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FQIS Compensator Probe Testing

(75 Pages)

Summary Data Report

Investigation of the Effects of Combustion on a Fuel Quantity Indicating System Fuel Compensator Probe

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Abstract

A series of destructive experiments of an unenergized Boeing 747 Fuel Quantity Indicating System (FQIS) fuel compensator probe was conducted in support of the National Transportation Safety Board's investigation of the TWA 800 accident. The tests were designed to establish the damage to the lead wire assembly of a fuel compensator probe, when it was subjected to ignition and explosion of Jet A fuel vapors. The location of the ignition source relative to the compensator was varied to examine sensitivity of observed damage to this parameter.

The series of tests produced a collection of compensator lead wire assembly specimens that were exposed to the combustion event. Following each test, the lead wire assemblies were extracted from the compensator, documented and photographed. Temperature histories and maximum pressures within the test chamber were recorded for each test, and a select number of tests were documented by high-speed video imagery. This report contains a summary documentation of these data.

Table of Contents

Section	Page
Abstract	i
Table of Contents	ii
List of Figures and Tables	iii
1. Introduction	1
2. Experimental Program	1
2.1 FQIS Compensator	1
2.2 Experimental Test Configuration	2
2.2 Experimental Configuration	2
2.3 Test Condition	2
2.4 Measurements and Diagnostics	3
2.5 Test Procedure	4
3. Experimental Results	5
3.1 Test Matrix	5
3.2 Test Results	6
Appendix A Test Results	14

List of Figures and Tables

<u>**Title**</u>	<u>**Page**</u>
Table 1. Text matrix	5
Figure 1. Schematic view of compensator.	7
Figure 2. Exploded view of compensator.	8
Figure 3. Exploded view of compensator recovered from TWA800 wreckage.	9
Figure 4. Experimental configuration.	10
Figure 5. Test container views (taken from test plan).	11
Figure 6. Test cell configuration .	12
Figure 7. Test Container Instrumentation Configuration	12
Figure 8a. Igniter positioned below compensator.	13
Figure 8b. Igniter positioned at the side of terminal block.	13

1. Introduction

The National Transportation Safety Board (NTSB) investigation of the TWA Flight 800 accident determined that the B-747's center wing tank (CWT) exploded. Further investigation to determine the cause of this explosion requires the identification of possible ignition sources. The Fuel Quantity Indicating System (FQIS) compensator probe was examined as a possible ignition source. Wreckage recovered from the accident site included a compensator, which exhibited thermal and mechanical damage.

An experimental program was developed to destructively test a fuel compensator probe. The tests subjected the compensator to combustion of Jet A fuel vapors. The objective was to provide specimens of compensator probe lead wire assemblies that were subjected to specific ignition sources locations of an explosion of Jet A vapors. The purpose was to examine the sensitivity of observed damage to the lead wire assemblies to the relative positions of the compensator and ignition source. Post test comparison of the observed condition of the test specimens to the compensator recovered from the TWA800 wreckage may assist investigators in determining the probability of this component as the source of ignition in the accident.

These tests were conducted at the Federal Aviation Administration, William J. Hughes Technical Center, in Atlantic City, NJ, in an explosion-testing chamber, located in Building 276. The tests were conducted by the FAA technical staff, under the supervision of Richard Hill, and test engineer John Reinhardt.

2. Experimental Program

2.1 FQIS Fuel Compensator Probe

The fuel compensator probe (hereafter referred to as the compensator) is a component of the Boeing 747 Fuel Quantity Indication System (FQIS). This system uses submerged fuel probes that convert voltage capacitance to the volume of fuel within the aircraft's fuel tanks. The compensator is used to adjust, or compensate, the fuel probe's readings for fuel capacitance variations caused by variations in fuel temperature . Within the B-747 CWT, there is one compensator.

Figures 1 and 2 show the schematic and exploded view of an undamaged compensator. Its essential components consist of a 9-inch long by 1-inch diameter, thin walled aluminum tube, surrounded by three concentric aluminum electrodes. A terminal block and two mounting brackets are secured to the exterior of the probe.

Two shielded lead wires, Hi Z and Lo Z, connect the terminal block to the electrodes. An unshielded ground wire connects the Hi Z lead wire to the compensator tube. A lead wire support is located internal to the probe. These form the lead wire assembly. This assembly is extracted from the compensator, photographed, cataloged, and replaced after each test.

