COMPOSITE MATERIAL FIRE FIGHTING

Presented to: International Aircraft Materials Fire Test Working Group
Renton, Washington, USA

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External Fire Control Defined

- **Extinguishment of the body of external fire.**
  - Our question: Will the composite skin continue to burn after the pool fire is extinguished, thereby requiring the fire service to need more extinguishing agent in the initial attack?
- **Cooling of the composite skin to below 300°F (150°C).**
  - Our question: How fast does the composite skin cool on its own and how much water and foam is needed to cool it faster?
    - 300°F (150°C) is recommended in the basic ARFF training.
    - Common aircraft fuels all have auto ignition temperatures above 410°F (210°C).

Testing in Two Phases

First phase:

- **Determine if self-sustained combustion or smoldering will occur.**
- **Determine the time to cool below 300°F (150°C)**

Second phase:

Determine how much fire agent is needed to extinguish visible fire and cool the material sufficiently to prevent re-ignition.

Phase I testing completed.

Exposure times of Phase I tests:

- 10, 5, 3, 2, & 1 minutes
  - FAR Part 139 requires first due ARFF to arrive in 3 minutes.
  - Actual response times can be longer or shorter.

Material Used

- **Air Force carbon fiber laminate composite.**
  - Flat panels, 12 inches by 18 inches.
  - Unidirectional prepreg; Cytec 5208/T-300, 16 plies, (0, 90, +45, -45)S2.
  - 350°F cure, Tg 410°F.
- **Panels built at Ogden ALC in the composite shop.**
  - Made for F-16 composite repair training.
- **Epoxy/Fiber content test performed by Cytec and the Air Force.**
  - 60% fiber, 40% resin.

Results: Panel Weights

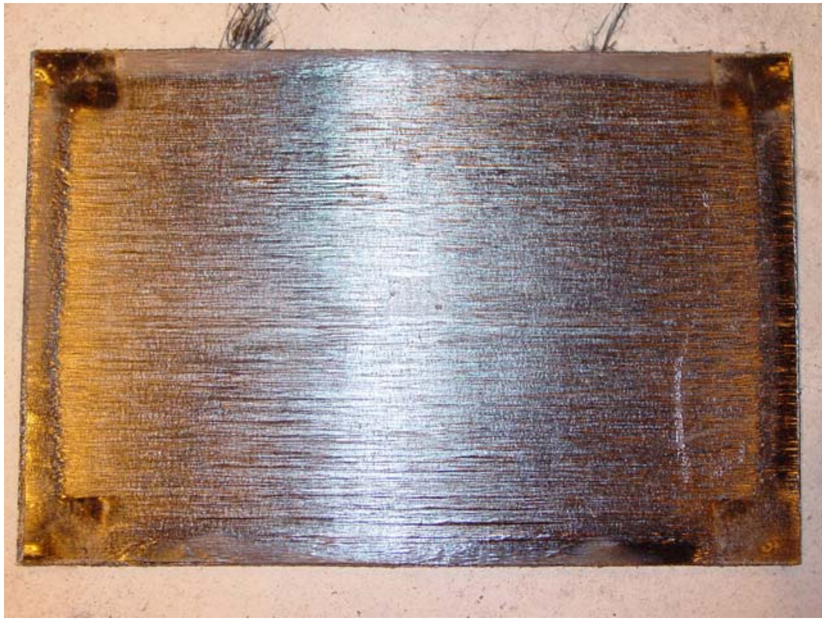
- **At 1 minute exposures (average of 4 tests) 83.875% of the panel weight remained.**
- **After 10 minute exposures (average of 5 tests) 68.68% of the panel weight remained.**
- **Longer exposures burn off more epoxy, and regularly caused release of fiber clusters due to severe damage to the exposed surface.**
- **Burner caused a roughly circular hole in the center of the panel.**
  - Damage penetrated through first 4 plies.
  - Jagged cut and fragile gray fiber ends noted along edges of the hole which appear to be the result of fiber oxidation.

Results: Panel Weights cont.

