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NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C

FLIGHT TEST GROUP CHAIRMAN'S FACTUAL REPORT OF INVESTIGATION

by

Daniel R. Bower, Ph.D.

Trans World Airlines Flight 800
East Moriches, New York

July 17, 1996

DCA96MA070

(23 Pages)

FACTUAL REPORT

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Washington, D.C.

November 19, 1997

FLIGHT TEST GROUP CHAIRMAN'S FACTUAL REPORT OF INVESTIGATION

A. ACCIDENT: DC A-96-MA-070

Location:	East Moriches, New York
Date:	July 17, 1996
Time:	2031 Eastern Daylight Time
Airplane:	Boeing 747-131, N93119

B. GROUP IDENTIFICATION

The group met at **JFK Airport** on July 11, 1997, through July 20, 1997. The following group members participated in the investigation.

Chairman:	Daniel R. Bower, Ph.D. NTSB
Test Director:	Robert Benzon NTSB
Member:	Michael Collins Federal Aviation Administration
Member:	Roland Johnson Boeing Commercial Airplane Company
Member:	Steve Green Air Line Pilots Association
Member:	Terry Stacey Trans World Airlines

Additional participants were involved for the implementation of the Flight Test. These participants were:

Member:	Kevin Rickard Evergreen Airlines
Member:	Steven A. Bongardt FBI/DOD Coordinator
Member:	Robert L. Swaim NTSB Systems Group Chairman
Member:	Merritt Birky, Ph.D. NTSB Fire and Explosion Group Chairman

FlightCrew:

Captain:	Dale M. Ranz Boeing
First Officer:	Jamie C. Loesch Boeing
Flight Engineer:	George E. Kegebein Boeing

C. SUMMARY

On July 17, 1996, at 2031 EDT, a Boeing 747-131, N93119, crashed into the Atlantic Ocean, about 8 miles south of East Moriches, New York, after taking off from John F. Kennedy International Airport (JFK). The airplane was being operated on an instrument flight rules (IFR) flight plan under the provisions of Title 14, Code of Federal Regulation (CFR), Part 121, on a regularly scheduled flight to Charles De Gaulle International Airport (CDG), Paris, France, as Trans World Airlines (TWA) Flight 800. The airplane was destroyed by explosion, fire, and impact forces with the ocean. All 230 people aboard were killed.

In support of the investigation into the TWA Flight 800 accident, a series of nine flight tests were performed to obtain time/temperature histories within a 747-100 series airplane. The tests followed specific preflight, taxi, takeoff, and climb flight profiles. Data was collected from center wing tank (CWT) surface temperatures, CWT air temperatures, and pressure within the several bays of the CWT and the wing tip surge tanks. Also obtained were the air temperature time history of the environmental control system (ECS) air-conditioning pack bay beneath the CWT, air conditioning pack component surface temperatures, and vibration measurements, CWT ullage vapor samples, and some electromagnetic interference data.

Data was acquired with selected combinations of air-conditioning packs in operation, and with three levels of fuel in the CWT. The pre-flight conditions, operations, weight, taxi, takeoff, and flight path of TWA 800 were determined in detail and these conditions were approximated as closely as practical in one of the flight tests. CWT ullage fuel/air vapor samples were obtained on several flights at taxi, takeoff, and at altitude, and liquid fuel samples were obtained from the CWT before and after several flights.

This report documents the formulation of the flight test plan, and implementation of the flight test. Temperature measurement locations are detailed, and the conditions for each individual flight test are described. Composite plots will show the temperature time history of several measurement locations when key events in each flight test occurred. In the text of this report, several documents, drawings, and plots are referred to. These documents are contained in the following attached exhibits:

Exhibit 23B - Flight Test plan
Exhibit 23C - FAA Comments on Flight Test Plan
Exhibit 23D - Component Drawings
Exhibit 23E - Test Item Requirements List (TIRL), Instrumentation Location, Flight Test Schedule
Exhibit 23F – Flight Test Results: TWA800 Emulation Flight

D. DETAILS OF THE INVESTIGATION

Section I – Flight Test Series

The flight tests consisted of a total of nine flights. Three of the nine flights were performed for Boeing Aircraft. Data from the flights performed for Boeing is considered to be proprietary information. A portion of one NTSB flight was used to obtain data for the FBI, and a portion of another NTSB flight followed fuel management procedures suggested by the FAA. The flight test procedure and the data obtained in the six NTSB flights is summarized in this document. Details of the flight test planning, instrumentation requirements, and each flight profile requirement are included in the original Flight Test Plan given in exhibit 23B, pages 1 through 50.