Figure 3 shows an exploded view of the compensator recovered from the TWA800 wreckage. Of particular note are the items identified as parts 5.6A, 5.6D, 5.9 LO-Z, and 5.7. These items exhibited thermal damage.

2.2 Experimental Test Configuration

Figure 4 shows a drawing of the experimental configuration. In this set-up, the test cell serve as the surrounding for the experiment. In addition to maintaining a stable surrounding for the test container, the test cell mainly provided isolation of the container from the laboratory environment. Flammable vapors and post combustion gases were contained within the cell, which also protected the surroundings from the potential dangers associated with an explosion, such as fire, projectiles, etc.

Within the test cell was the test container, as shown in Figure 5. This contained the compensator test article, ignition source, and Jet A vapor environment. The closed container was constructed of heavy gage aluminum walls on the bottom and sides, and a Plexiglas top with a 10-inch by 10-inch aluminum foil blow out panel. The container was 9 cubic feet in volume, 3 ft. wide by 3 ft. long and 1 foot in height. The compensator was mounted in a vertical position, along the side and bottom of the container, held securely by its mounting brackets to a steel bracket mounted to the container wall. The location of the side and bottom of the compensator relative to the container walls approximated the orientation and spacing used in the aircraft installation. The container held a shallow pan, which was filled with the appropriate amount of Jet A fuel. Electrical resistance heaters were positioned on the bottom exterior of the container, which conducted heat upward through the container to the fuel pan. The sidewalls were thermally insulated. The container is mounted on a rail for ease of removal from the test cell, and was rigidly fastened to the test cell rail during the test. The container was fitted with multiple feed through ports for instrumentation, ignition source electrical supply, and nitrogen purge fire extinguishing ports. These lines were connected to the test cell bulkheads, and out to the assigned laboratory locations.

The ignition source consisted of a set of direct current (DC) arc igniters connected to a DC transformer. The igniters were held in a portable fixture, which was positioned within the test container, to provide ignition at various predetermined locations relative to the compensator. The transformer was located outside the test cell, and provided 10,000 Volts and 23-mA output, delivering 230 Watts of continuous power. A manual remote trigger provided a continuous spark discharge. A spark igniter gap of 0.25 inches was used to ignite the fuel vapors.

2.3 Test Condition

The NTSB accident investigation indicated that a combination of elevated fuel tank temperature and the reduced atmospheric pressure at the accident altitude developed a flammable condition within the CWT of TWA flight 800. For consistency between the accident event and this testing, a flammable mixture of Jet A vapors was used as the flammable environment for the compensator testing.

Testing was conducted with the test cell maintained at ambient pressure. This required heating of Jet A fuel above ambient temperatures to create a flammable vapor condition. This condition was achieved by heating the bottom surface of the test container via controlled, electrical resistance heaters, which conduct heat through the bottom of the container into the pan of fuel. 28 fluid ounces of 112 °F flashpoint Jet A fuel was used for each test. Strict control of the temperature and fuel vapor concentration within the test cell was not mandated, as long a flammable environment was generated.

2.4 Measurements and Diagnostics

Thermodynamic measurements were acquired for monitoring test progress and recording of testing events. All data were digitally recorded, using either one Hertz, or one kiloHertz sampling rates. Figures 6 and 7 show the test cell and container instrumentation and diagnostic configurations.

Temperature measurements were made using Type E thermocouples. Calibration was achieved using the ice point and boiling point of water. Two, 1-Hertz temperature measurements of the fuel were made by thermocouples suspended in the liquid fuel layer within the shallow fuel pan. Two, 1-Hertz temperature measurements were taken of the ullage space within the test container, above the fuel pan. The temperature histories of the ullage and fuel during the test container heat up and during the ignition are documented in the Results Section of this report. A single, 1kHz measurement of temperature was made within the compensator body, but due to technical difficulties, could not be obtained for all tests.

Two pressure measurements, at one Hertz and 1 kHz, were made of the test container. The piezoresistive transducers were attached to pressure ports in the side of the container. The maximum pressures recorded during the combustion event are documented in the Results Section of this report.

High-speed motion pictures were taken of four tests. The pictures were at a glancing view through the top of the test container, which was fabricated of transparent Plexiglas. A video archive of these motion pictures is contained in the accident docket. Observations made of this footage are included in the Results Section.