Test 6, a 10 minute exposure

Front (fire side)

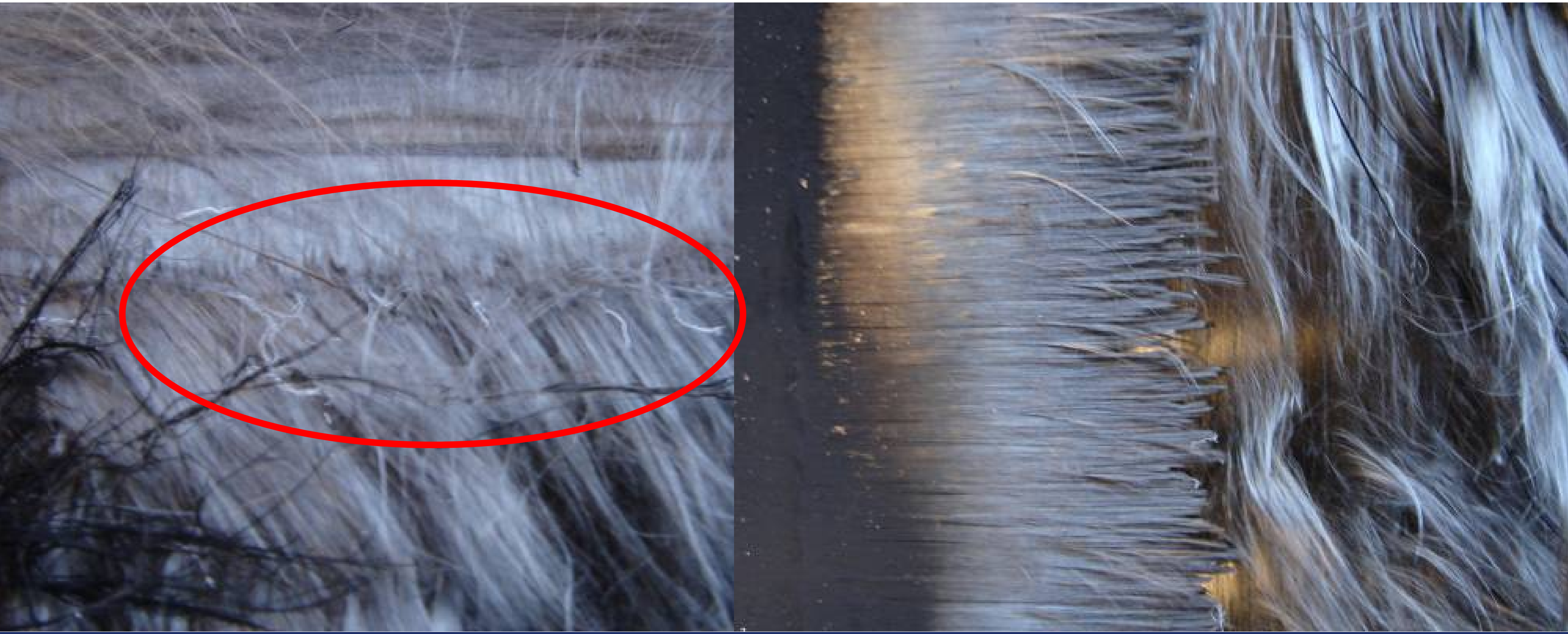
Edge View



Back (non-fire side)

Results: Panel Weights cont.

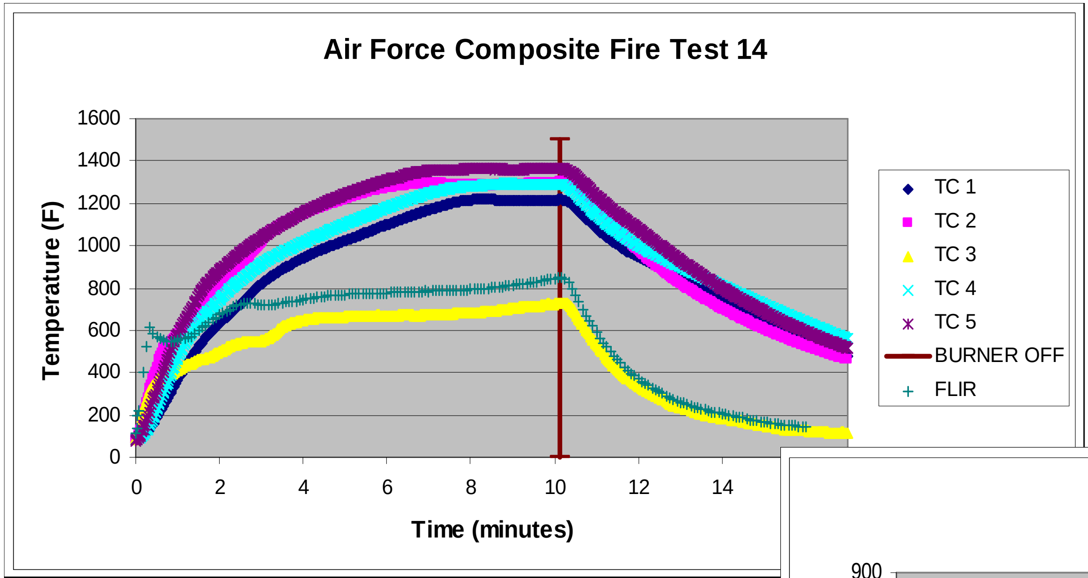
- **Close up of gray and jagged cut fiber ends from Test 15**