Section I-A - Test Aircraft

The flight tests were performed on a Boeing 747-121 series airplane. The airplane was leased from Evergreen Airlines, and Evergreen Airlines staff was utilized for mechanical dispatch, maintenance, operations, and ground support of the flight test series. The aircraft, N480EV, was built as Boeing line number 106 (Serial Number

20348), and was configured as a freighter at the time of the flight test. Prior to flight test, the airframe had accumulated 92,504 flight hours and had 19,803 cycles. The aircraft was flown on an experimental certificate for the flight tests. Evergreen provided ballast weight and arranged fueling such that the airplane weight and balance, dispatch fuel load, and takeoff fuel load for all the flights matched TWA800 as closely as practical.

Section I-B - Flight Test Plan

The Flight Test Plan given in exhibit 23B was developed by the Safety Board staff and forwarded to the parties for comment. The flight test plan was developed such that modification of some procedures in the flight test plan could be accomplished during the flight test program. Hence, the flight test plan developed was modular in nature for each flight, and the order of flights was determined as necessary throughout the course of the flight test series.

In responding to the request for comments about the flight test plan, the Federal Aviation Administration (FAA) requested additional temperature measurements to be made, and a crossfeed procedure to be followed on one of the test flights. These requests were implemented, and the additional temperature measurements and procedure were included in the flight test program. Copies of the FAA comments and requests are included in exhibit 23C, pages 1 through 6.

The flight tests were designed to examine possible combinations of ECS pack operations prior to pushback and taxi. The combinations of pack operations were used to provide possible differing heat loads and heat distributions to the CWT.

The general parameters for each of the flights in the flight test series are given in table 1 below. Details of the specific pre-flight procedures and operations during each flight are given in the attached Flight Test Plan, and are described briefly in later sections of this document. For the flight in which ECS packs 1 and 3 were used, the ECS pack operation was extended to accurately depict the pre-flight operations of TWA800. All of the flight tests utilized an ascent flight profile similar to that of TWA flight 800 up to 17,500 feet altitude[1]. Several flights continued along a typical climb profile to reach a cruise altitude of 35,000 feet altitude.

Section II – Airplane Areas of Interest

Center Wing Section Fuel Tank

The center wing tank of the 747-100[2] series of airplanes is illustrated in exhibit 23D, pp. 2 - 3. As seen in these illustrations, the entire 20'x21'x(4.5-6.0)' center wing

[1] All altitudes shown are mean sea level (msl) altitudes unless otherwise noted.
[2] The –100 series included the –121 variant used in the flight tests, and the –131 variant, which was the accident airplane.

TABLE 1
FLIGHT TEST PARMETERS

ECS Packs in Operation	ECS Duration before take-off	Fuel in CWT	Additional Data Obtained
2 & 3	2.5 hours	50 Gallons (from Athens)	Liquid Fuel Sample
All 3	2.5 hours	50 Gallons (from Athens)	Fuel/Air Vapor and Liquid Fuel Sample
1 & 3	3.5 hours	50 Gallons (from Athens)	Fuel/Air Vapor and Liquid Fuel Sample
1 & 2	3 hours	50 Gallons (from Athens)	Fuel/Air Vapor and Liquid Fuel Sample
All 3	3 hours	6000 pounds	Liquid Fuel Sample and EMI Interference
2 & 3	1.5 hour	12000 pounds (1/2 hour before taxi)	
1 & 3 (Boeing)	3 hours	50 Gallons	(Proprietary)
1 & 3 (Boeing)	3 hours	50 Gallons	(Proprietary)
1 & 3 (Boeing)	3 hours	50 Gallons	(Proprietary)

section consists of a forward dry bay, and several wet[3] bays. The lateral separations are labeled from fore to aft as spanwise beam 3 (front wall of the first wet bay), spanwise beam 2, the mid spar, spanwise beam 1, and the rear spar (rear of tank). The bays aft of the mid spar also have a partition (butt line[4] zero [BL 0] rib), separating the mid and aft bays into left and right sides. Each bay communicates[5] with the adjacent bays via small holes located near the top and bottom corners of each bay partition to allow fuel and vapor to flow between bays. In some of the lateral partitions are openings for tubing such as the pick-up tube for the scavenge pump. The opening where the tube passes through the partition is a larger diameter than that of the tubing, creating additional small communication area exists in those locations also.