Vapor concentration within the test container was monitored every five minutes during the heating of the container with a total hydrocarbon analyzer. However, due to technical difficulties, quantitative measurements could not be obtained. The hydrocarbon concentration results were used as a qualitative measurement, to monitor the thermochemical equilibration of the test container. In this sense, container heating rates were monitored to achieve a quasi-equilibrium condition, where container temperature levels and non-calibrated fuel vapor concentration readings rose and stabilized similarly.

2.5 Test Procedure

While the test container was located outside the test chamber, it was disassembled from the previous test, and refurbished for the next. The compensator was cleaned and fitted with a new set of lead wires and lead wire support, on the laboratory bench. This assembly was fastened in place to the test container wall. The fuel pan was filled with 28 fluid ounces of Jet A fuel, and placed in the bottom of the test container. The ignition spark gap was positioned for the location of choice. The thermocouples are checked for position, and the container top was fastened in place, with the aluminum foul blow out panel secured in place. The container was positioned inside the test cell. All plumbing and electrical/electronic connections were made. Cameras were positioned, and the test chamber door was closed.

Monitoring of the test container was done by live video feed to the command center, located outside the test chamber building. The test container heaters were energized, and the fuel and ullage temperatures were monitored. Fuel vapor concentration samples were drawn and analyzed remotely at five minute intervals. When the temperature and fuel vapor indicated the appropriate conditions had been reached, the spark was triggered, and the explosion event occured. Data were recorded at this moment, and an automatic fire extinguishing purge of nitrogen was simultaneously flushed into the test container, to minimize any post combustion fires.

Following the test, the container was removed from the cell. The compensator was removed, photographed and the lead wire assembly photographed and cataloged.

3. Experimental Results

3.1 Test Matrix

19 tests were successfully conducted and are reported here. The tests were conducted with one parameter variation, that of ignition location. Four ignition locations were examined. These were: at the top, external opening of the compensator; at the bottom, external opening of the compensator; at the side, located ¼ inch from the center of the terminal strip; and at a remote location, one foot from the compensator, at the mid-height of the container. Examples of this are shown in Figures 8a and 8b. All ignition locations used the same source and ignition energy circuit. The test matrix is shown in Table 1.

Test Number	Test Identification Number	Date	Ignition Location
3	060999T1	9-JUN-99	1/2-inch from compensator terminal block, near ground screw
4	060999T2	9-JUN-99	1/2-inch from compensator terminal block, near ground screw
5	061099T1	10-JUN-99	1/2-inch from compensator terminal block, near ground screw
6	061199T1	11-JUN-99	Under center compensator
8	061499T1	14-JUN-99	Under center compensator
9	061599T1	15-JUN-99	Under center compensator
11	061799T1	17-JUN-99	Under center compensator
12	061899T1	18-JUN-99	Under center compensator
13	062199T1	21-JUN-99	Under center compensator
14	062299T1	22-JUN-99	1/2-inch from compensator terminal block, near ground screw
15	062299T2	22-JUN-99	1 foot away from compensator
16	062399T1	23-JUN-99	Above top center of compensator
17	062499T1	24-JUN-99	1 foot away from compensator
18	062599T1	25-JUN-99	1 foot away from compensator
19	062899T1	28-JUN-99	1 foot away from compensator
20	062899T2	28-JUN-99	1 foot away from compensator
23	070299T1	2-JUL-99	Above top center of compensator
24	070299T2	2-JUL-99	Above top center of compensator
25	070699T1	6-JUL-99	Under center compensator

Table 1. Test Matrix.

3.2 Results

The results of each test are presented in Appendix A. Details of each test are presented. Histories of the fuel and ullage temperatures during the heating of the test container are shown. Maximum pressures attained inside the test container during the combustion event are reported. Photographs of the post test condition of each lead wire assembly are presented.