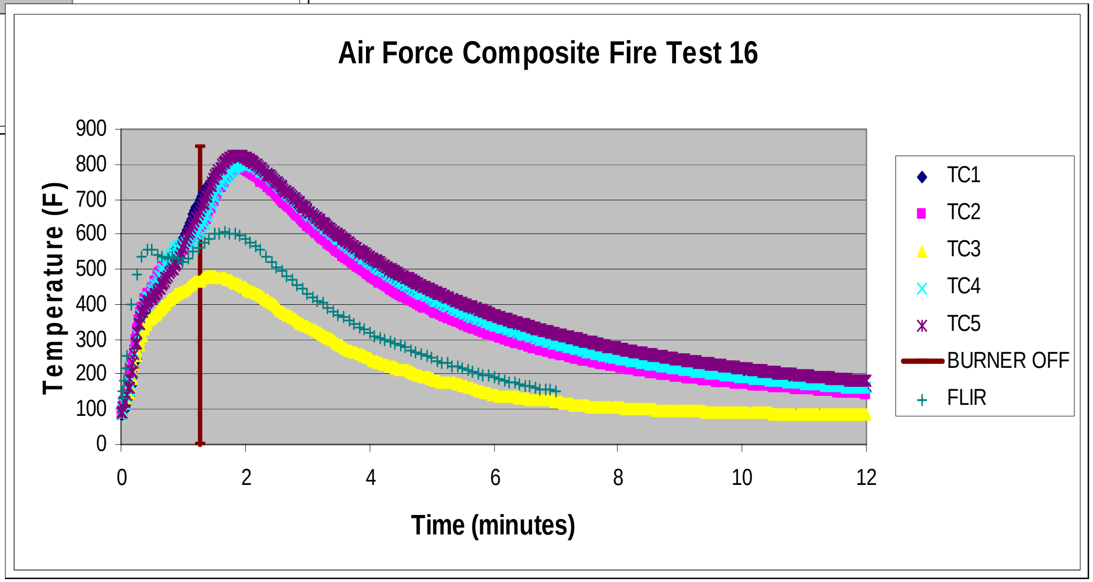


Panel Temperatures

- Exposures less than 10 minutes had maximum temperatures around 700°F (374°C) on average, and occurred *after* burner removal.
- 10 minutes exposures reached an average of 822°F (442°C), normally *prior* to burner removal.
- Maximum temperatures always achieved just before or just after burner removed.

Panel Temperatures cont.