ECS Units

The ECS units are located in an enclosed area directly below the CWT. The ECS packs and related pneumatic system are arranged schematically on the airplane as shown in exhibit 23D, page 1. Hamilton Standard Inc. manufactured the ECS units on

[3] Wet refers to **bays** that contain fuel.
[4] "Butt line #" refers to the number of inches to the **left** or right from the airplane centerline.
[5] For the purpose of this report, "communicates" refers to the ability to permit liquid fuel and vapor to pass between bays.

the test aircraft and on the TWA800 aircraft. Each pack receives regulated bleed air from the engine compressors, removes heat from the bleed air with a primary and a secondary heat exchanger, and exhausts the excess heat beneath the airplane. The cooled bleed air is routed to the cabin to provide a pressurized interior climate with comfortable temperature. Drawings of the ECS units, with appropriate station locations, are shown schematically in exhibit 23D, page 4.

Wing Tip Surge Tanks and Vent Stringers

The CWT and the wing fuel tanks maintain relative pressure equilibrium with the atmosphere. The tanks are vented via enclosed stringers[6] in the wings, which lead to a surge tank at each wing tip. The vents from the CWT and from all of the tanks in that wing are collected into each wing tip surge tank. A single tube connects each surge tank with the outside atmosphere on the lower wing surface. These vents allow the tanks to equalize the internal tank pressure with the atmosphere during aircraft climb and descent. According to Boeing, the vents are sized to permit passage of fuel if a fault occurs during ground refueling. This design criterion requires a larger vent cross sectional area than required to provide air pressure equalization alone.

Section III - Instrumentation

The flight test instrumentation locations were designed to obtain air temperatures and pressures within the CWT and temperatures on surfaces within the CWT. Particular attention was made to obtain the surface temperatures on the CWT lower tank skin external surface. Air temperatures were also obtained in the ECS pack bays below the CWT, and several ECS pack component surface temperatures were recorded. Also obtained was air temperature and pressure measurements were made within the wing tip surge tanks and in some vent stringers leading to the wing tip surge tanks. Descriptions of each sensor location are described in detail in the Flight Test Plan. Instrumentation locations are additionally described in the Test Item Requirement List (TIRL), developed by Boeing and shown in exhibit 23E, pp. 1 - 40. Overviews of the sensor locations are given in the sections below. Each of the sensor locations and installations were photographed.

Section 111-A Temperature Instrumentation

The temperature thermocouples used in this experimental test program were constructed of bimetallic, type K, Chromel/Alumel. The thermocouples were constructed of 20-gage wire (USWG) for use in the tank, and 24 USWG for use in the ECS equipment bay. All thermocouples were designed to introduce no more than 0.02 milli-

[6] **A** stringer is a structural member of the wing, which acts to support and reinforce the wing skin. In the 747-100, wing stringers run from the wing root to wingtip. Passageways between adjacent stringers form the vents.

joules into the CWT in a normal or failed condition. The thermocouples were either mounted at their prescribed locations for air temperature measurement, or bonded to the surface for surface measurements.

CWT Ullage[7] Air Temperatures

As described in previous sections, relatively small communication is possible between adjacent bays of the CWT. Each bay was instrumented individually to determine any spatial temperature gradients between the bays. Additionally, each bay was instrumented to determine any vertical (top to bottom) temperature gradients. The air temperature instrumentation locations are shown schematically in exhibit 23E, page 41. Each of the rear bays was equipped with a vertical array of three thermocouples. In the forward two bays, vertical arrays of three thermocouples were placed on each side of the bay. In addition, placed in the center laterally in the forward two bays was a larger array of thermocouples. The center arrays consisted of five thermocouples near the top and bottom of the CWT, placed at one-inch intervals. Thermocouples were also placed in the center of each vent inlet.

CWT Fuel Temperatures

Instrumentation intended to measure liquid fuel temperature was placed at four locations in the CWT. The locations were used with the recognition that the small amount of fuel present in the CWT during the flights with 50 gallons of fuel in the CWT would migrate to different portions of the tank with changes in aircraft attitude. Hence, thermocouples were centered laterally in each rear bay, ½ inch from the CWT lower tank skin internal surface. Additionally, thermocouples were placed at the calculated lowest location in the CWT as the airplane sits on the ground, ½ inch from the CWT internal lower skin surface.

CWT Internal Surface Temperatures

Several locations inside the CWT were instrumented to obtain internal surface temperatures. Thermocouples were mounted in the center of the side of body rib in each bay, on both left and right sides. The centers of the CWT internal upper skin of the two forward bays, and the left aft bay were instrumented with surface thermocouples. The rear spar, in the center (vertically and horizontally) of the left and right rear bays was also instrumented with surface thermocouples. Additionally, a thermocouple was placed where the crossfeed tube intersected the Butt Line 0 rib.