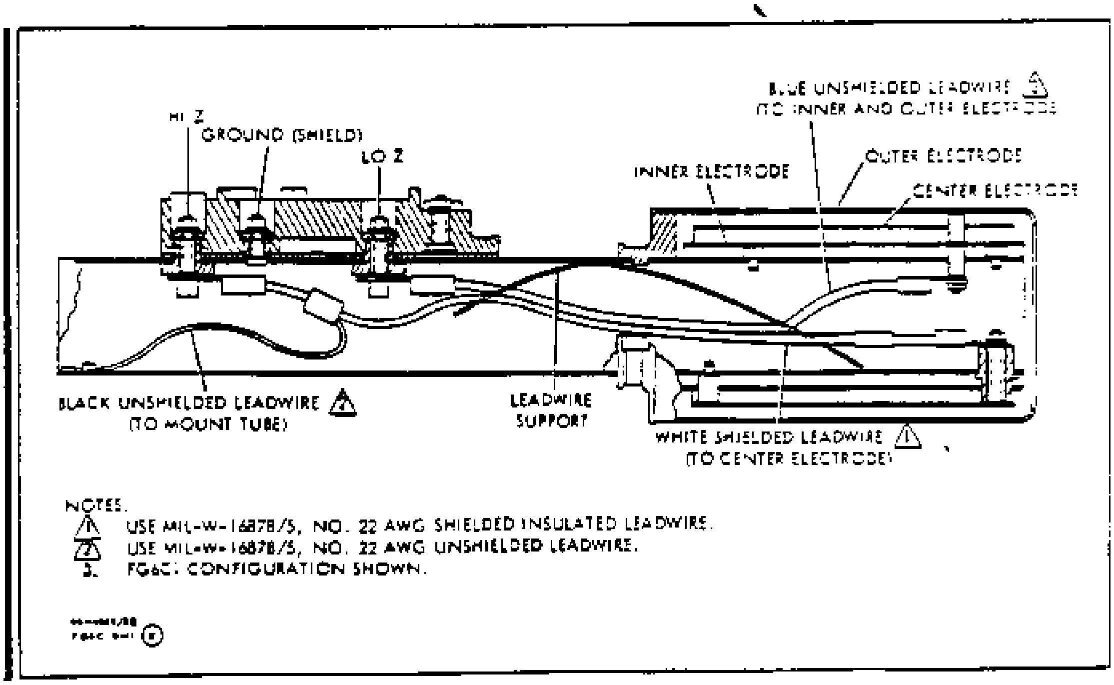


Figure 1. Schematic view of compensator.