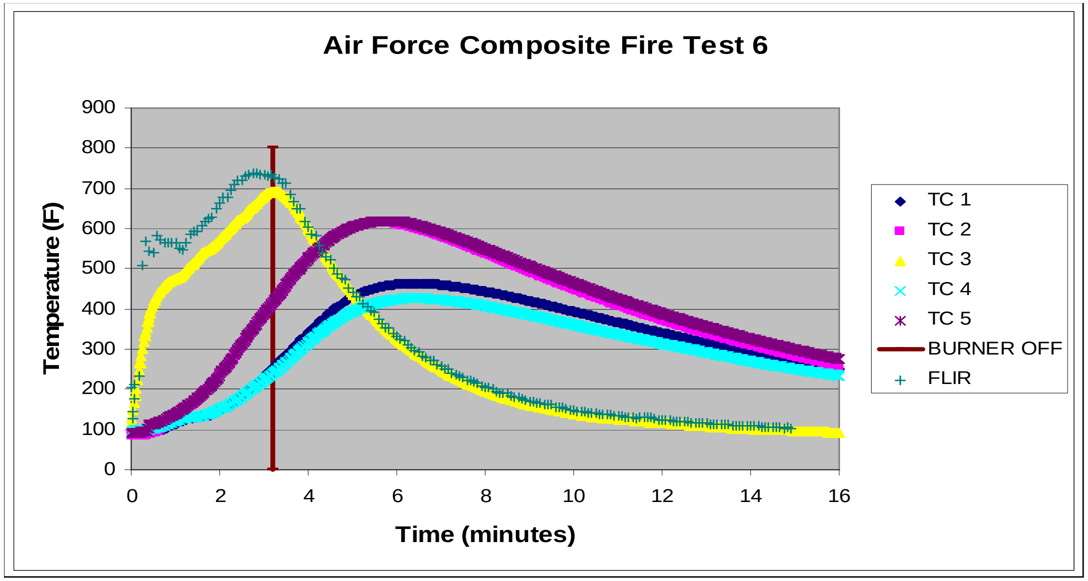


Cooling Below 300°F

- Times to cool below 300°F (150°C) ranged 87 to 691 seconds.
- Median time of 133 seconds (2 minutes 13 seconds).
- Temperature measured at panel center, which is open to the air on both sides allowing heat to readily dissipate.

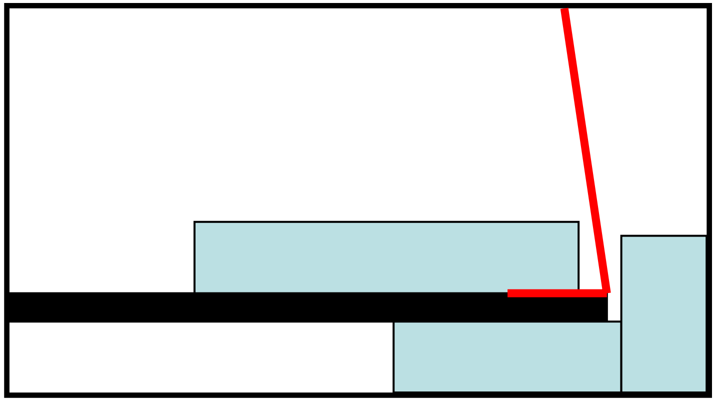
Hidden Areas

- **Initial thermocouple placement caused hidden corner temperatures to be shielded during exposure, then continue to heat up after burner removal, reaching peak temperatures minutes later.**

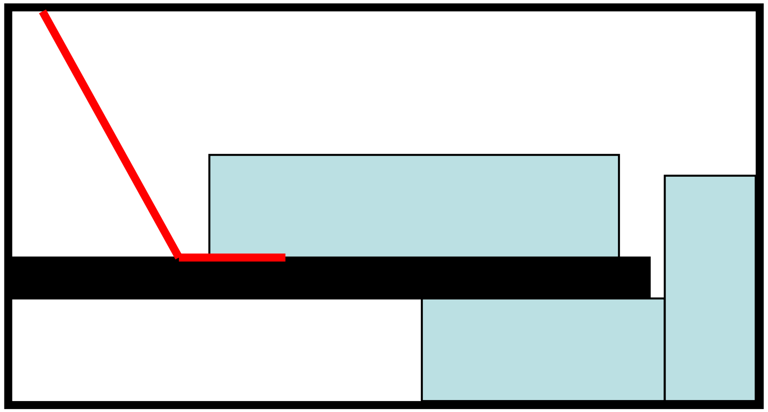


Hidden Areas cont.

