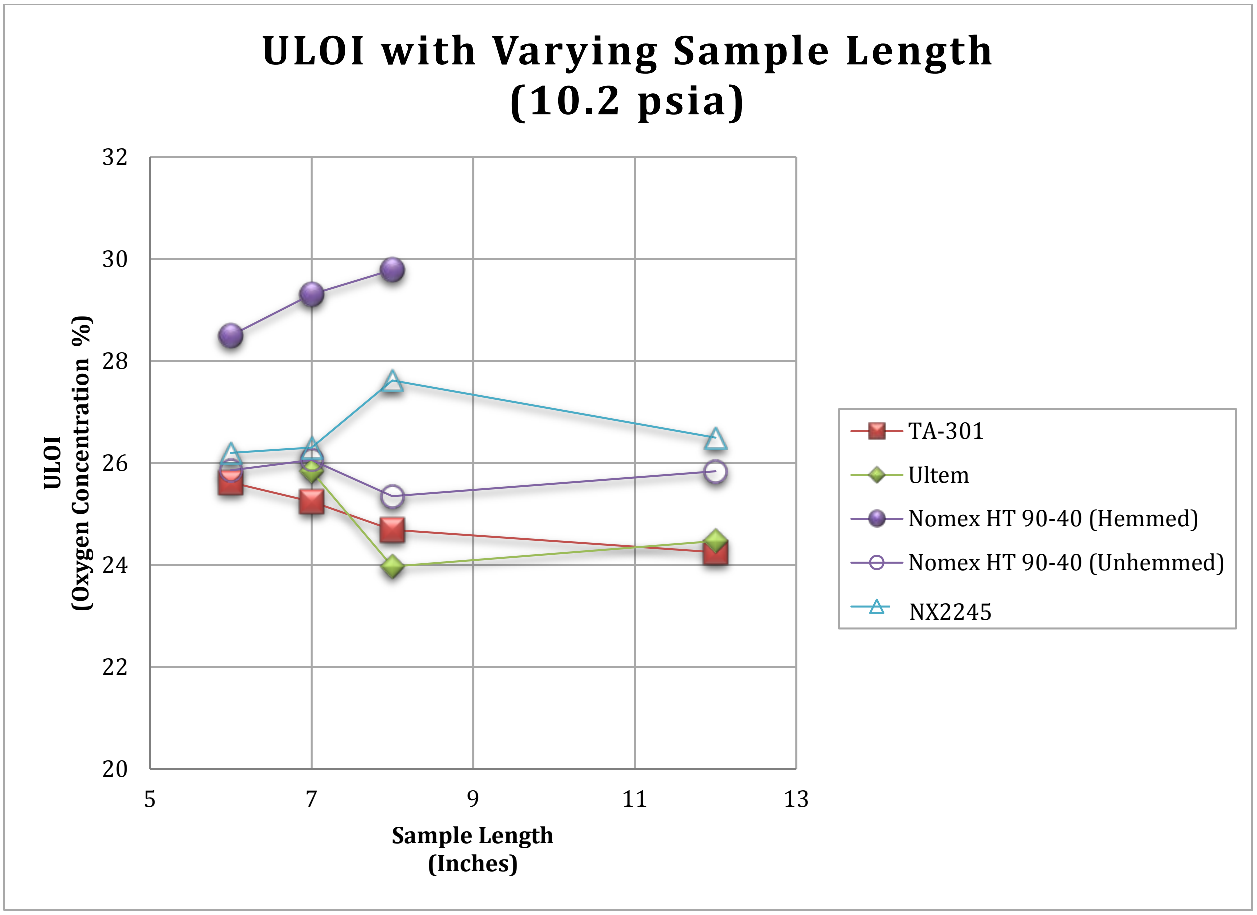



**Figure 3: NASA-STD-6001B Flammability Test 1 Upward Limiting Oxygen Index (ULOI) Sample Length Impact Evaluation**

Examination of MOC data in Figure 2 reveals no sample length impact on MOCs for Ultem, Nomex HT 90-40 (Hemmed), and NX2245. All oxygen concentration measurements were made to a tolerance of +0.15%/-0.0 %. The MOC measurements presented here are considered a single data point resulting from multiple burn length determinations. Replicate MOC tests would be required for error determinations to be made.

