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1/4-Scale Testing. Part II
Simulant Repeatability Series, Jet A Vapor and Quenching

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Summary

Testing has been carried out to investigate the effect of fuel type and ignition location on explosion of fuel vapor in a scale-model of the center fuel tank under conditions simulating that in the explosion of TWA Flight 800. A set of 40 tests (31 in 1998 and 9 in 1999) were carried out in the 1/4-scale test facility. The purposes of these tests were to determine the repeatability of the initial series of 30 tests carried out in 1997 with simulant fuel (propane-hydrogen mixture) and to determine the behavior of Jet A vapor/liquid in the 1/4-scale facility. The facility was identical to that used in 1997 (Shepherd et al. 1998) with the addition of a thermal control system and environmental enclosure so that the tank and contents could be maintained at a set temperature to simulate the accident tank environment. The raw data and details of the experimental set up are given in Brown et al. 1999.

The first 12 tests (31 to 39) were carried out with the simulant fuel at temperatures between 25 and 45°C at a pressure of 0.8 bar. These tests were carried out with a full set of partitions (fixed) to simulate all 6 bays involved in the explosion of the actual tank. One test and at least one replica were carried out for ignition locations of 5, 1 and 2 in order to determine the repeatability of the results. As long as all variables were carefully controlled, reasonable repeatability was obtained as evidenced by overlays of pressure signals from replicated tests. Sensitivity of the results to ignitor location was observed.

Thirty-one tests were carried out with Jet A vapor and a thin liquid layer at temperatures of 40 and 50°C and a pressure of 0.585 bar, conditions simulating those in the TWA accident at an altitude of 13.8 kft. The liquid fuel used in these tests was 115°F flash point Jet A, all from a single batch obtained from the ARCO refinery in LA. The liquid fuel amount simulated the mass loading (3 kg/m3) in the CWT at the time of the explosion. The effects of temperature (40, 45, and 50°C) and ignition location (2, 5, and 2L) were examined in 9 tests using the 6-bay, all-strong configuration. These tests demonstrated that flame propagation and pressure traces similar to those obtained with the simulant fuel could also be obtained in certain cases with Jet A as the fuel. In 3 cases, combustion was observed in all 6 bays of the facility. In 3 cases, combustion was observed to occur in all but 1 bay of the facility. In 3 cases, combustion did not occur in 4 of the 6 bays of the facility. The failure to obtain combustion in all bays was interpreted as being due to the quenching of the flame when passing through the passageways connecting the bays. The extent of the quenching was found to depend on both the location of the ignition source and the temperature of the fuel. Quenching was not observed in any tests with the simulant.

Ten additional tests (with a simplified two-bay configuration) were carried out to examine the quenching effect. The 1/4-scale facility was partitioned into two bays and a single orifice connected the bays. Various orifice sizes (0.25 to 2-in) and shapes (circular holes and slots) were tested in order to estimate the minimum quenching distance. The nominal quenching diameter for ARCO 115°F flash point Jet A is between 1 and 1.5 inch at 40°C and 0585 bar (14 kft altitude). In all tests with the 1/4 x 2-in slots, the flame quenched and in all tests with the 2-in hole, the flame propagated through the hole at both 50 and 40°C.

Flame speed and peak pressure of the Jet A fuel were determined both in the 1/4-scale facility and in the laboratory testing (Shepherd et al. 1997, Shepherd et al. 1998, Lee and Shepherd 1999) at Caltech. Three single bay tests were carried out at 40°C with ARCO 115°F flash point Jet A. Flame speeds at 40°C are between 29 and 34 cm/s vs. 54-66 cm/s for 50°C. The Jet A vapor was characterized by headspace gas chromatography by Woodrow and Seiber (1999) and the relationship between flashpoint and vapor composition was examined by Shepherd et al. (1999). During selected tests, vapor samples were collected and analyzed using methods similar to those described in Sagebiel (1997).

Implications for the TWA Accident Investigation

1. The simulant tests are sufficiently repeatable to be used as comparisons to validate the computational simulations.
2. Flame propagation in Jet A fuel vapor (and liquid layer) at both 40 and 50°C can, for certain ignition locations, produce sufficient pressures to cause the failure of SWB3 and FS observed in the TWA 800 accident.
3. The Jet A quenching tests indicate that in the full-scale tank, the flame may quench when passing through some of the annular spaces in the beams and spars but will propagate through all other passageways, such as upper and lower flow "mouse holes", the circular flow holes and the vent stringers.
4. Due to the dependence of quenching on the absolute size of the passageways, quenching effects will be much more pronounced in the 1/4-scale facility than in the full scale tank. The observations of quenching and failure to combust all the bays in certain 1/4-scale tests with Jet A does not imply that this behavior will occur in full scale. The separate quenching tests indicate that combustion should propagate to all bays in full scale, irrespective of ignition location at temperatures between 40 and 50°C.

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