- **Thermocouples moved**



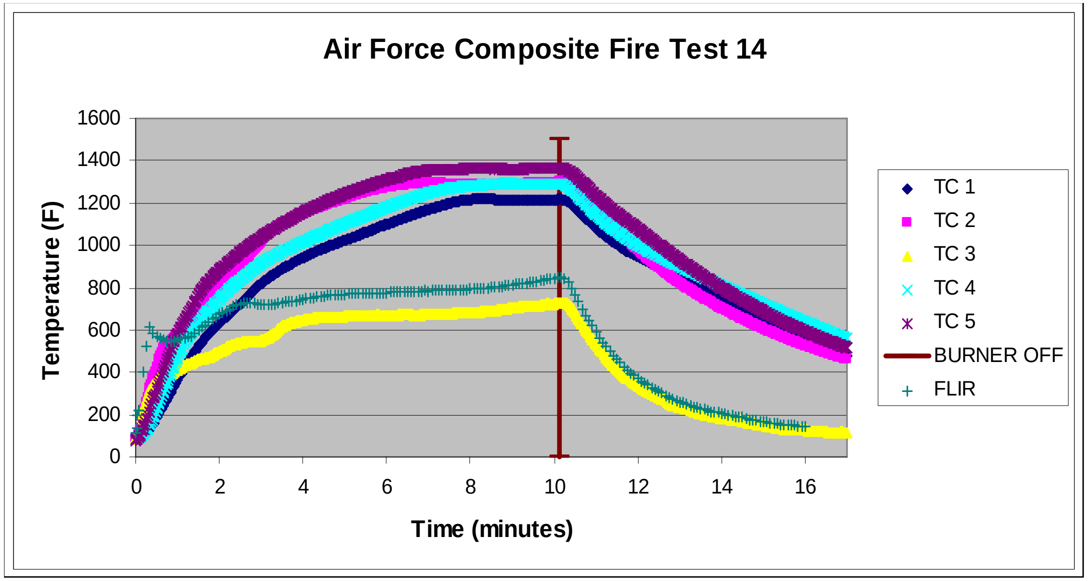
Initial thermocouple placement



Revised thermocouple placement

Hidden Areas cont.

- **Revised thermocouple position simulates aircraft skin with insulation backing**
- **Tracings no longer showed any lags**



Hidden Areas cont.

- **10 minute exposures reliably reached at or above 1200°F (654°C). Average 1367.2°F (741.7°C)**
  - Maximum 1425.6°F (774.2°C)
  - Minimum 1282.8°F (694.8°C)
- **1 or 3 minute exposures were on average about 200°F (93.3°C) above the measured panel temperatures. Average 828.1°F (442.3°C)**
  - Maximum 1293.2°F (700.6°C)
  - Minimum 619°F (326.1°C)
- **Maximum temperatures unchanged due to revised thermocouple position.**

Mechanical Failures

- **Test 4 panel shown**
- **7 tests suffered sudden mechanical failures**
- **Failures occurred in 30 seconds on average**

Mechanical Failures cont.

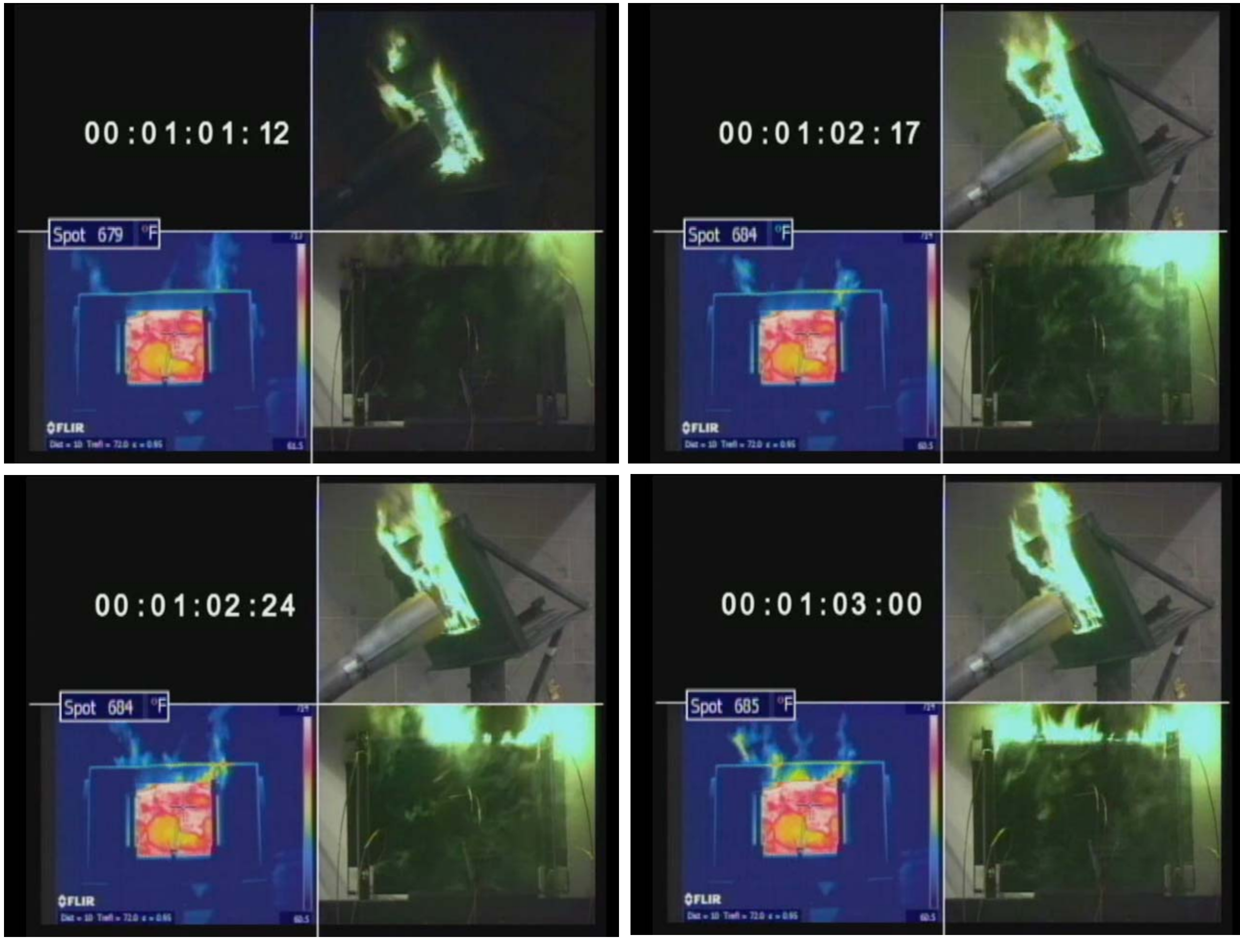
- Quintiere [1] attributed swelling to vaporization of epoxy, thereby causing internal pressure.
- All panels in these tests produced heavy out-flow of smoke from the edges, not the panel face, and swelled to varying degrees.
- In these tests, panel edges were sometimes tightly fit into back Kaowool board.
  - May have restricted outflow of smoke and off-gassing.
- It was observed during video review that in one test heavy smoking from the edge markedly reduced, when the failure occurred a surge of heavy smoke erupted from the failure site.
- The mechanical failures may have been due to over-pressurization but this was not further explored in this series of tests.