[7] Ullage **refers** to the space in the tank above the **liquid** fuel.

CWT Lower Tank Skin External Surface Temperatures

The external surface of the CWT lower skin, which forms the top surface of the ECS pack bay, was instrumented in several locations. On left and right sides of the CWT, thermocouples were centered under each CWT fuel bay (including the forward dry bay) at the left and right butt line **22** location. At the left and right butt line 58 position, 10 thermocouples were spaced approximately every two feet, starting 1 foot aft of the front spar (the front spar is the forward wall of the dry bay). Additionally, surface thermocouples were placed on the CWT external lower skin above the left and right pneumatic bleed ducts at the front and rear of the tank. These external locations and the locations on the internal side ribs are shown schematically in exhibit **23E**, page **42.**

ECS Pack Bay Air Temperatures

The ECS pack bay was instrumented with air temperature thermocouples located in several locations to determine any spatial air temperature gradients within the pack bay. On the right and left butt line **22,** thermocouples were place **4** inches below the surface thermocouples at those locations. At right and left butt line 58, thermocouples were placed **4** inches below every other surface thermocouple, starting at the rearmost surface thermocouple location. The locations relative to the CWT lower skin are shown in exhibit **23E,** page **43.**

ECS Component Temperatures

Thermocouples were placed on some components of each ECS unit. On each ECS unit, thermocouples were placed on the pneumatic bleed duct near the flow control valve, at the outlet of the water separator, on the upper surface of the inlet to the heat exchanger, and on the upper surface of the compressor outlet. In the Flight Test Plan, thermocouples were to be placed on one of the exhaust louvers of the heat exchanger. However, installation difficulties prevented a thermocouple placement directly on the louver, and the thermocouple was placed on the side support housing of the louvers.

Wing Tip Vent Surge Tanks and Tank **3**

In both wing tips, air temperature thermocouples were placed in the center of the surge tanks where the flow from all of the tanks combine to flow out the wing vent. Thermocouples were placed at each (left and right) overboard vent duct collector can, inside each surge tank. In the right surge tank, thermocouples were placed at the surge tank end of the vent stringer channel coming from the CWT, tank number 3, and tank number **4.** Vent outlet thermocouples **(2)** were placed in the left wing surge tank overboard vent duct. One was placed inside the duct near the bottom surface of the wing, and one was placed inside the horizontal section of the duct, approximately 8 inches inboard from the outboard end of the horizontal duct. The thermocouple in the horizontal section was installed such that there was an unobstructed path to the surge tank flame suppression sensor as installed on the TWA800 accident aircraft[8]. A surface thermocouple was also placed on the vent stringer exit from the number 3 tank, on the inside surface of the top wing skin.

At the request of the FAA, air temperature thermocouples were placed inside main fuel tank number 3 (right inboard main tank). A thermocouple was placed at each vent inlet, and a thermocouple was placed near the high point of each fuel pump power conduit. The details of the locations of the thermocouples are included in the FAA response to the Flight Test Plan. These locations are shown schematically in exhibit 23E, page **44.** This drawing shows the CWT, tank 3, and the vent stringers leading to the wing tip. The air temperature measurement locations at the CWT and tank 3 vent inlets are shown. Also shown are the measurement locations in tank 3 near the fuel pump power conduits.

Section III-B Pressure Instrumentation

The pressure gages used in the flight tests were manufactured by Rosemount Inc., (part # 1332A16EP2), and measured total pressure. Pressure was measured near the vent inlets in the forward two bays and near the vent inlet in the rear bay. Pressure gages were also placed in each (left and right) of the wing tip surge tanks.

Section III-C Acceleration Instrumentation

Acceleration of the CWT lower skin surface was measured using three accelerometers, one aligned along each axis of the aircraft (vertical, longitudinal, and lateral). Endevco Inc. manufactured the accelerometers (part # 7290A-10M41A) used for all axes. The acceleration data was acquired by the recording system (described in a later section) maximum sampling rate of 800 Hz.

The accelerometer block was to be mounted on the external surface of the CWT lower skin, centered underneath the right rear bay. However, a structural support member was located at the point mid way between the keel beam and the side of the tank. Hence, the accelerometer block was located midway between the support beam and the keel beam, at butt line 31. The acceleration block was centered longitudinally between the right rear spar and spanwise beam 1.

Section III-D Vapor Sampling Equipment

A device to sample fuel/air vapors from the CWT ullage was designed and constructed by Boeing with design input from the Desert Research Institute (DRI). The sampling unit consisted of six one-liter evacuated stainless steel canisters. The unit was

[8] The flight test airplane was not equipped with **a** surge tank flame suppression sensor.

connected via copper tubing to the forward CWT wet bay (between spanwise beam **2** and spanwise beam 3). The tubing was installed through a replacement access door, and the inlet to the sampling unit was approximately 2.5 feet from the CWT internal lower skin as installed.