2. DISASSEMBLY.

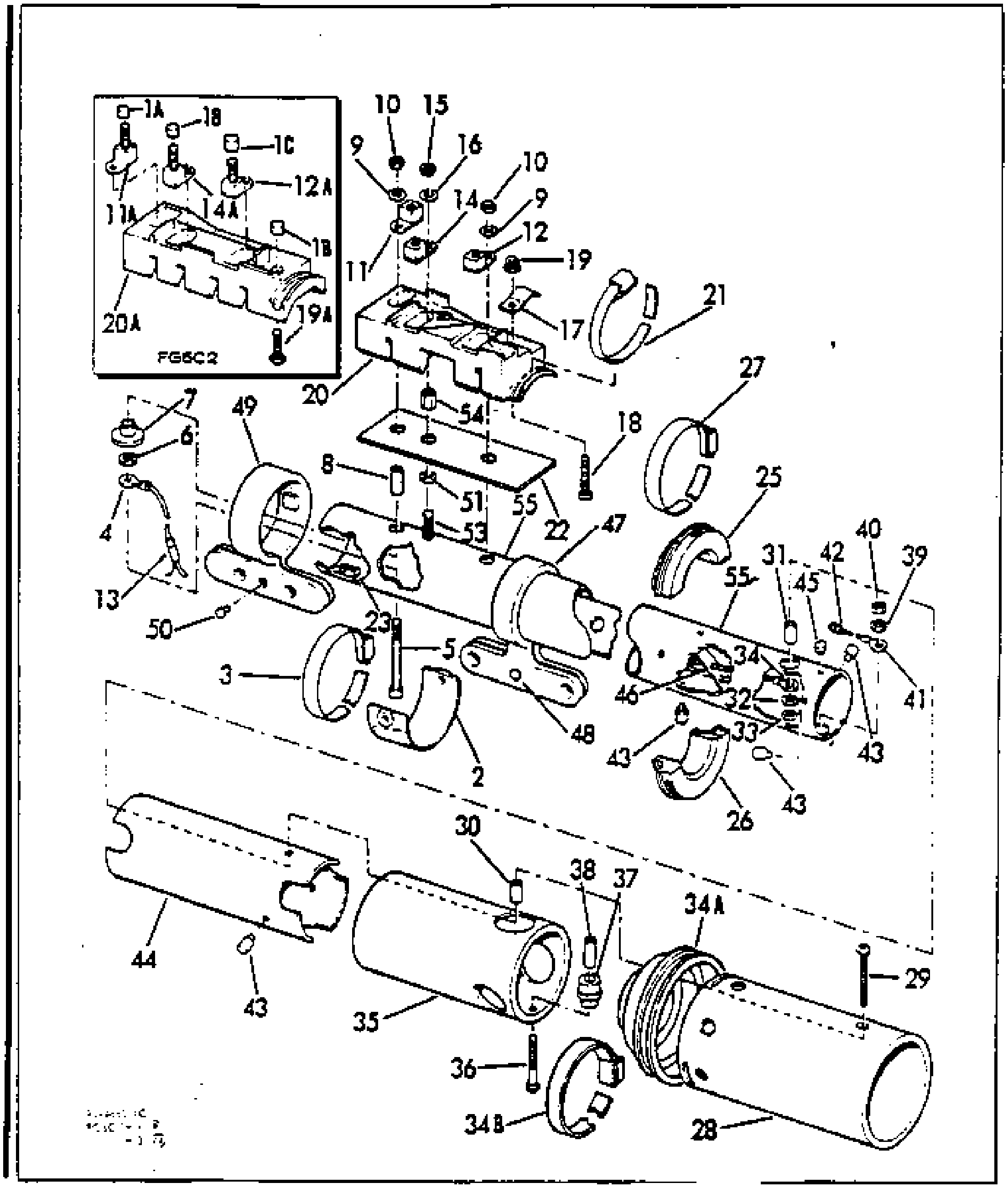


Figure 2. Exploded view of compensator.