Smoking

- All panels emitted smoke.
- Onset of smoke production ranged 111°F (44°C) to 392°F (202°C) by thermocouple measurement.
- FLIR temperatures at the onset of smoke production ranged 139°F (60°C) to 621°F (330°C).
- Definitively, smoke did not occur under 100°F (38°C).
- Firefighters could use smoke production as an indicator of continued combustion but an imprecise indicator of temperature. Where smoking persists temperatures may still be above 300°F (150°C), and should be assumed so unless proven otherwise.

Rear Flashover

From Test 18 video

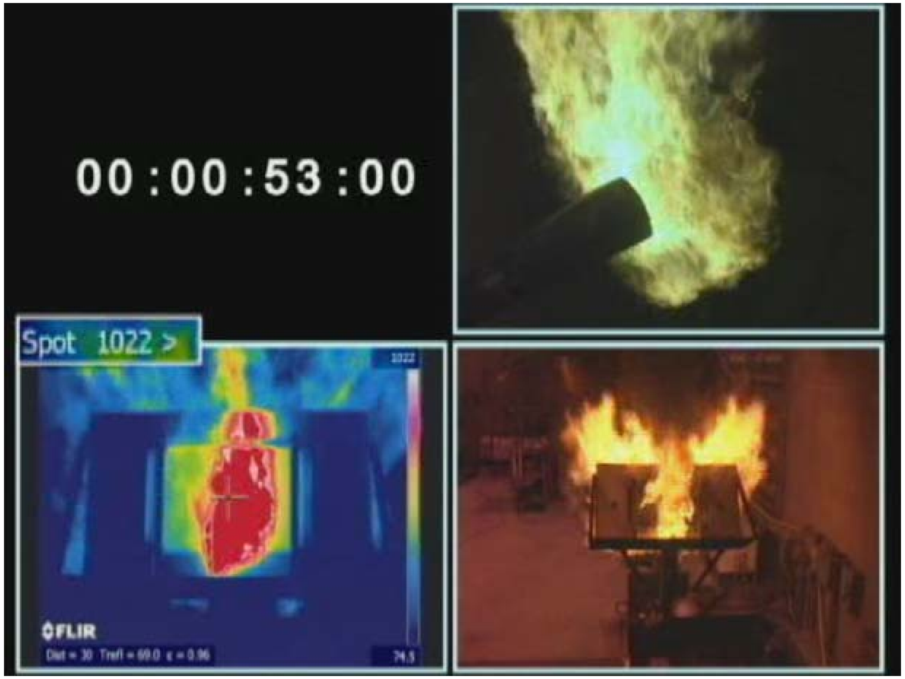


- **Heavy smoke from the backside was sometimes ignited by the front side flame. This was clearly observed during the video review.**
- **Here, the ignition of back-side off-gassing happened *after* the burner was turned off.**