The sampling unit consisted of a six port manifold within an aluminum case, equipped with a main cutoff valve, and six individual cutoff valves, one for each of the evacuated sampling canisters. Two samples were required at each vapor acquisition; one sample canister was used to purge the lines leading to the unit, and one sample canister collected the actual sample to be analyzed. Thus, three valid samples could be collected on the desired flights. The entire unit was installed in the main cargo compartment, and was operated manually during the flight tests at the desired collection times. Details of the vapor sampling equipment are included in the vapor sample factual report' developed by DRI.

Section 111-E FOIS Parameters

During the System Group investigation, the fuel quantity indication system (FQIS) was found to have two unshielded wires and one sheilded wire routred between the rear win spar and the cockpit. One of the wires, known as the LO Z[10] wire, was instrumented with shielded wiring to record the system voltage and current. Prior to one flight, the FQIS wiring was exposed to various external sources of electromagnetic induction (EMI). Sources such as a hand held transceiver, laptop computer, cellular telephone, electric shaver and airplane systems were operated in the cockpit and cabin compartments. A description of the procedure used to test the energy induced by each device is described in a later section.

Section III-F Flight Parameters

Several flight parameters were recorded on the data acquisition unit. Parameters such as airspeed, altitude, roll angle, pitch angle, heading, total air temperature, were recorded. Flight parameter data was obtained from the aircraft air data computer, inertial reference unit, and global positioning system (GPS) unit. The fight data recorder was secured following the first three flights **as** a backup data source.

Section III-G Data Acauisition

The Boeing Commercial Aircraft Company provided the flight test instrumentation, flight data acquisition equipment, and performed the installation and removal of flight test instrumentation. Safety Board personnel provided installation

[9] The Vapor Sampling Factual Report compiled by DRI is included in the Fire and Explosion Group Chairman's Factual Report.
[10] For **a** description of the FQIS LO Z wiring, see the System Group Chairman's Factual Report.

requirements, and provided oversight of the installation procedure. Boeing furnished instrumentation operation personnel and the flightcrew as detailed in the Flight Test Plan. All flight test data was recorded using a Loral Portable Airborne Digital Data System (PADDS 11) system. The PADDS unit consisted of an analog to digital converter, Remote Multiplex unit (RMUX), and the Central Multiplex unit (CMUX) which amplified the signals from the individual thermocouples and converted the signals into numbered counts[11]. The signal counts were then passed into a laptop computer for conversion into engineering units. The data time history, in engineering units, were recorded on magnetic tape at the respective sampling rate.

Section IV - Flight Tests Description

Members of the flight test group, the flight crew, and instrumentation technicians attended a flight readiness review on July 8-10, 1997, at JFK Airport. The procedures and the overall safety of the flight test series was discussed and agreed upon by all parties, and approval of the flight test plan was obtained from all parties. Installation of the instrumentation, vapor sampling equipment, data acquisition equipment, and maintenance repairs to the aircraft continued through July 14.

Jet A fuel was procured and placed in the CWT prior to the first flight of the flight test series. The fuel, purchased from Olympic Airways, was originally loaded onto an Olympic Airways 747 in Athens, Greece, and flown on a regular service flight from Athens to JFK. The route was similar to the last leg completed by the accident airplane. The fuel was unloaded from the Olympic Airways 747 wing tank into a fuel truck, transported, and 50 gallons of fuel was loaded into the test airplane CWT prior to the first flight. This fuel remained in the CWT for the first four flights.

During the flight tests, the occupants of the aircraft were limited to the flight crew and personnel required for conducting the test. In addition to the flightcrew, the NTSB Program Test Director, the NTSB Flight Test Group Chairman, Boeing Test director, Flight Analysis engineer, and Flight Instrumentation engineer were on board the aircraft for all flights. For the flights in which vapor sampling was performed, an additional vapor-sampling operator was on board.

This portion of the document describes the flights performed for the NTSB only **(six** total flights), and describes procedures as performed in the flight tests. All times in this report are Eastern Daylight Time (EDT), and are given in 24-hour format HHMM or HHMM:SS. The flight test series, showing flights as performed, are given in the schedule shown in exhibit 23D, page 45.

[11] The "counts" are a direct conversion of voltage to a number based on the voltage acquired as compared to the entire voltage range of the measuring device.