For material TA-301, the sample length of 6 in. shows a one percent lower MOC than MOC at 7, 8, and 12 in. in Figure 2. This relatively small drop of one percent in MOC for the 6-in. sample length compared to the other sample lengths may be due to standard TA-301 NASA-STD-6001B flammabity performance variability as the drop can be attributed to a single 6-in. sample burning the full length at 23 percent oxygen while the rest of the data points fall well into family with the remaining burn lengths at that concentration regardless of sample length (Figure 4). More data is required to evaluate the statistical uncertainty of the test method in regards to this test material.

If further testing concludes that a one percent drop is not within standard performance variability for this material at these conditions, two possible explanations for a drop of MOC at the 6-in. burn length may exist. A first theory is that additional material beyond the 6-in. failure criteria functions as a heat sink. Without any extra material beyond the 6-in. failure criteria, the heat may accumulate and cause the material to burn more aggressively as it approaches the edge. Another theory is that as the flame approaches the trailing edge of the sample, that flame stretching upward may have the propensity to ignite the edge of the sample and burn back. Though the variation for 6-in. The TA-301 samples of one percent may be due to standard test variability, but nonetheless it may be a best practice to perform testing with a minimum of 7-in. samples due to the heat sink and trailing sample edge burn-back concerns presented above.

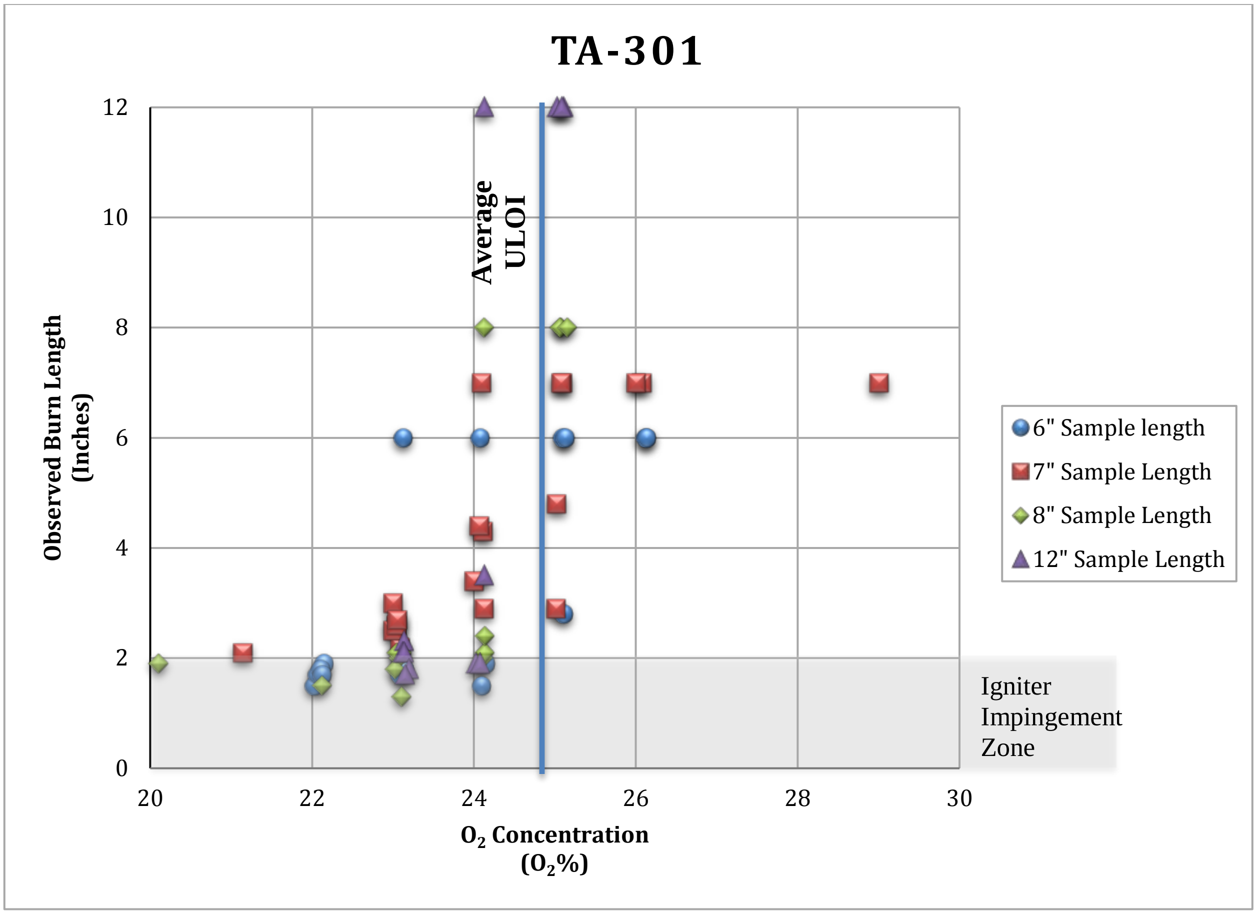



**Figure 4: NASA-STD-6001B Flammability Test 1 Sample Length Impact Evaluation, TA-301 Individual Sample Burn Lengths**

For Nomex HT 90-40 there are two points of interest to examine. First, that MOC in general falls one percent lower than the same material tested in a hemmed configuration (Figure 2). Secondly, a double-rolled hem can act as a heat sink both at the beginning edge of the material as well as the trailing edge. This heat sink effect is evident when comparing the ignition of hemmed and unhemmed Nomex test samples. The double-rolled hem configuration is known to act as a fire stop, impeding flames from stretching up and attaching to the trailing edge of the sample and burning back. Double-rolled hems have also been observed to perform as a fire stop for general flame propagation at various oxygen concentrations. In combination, both of these factors allow the implementation of a double-rolled hem to increase MOC by one percent.