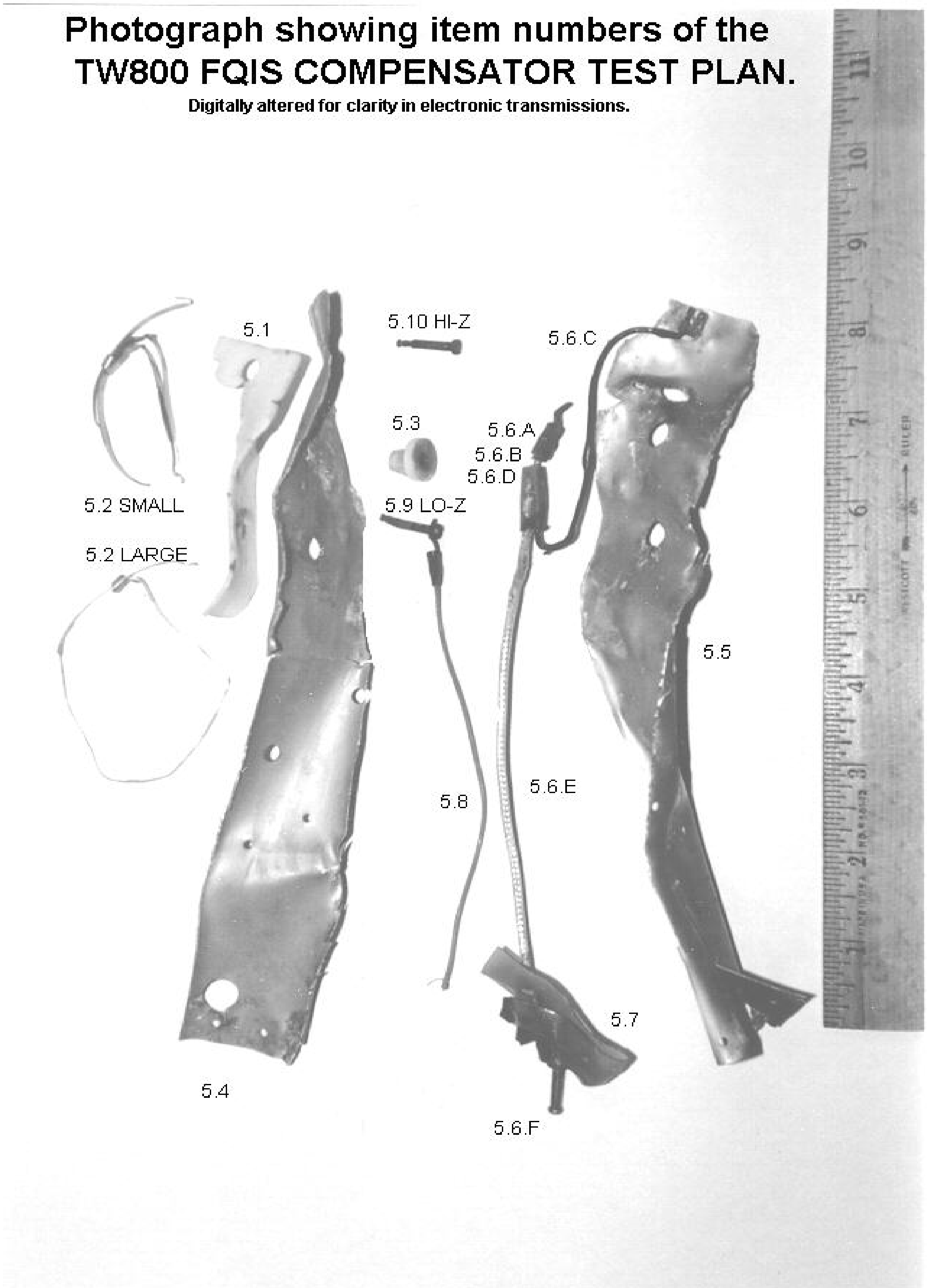


Figure 3. Exploded view of recovered compensator.

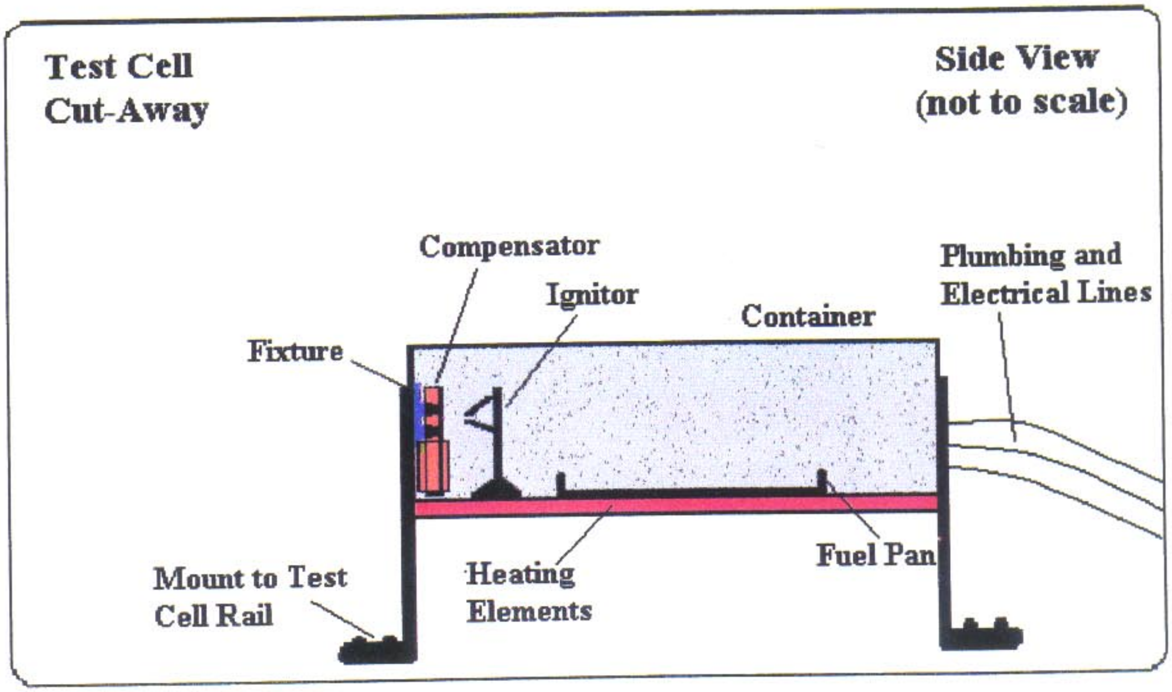
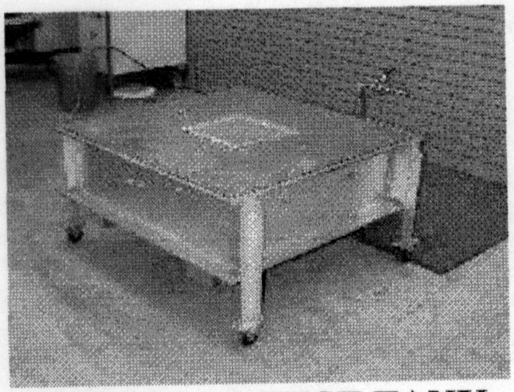
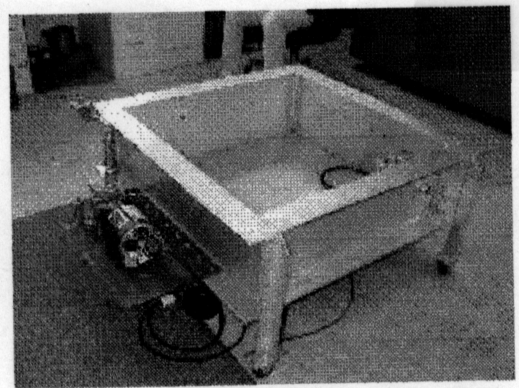