Monday, July 14, 1997

Packs 2 and 3

The first flight of the test series began on Monday, July 14. The data acquisition unit started recording data before the auxiliary power unit (APU) or any ECS packs were in operation. The data recording commenced at 0920 Eastern Daylight Time (EDT). ECS packs 2 and 3 were started at close to 0950, and operated at full cold. Fuel began to be loaded into the main tanks at approximately 0930, and the fuel truck delivery temperature of the fuel was 80" F. The outside air temperature (OAT) at ECS startup was 86" F. The ECS packs ran continuously after initial startup. By the time pushback from the blocks occurred and initial engine start was accomplished at 1210, the outside air temperature had risen to 91° F.

The TWA procedure for engines start (as included in the Flight Test Plan) during taxi was utilized. This procedure entails shutting down the ECS packs during all engine starts. The aircraft proceeded to taxi, and liftoff from **JFK** occurred at approximately 1237. The TWA800 ascent profile was used up to 14,000 feet altitude, and a similar climb rate was used up to 17,500 feet altitude. The aircraft remained at 17,500 feet altitude, 250 knots indicated airspeed (KIAS) from 1253 until approximately 1522. The airplane then continued to the Atlantic City, NJ airport to perform additional flight testing for the FBI. During this series of tests, data was continually recorded. After the testing for the FBI was completed, the aircraft returned to **JFK** airport at approximately 1910.

Tuesday, July 15

All three packs

On the second day of testing, the airplane fuel was loaded in the main tanks prior to the APU startup at 0830. The data acquisition unit started recording data 15 minutes after APU start. The temperature of the fuel at delivery was 82° F as measured on the fuel truck. The ECS packs **1**, 2, and 3 were started at approximately 0845, and all were operated at full cold. The outside air temperature at ECS startup was 82" F. At 1128, a problem with the bleed air isolation valve occurred during the engine start procedure. The aircraft was pushed back into position, and the valve was manually opened. The ECS packs remained off during this procedure. After the valve was closed, pushback was performed a second time. When all four engine starts were accomplished by 1202, the outside air temperature had risen to 90° F and the fuel temperature in the main wing tanks had risen to 91° **F.**

During the taxi, an ullage vapor sample was collected in the vapor-sampling unit at 1206. Takeoff roll and rotation occurred at 1211. The TWA800 ascent profile was used up to 14,000 feet altitude, and a similar climb rate was used up to 17,500 feet altitude. During the ascent, a fuel/air vapor sample was acquired at 1218 when the aircraft was at 10,300 feet altitude. The third vapor sample was acquired at 1224 as the aircraft passed 14,200 feet altitude. At 1226, the aircraft leveled at 17,500 feet altitude, and remained at that altitude for approximately 1 hour. At 1330, the airplane began to ascend to 35,000 feet altitude, and the ECS packs operation was switched to automatic. The aircraft remained at 35,000 feet altitude for approximately 2 hours, and started to descend at approximately 1600. The aircraft touched down at JFK at 1628. Upon landing, pack 2 was switched off, and packs 1 and 3 remained running on full cold. The remaining fuel in the main tanks was 53" F; the outside air temperature at touchdown was 90° F. The engines were shut down at 1637. The APU and ECS packs 1 and 3 remained running for the next flight test.

Packs 1 and 3 (TWA800 Emulation Flight)

The airplane was taxied into position for the preparation of the TWA800 emulation flight. The airplane main tanks were defueled to the proper level as determined by the Operations group to be representative of the fuel load of TWA 800 prior to fueling. ECS packs 1 and 3 continued in operation during the entire on ground phase. The fuel load for the TWA800 emulation flight was loaded in the aircraft main tanks beginning at 1800. The same amount of fuel that was loaded onto TWA800 was loaded into the wing main tanks of the test airplane. Four trucks were used to fuel the airplane, and the temperature of the fuel delivered ranged from 88° F to 91° F. The outside air temperature at fuel loading was 88" F, and the fuel loading was completed at 1908.

Pushback occurred at 1940, and engine number **4** was started five minutes later. Engines one and two were started approximately 10 minutes after engine number **4.** The ECS packs were turned off for the engine starts. At 1957, the first vapor sample was taken during the start of taxi. Engine three was then started at 2012. The TWA takeoff procedure (as given in the Flight Test plan) was followed, and the packs were turned off for takeoff. Liftoff from JFK runway 22R occurred at 2021. The landing gear was raised, and the TWA procedure for ECS pack restart was followed. ECS pack 1 was started at 400 feet altitude, pack 2 at 600 feet altitude, and pack 3 at 800 feet altitude. All three **ECS** packs remained in operation for the rest of the flight.