When looking at the Nomex HT 90-40 data and comparing sample length effects on MOC, a relatively small drop of one percent in MOC for the 12-in. sample length compared to the other sample lengths (6, 7, and 8 in. as seen in Figure 2). This drop may be due to standard Nomex HT 90-40 NASA-STD-6001B flammabity performance variability Figure 5). This periodic erratic performance observed between 24 and 27 percent is typical transition zone behavior (Figure 5). Material flammability performance is not fully consistent or predictable with these observed increased flammability performance outliers arising within the oxygen concentration transition zone. This preliminary assumption would require further testing in order to validate in which Nomex HT 90-40 burn length statistical flammability variability at 24 percent oxygen would be further examined. When looking at Figure 5 bulk burn length data, it is also observed that a steady increase in burn length as a function of oxygen concentration in addition to periodic erratic longer burn lengths are indicative of the flammability MOC transition zone.

Test results for ULOI (Figure 3) show no appreciable dependence on pretest sample length. Variation in the ULOI data is likely a result of the test method variability. Replicate test series at each sample length are needed to validate this assumption. If an average of the ULOI results is taken across the pretest sample lengths, represented by a horizontal line, a representative ULOI for each material can be obtained. These representative values are shown as vertical lines in Figures 4 and 5. The ULOI represents the oxygen concentration with 50 percent probability of failure.

This coincides well with the data (Figures 4 and 5) as this vertical line is visually located within the transition zone, the region of oxygen concentrations where a material transitions from low burn length/self-extinguishment (test pass condition) to high burn lengths (test fail condition).

One percent MOC drops for a single length of TA-301 and Nomex HT 90-40 (unhemmed) may be due to standard flammabity performance variability as the drop can be attributed to a single data point burning past the failure criteria for that sample length while the rest of the data points fall well into family with the remaining burn lengths at that concentration regardless of sample length (Figures 4 and 5). This one percent drop helps establish the lower bound of the transistion zone. Further testing is needed to better capture the errors of these data.