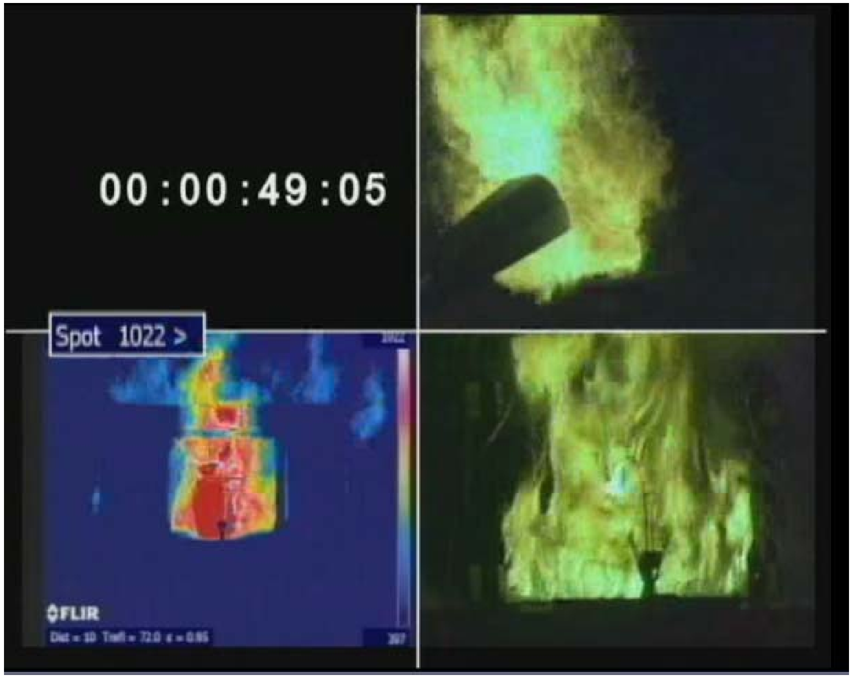
Rear Flashover cont.

- **Two tests suffered mechanical failures at the bottom edge that allowed high heat to contact and ignite smoke emitting from bottom edge.**
- **Ignition of edge involved part of the panel face which evolved into flashover of the backside.**

Test 4 Flashover



Test 21 Flashover



Post-Exposure Flaming

- **Some amount of flame continued after burner removal in every test.**
  - Duration of the flame; as little as 1 second or as much as 3 minutes.
- **Test 6 & 16; flickers of flame could be seen inside the panel, behind delaminated outer plies.**
- **Median flame extinction times were;**
  - 75 seconds for 1 minute exposures
  - 50 seconds for 3 minute exposures
  - 25 seconds for 5 minute exposures
  - 17 seconds for 10 minute exposures
- **This, and panel weight after exposure, reinforce the theory that duration of flaming combustion is a factor of epoxy content.**

Post-Exposure Smoldering

- During review of the video for the first 12 tests, areas of smoldering were observed.
- Color camera view after test 12 was tightened so that occurrences of smoldering could be seem more clearly.
- 14 of the 23 total tests had at least one occurrence of smoldering. Some tests had two or more separate occurrences. Each separate location was considered an occurrence.
- Most occurrences were in the corners. Test 16, a 1 minute exposure, showed smoldering in the center of the panel.

Post-Exposure Smoldering cont.

- Corner temperatures at onset and extinction of smoldering were compared to panel temperatures, where sufficient data was available.
- Corner temperatures reduced 30% from onset to extinction while the panel temperature reduced 50%.