Figure 4. Experimental Configuration.



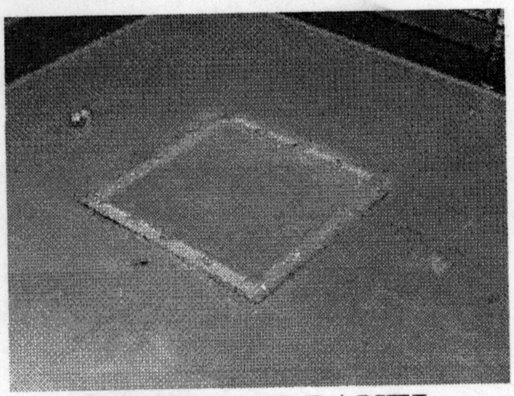
PROPOSED TEST TANK



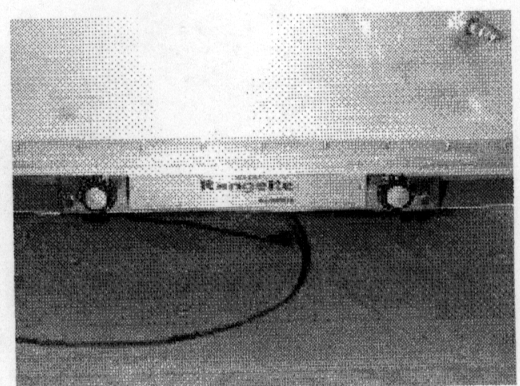
TANK WITHOUT COVER

This tank set up was designed to fit inside the pressure vessel in Building 276. It has installed the equipment needed to conduct and record the explosion tests.

This tank has a volume of 9 ft3 (3' x 3' x 1'). A smaller pan can be placed inside this tank to hold the needed fuel.



BLOWOUT PANEL



HEATING PLATES

Here is a shot of the blowout panel. This aluminum foil panel measures 10" x 10" in dimensions.

Under the tank, there are two speed heating plates, Rangette by Capitol, rated at 825 Watts each. These plates are capable of providing sufficient heat in order to reach and exceed the flash point of the fuel.

Figure 5. Test container views (taken from test plan).