At 2028, the second vapor sample was obtained as the airplane passed through 10,000 feet altitude. Also at that altitude, the main tank cross-feed procedure as defined in the TWA Flight Handbook for fuel management (and given in the appendix of the Flight Test Plan) was performed. The emulation flight reached the TWA800 event altitude at 2032. At 2033, when the airplane passed through 14,200 feet altitude, the third vapor sample was obtained. The airplane continued to climb, and leveled at 19,000 feet altitude at 2036. The airplane remained at 19,000 altitude and started descent at 2239. Touch down occurred at 2257, and the airplane was parked at 2313. The data recording equipment was operated for approximately 20 minutes after engine shutdown.

Wednesday, July 16

Boeing Flight 1

On the morning of July 16, the first flight for the Boeing Commercial Aircraft Company was performed. ECS Packs 1 and 3 were started at 0750, and fuel was loaded in the main wing tanks at 0815. Pushback occurred at 1011, and taxi began at 1031. Takeoff from JFK occurred at 1044, and the same climb profile as the previous tests was used up to 18,000 feet altitude. Starting at 1100, the aircraft remained at 18,000 feet altitude and 300 KIAS. At 1328, the aircraft started to climb, and reaching flight level (FL) 350[12] at 1345. The airplane remained at this altitude for two hours. Descent from FL 350 began at 1545, and the aircraft landed at JFK at 1628.

Packs 1 and2

The data recording for this flight test began at 1636, immediately after the previous test. Packs 1 and 2 were switched to full cold at that time. At 1704, the fueling of the main tanks was started, and was completed approximately 45 minutes later. The fuel temperature upon delivery was 84° F, and the outside air temperature was 81". Push back occurred at 1918, and after engines start, taxi commenced at 1932. The first ullage vapor sample was obtained two minutes later.

Liftoff from JFK occurred at 1955. The TWA pack restart procedure was used on climbout, and all three packs were operated for the duration of the flight. At 2001, as the aircraft passed through 6000 feet altitude, the crossfeed procedure as specified by the FAA was initiated (see the Flight test Plan, appendix II for details). Over the next five minutes, tank 3 supplied the fuel for engines 1, 2, and 3 with both number 3 boost pumps operating. Tank 4 supplied the fuel for engine 4, with both number 4 boost pumps operating. After five minutes had elapsed, the TWA Flight Handbook fuel management procedures were resumed.

Fuel vapor samples were obtained as the aircraft passed through 10,400 feet altitude at 2006. The third vapor sample was obtained at 2012, as the aircraft passed through 14,700 feet altitude. The aircraft leveled off at 17,500 feet altitude and remained for approximately two hours. The aircraft touched down at JFK at 2241. The data recording units continued to record data for approximately 20 minutes after engine shutdown.

Thursday, July 17

6000 Pounds Fuel in CWT

Refueling of the main wing tanks and CWT with two trucks began at 0726. The temperature of the fuel at the beginning of fueling was 80" F from one truck, and 82" F from the other. The outside air temperature was 80" F. At 0732, the data recording

[12] Flight level (FL) refers to the mean sea level altitude divided by 100 feet; hence, FL 350 is analogous to 35,000 feet altitude above mean sea level.

commenced, and all three packs were turned on and placed in full cold mode. By 0751, the fueling was completed, and 6000 pounds of fuel had been placed in the CWT.

During the ground portion of this flight test, the EMI from several personal electronic devices was tested. A cellular phone, pager, ham radio, and electric shaver were operated in the cabin areas. A laptop computer was operated, employing the file save operation and a CD-ROM operation. These devices were operated as they were walked along the upper deck wall, near the FQIS CWT wiring. The devices were then walked along the left side of the main deck, near the CWT FQIS wiring. Additionally, several airplane systems were operated from the flight engineer's panel. The external and internal lights were cycled on and off, each radio was transmitted, and the radar altimeter and radar transponder was operated. The pitot heat, window heat, stall warning, and electric trim actuator were activated in the cockpit. During these personal electronic device and airplane system operations, the FQIS system LO Z voltage and current were monitored real time and also recorded on the data recording system.

Pushback occurred at 1017, and taxi commenced at 1030. At 1043, the airplane lifted off, and performed the same ascent profile as the previous flights. By 1059, the aircraft had leveled at 17,500 feet altitude. Ascent to FL350 started at 1200, and reached FL350 at 1217. Descent began at 1427, and the CWT was used to fuel all engines during the descent. The aircraft touched down at 1452. Engine shutdown occurred at 1501, and the flight engineer panel AC power switches were cycled on and off. Data recording was stopped approximately 15 minutes after engine shutdown.