	Time to Begin after Burner Off (seconds)	Onset Temp (°F)	Onset Temp (°C)	Panel Temp (°F)	Panel Temp (°C)	Time to Cessation after Begin (seconds)	Stop Temp (°F)	Stop Temp (°C)	Panel Temp (°F)	Panel Temp (°C)
Average	90	940	509	434	225	155	665	354	205	97
Median	95	916	495	434	225	159	668	356	198	93
Max	153	1367	748	727	389	313	957	518	419	217
Min	0	629	334	231	112	42	390	200	113	45

Introduction of a Fan

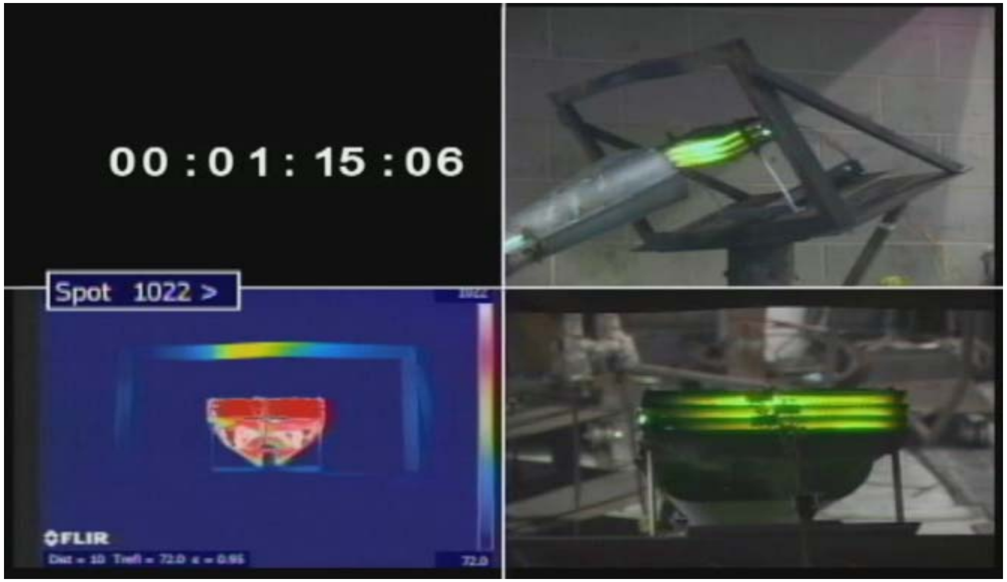
- **A small floor fan was used to simulate airfield wind conditions.**
  - Fan produced 7-8 mph of wind speed at a 4 foot distance.
  - Used in 5 tests.
- **Fan intensified smoldering in some cases but blew-out flames. However, there were cases where backside flames were promoted by increased oxygen flow.**
- **In other instances, wind promoted smoldering where it did not initially exist.**
  - Test 18, smoldering initiated 90 seconds after removal of the burner.
  - Other tests experienced an onset of smoldering up to 2 minutes, 33 seconds after fire exposure.
  - 10 minute exposures had more and longer occurrences of smoldering.

Re-Ignition

- **Re-ignition noted in three tests.**
  - Two of those tests the re-ignition was not significant. One was just a flicker, the other was likely continued flaming.
  - Test 19 (10 min, with fan) ignited 64 seconds after burner removal and intermittently persisted for almost 3 minutes.
- **Wind seems to promote flaming and re-ignition in areas where the flow of oxygen is increased but protected from the wind, which would otherwise blow-out the flame.**

Other Test Configurations

- **Tests 22 and 23**
  - The panel was cut into 4 pieces and stacked with ¾ inch (76.2mm) spaces between.
  - Thermocouples placed on top surface of each layer.
  - Exposure time; 1 minute.



Other Test Configurations cont.

- **Measured temperatures in the vicinity of 1750°F (962°C).**
- **As smoldering continued, plies could be seen to drop onto layers below.**
  - When layers were taken apart for disposal they had virtually no structural strength.
- **Wind (in Test 22) caused smoldering to last 52 seconds longer.**

Moving Forward

- **Phase II testing test plan being written.**
  - Gas fired line burner planned for fire source. Burner will be 2 ft (60.96 cm) wide, flame height could be as much as 6 feet (182.88 cm).
  - Thermocouple array or similar will be used to characterize the flame. Replication of aviation fuel pool fire temperatures still the objective.
  - Sample panels will be 4 ft wide by 6 ft tall to avoid edge effects.
  - Standard aircraft insulation will be included to see if certain results noted here can be replicated.
- **Agent application planned to be remotely controlled and from a fixed device to limit variability of human application.**
  - Straight stream and cone pattern flows considered.
- **Simple geometries, (T-type form) mentioned in October, are not part of Phase II plan. However, may be the focus of a separate study, but nothing planned yet.**

References

1. Quintiere, J.G., Walters, R.N., Crowley, S., "Flammability Properties of Aircraft Carbon-Fiber Structural Composite," FAA report DOT/FAA/AR-07/57, October 7, 2008.

Participation welcome