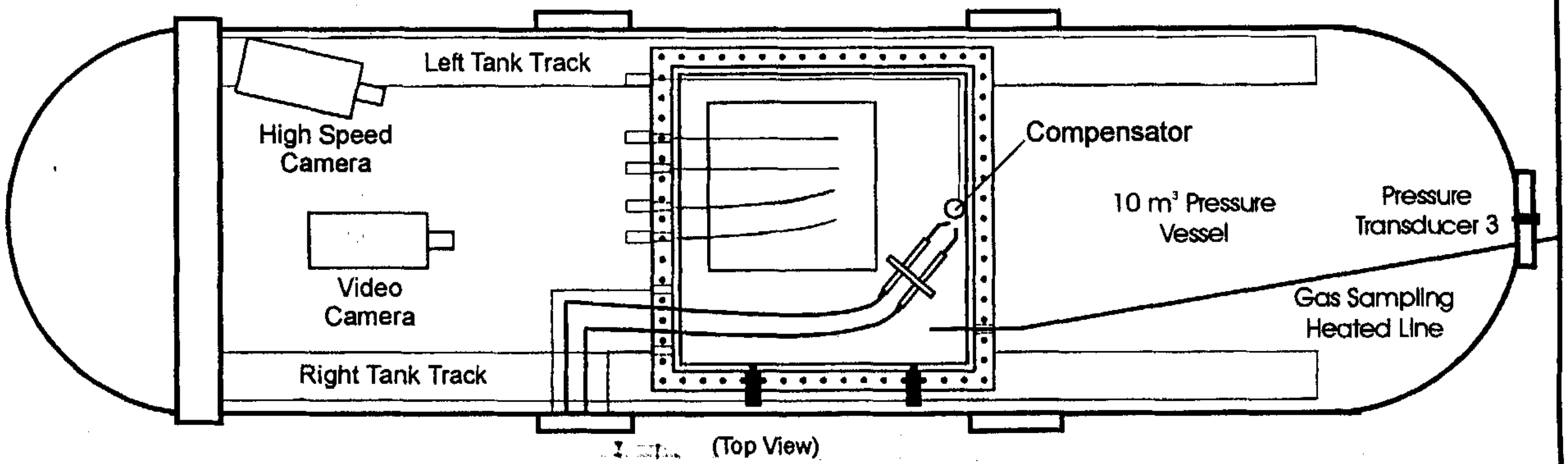


Figure 6. Test Cell Configuration.

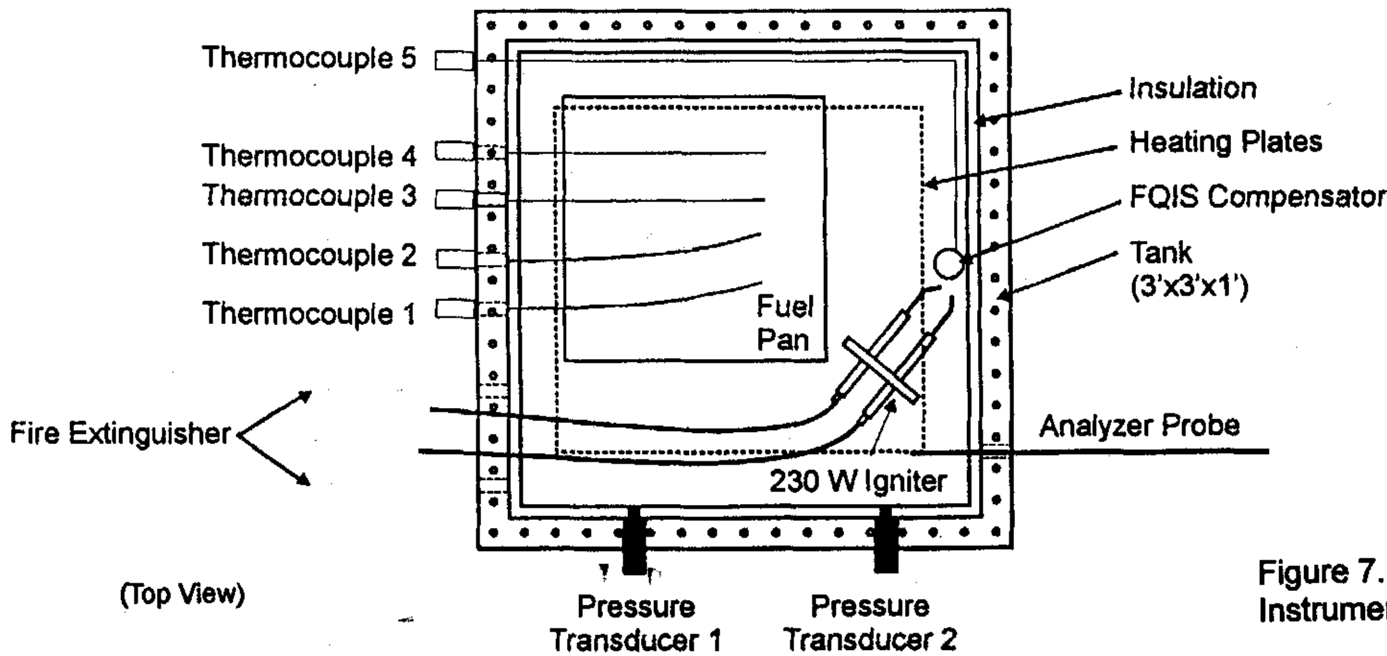


Figure 7. Test Container Instrumentation Configuration.

Figure 8a. Ignitor positioned below compensator.

Figure 8b. Ignitor positioned at the side of terminal block.