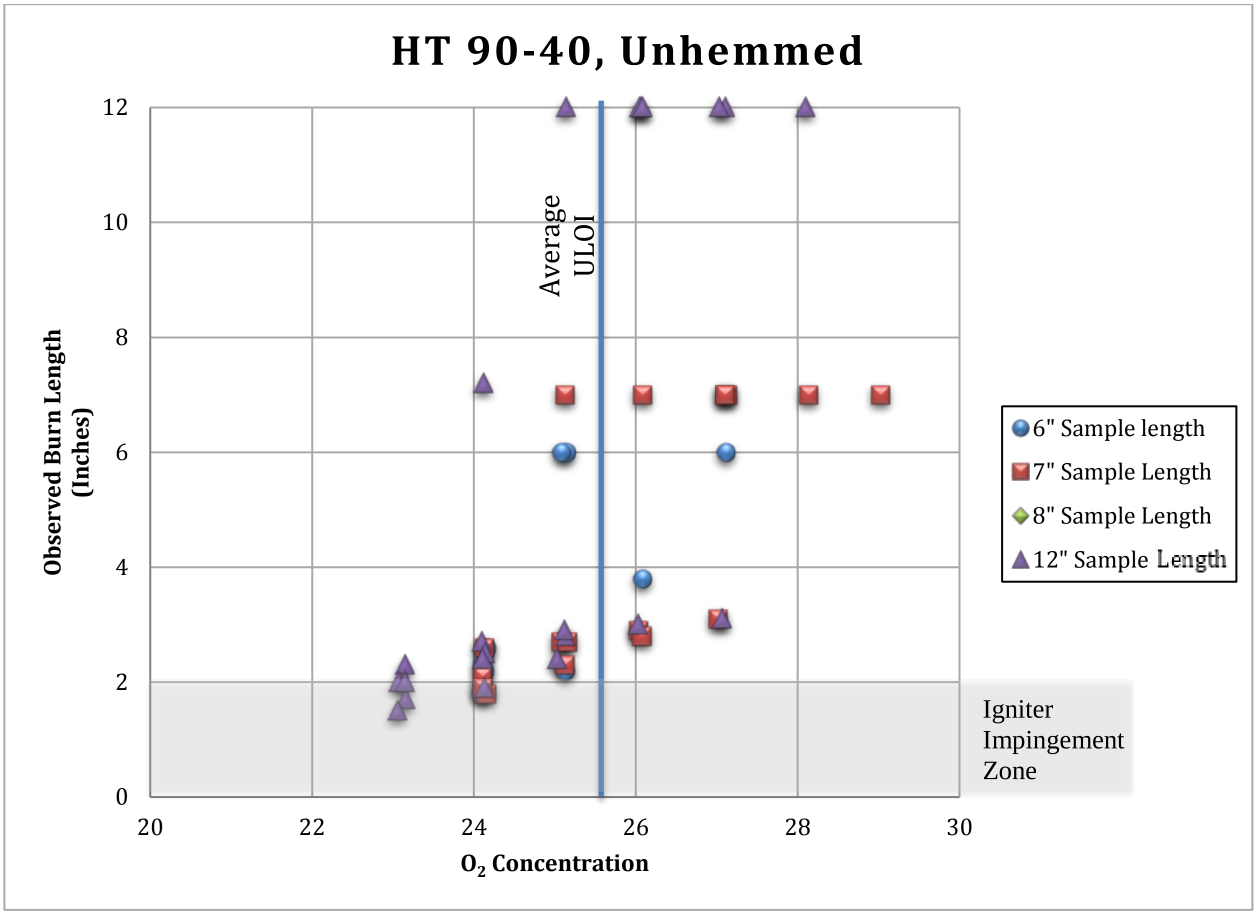



**Figure 5: NASA-STD-6001B Flammability Test 1 Sample Length Impact Evaluation, HT 90-40 Individual Sample Burn Lengths**

## IV. Conclusion

In conclusion, examination of sample length impact on NASA-STD-6001B Flammability MOC data reveals no sample length impact for three of the five materials tested (Ultem, Nomex HT 90-40 (Hemmed), and NX2245) when tested at 6, 7, 8, and 12 in. A one percent drop over consistent data for other sample lengths was observed for the 6-in. sample of TA-301 and for the 12-in. sample of the Nomex HT 90-40 unhemmed material. The one percent MOC drops for a single length for TA-301 and Nomex HT 90-40 unhemmed may be due to standard flammability performance variability as the drop can be attributed to a single data point burning past the failure criteria for that sample length while the rest of the data points fall well into family with the remaining burn lengths at that concentration regardless of sample length (Figures 4 and 5). As MOC measurements are single data points resulting from multiple burn length determination, this preliminary assumption would require further testing to validate statistical flammability variability at the oxygen concentration of interest.

Though additional data needs to be generated to provide statistical confidence, preliminary findings are that the use of variable sample lengths has minimal impact on NASA-STD-6001B flammability performance and MOC determination and that data generated with variable sample length materials can be considered acceptable. Nonetheless, due to potential heat sink effects that longer sample lengths may provide, and concerns with concluding sample edge burn back, it is still good practice to use a minimum of an 8-in. sample length if at all possible and ideally, the standard 12 in. when material is readily available. To further investigate the heating effect theory, additional testing is planned with the use of infrared videography to characterize how additional sample length affects thermal transfer within the sample.

## Acknowledgments

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## References

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