Friday, July 18

12,000 Pounds Fuel in CWT

Upon completion of the previous flight and review of the preliminary data, it was decided a flight in addition to those outlined in the Flight Test Plan should be performed. After consultation with the instrumentation crew and the flightcrew, an additional flight was planned for Friday morning. It was determined that the addition of an extra flight at this point in the flight test program would not greatly affect the overall flight test schedule and completion date.

On the morning of the 18th, ECS packs 2 and 3 were turned on and the data recording units were started at 0652. The ECS packs were placed in auto mode; the outside air temperature was 79" F at pack startup. **At** 0720, fuel was loaded into the main tanks and CWT. The CWT was loaded with 12,000 pounds of fuel. The fuel temperature upon delivery was 80" F, and fuel loading was completed by 0749.

Pushback occurred at 0800. By that time, the outside air temperature had risen to 81° F. **As** in the previous tests, the packs were turned off for engine startup. Taxi was initiated at 0809, and liftoff from JFK occurred at 0832. The same ascent profile was used during the climb, and level off at 17,500 feet altitude occurred by 0847. At 0916, a further ascent was initiated, but the airplane was asked to remain at FL190 by air Traffic

Control (ATC). The airplane continued its climb at 0923. By 0938, the aircraft had leveled at FL350. Fuel from the CWT began to be used for all engines at 0941. By 1010, the fuel level in the CWT had been reduced to 2,000 pounds, and the flight engineer determined that the pumps probably could draw no more fuel from the CWT until descent, and engine fuel source was switched back to the main wing tanks. The fuel level remained at close to 2,000 pounds until descent.

Descent from FL350 started at 1038, and the CWT fuel pumps were placed back on, and the remaining CWT fuel was used for the engines. At 1043, the right CWT pump was turned off. The left CWT fuel pump was turned off at 1046, and the scavenge pump was turned on. The scavenge pump remained on until 1106, when the CWT fuel quantity gage read nearly zero. Touchdown at **JFK** occurred at 1113. Engine shutdown occurred at 1127, and the data recording remained in operation for an additional 15 minutes.

Fridav. July 18 (PM) and Saturdav, July 19

The final two flights of the flight test series were performed for Boeing. The first flight on Friday afternoon utilized a modified pack bay inlet, and the flight on Saturday was made following replacement of the ECS pack bay seals with new hardware. Both flights were performed with 50 gallons of fuel in the CWT, and with packs 1 and 3 running 3 hours before takeoff. The same flight profile as the first Boeing flight was followed for both flights.

The flight test program was completed on Saturday, July 19. The aircraft was refurbished and returned to Evergreen Airlines over the next two days. During the flight test series, a total of 39 hours, **43** minutes of flight time was accumulated. A total of close to 70 hours of data consisting of temperatures, pressures, accelerations, and flight parameters were recorded during the flight tests.

Section V - Flight Test Data

Temperature and flight parameter data collected during the flight test series is presented in this section. However, due to the large volume of data collected, much of the data will be presented in separate documents[13]. This section of the report will discuss pertinent results from the TWA800 emulation flight (Tuesday, July 16 PM) only.

Upon completion each flight test, the Flight Test Group Chairman took the recorded data into custody, and delivered the data tape to Tom Jacky of the NTSB. Mr. Jacky supervised the readout of the data at Boeing facilities in Seattle, WA. Once the

[13] All of the flight test data will be included in separate Addendums to the Flight Test Group Chairman's Factual Report of Investigation. The ullage fuel/air vapor sampling data and liquid fuel sampling data are reported in separate documents within the Fire and Explosion Group Chairman's factual report. Acceleration data will be included in a separate addendum document to the Flight Test Group Report.

data was read out, the data was transferred electronically to the Safety Board headquarters in Washington, DC. The length of each flight test, the number of recorded parameters, and the sampling rate of each parameter resulted in several gigabytes of data for each flight test.

The plots described in this section contain the temperature time histories of several CWT ullage and surface locations, ECS pack bay temperatures, and wing-tip surge tanks for the entire flight. Examination of the data as recorded (one sample per second) showed that the temperatures for much of the CWT vary relatively slowly with time. Displaying the data at one sample per minute still accurately captures the temperature change with time, and allowed the creation of smaller size data files. Hence, the data for an entire flight have been sub-sampled[14] to one sample every 60 seconds. For portions of the data with larger temperature gradients over time, such as the ascent portions of the flight, the data is presented in one sample per second format. The data in this section is displayed as a function of elapsed time, which represents the elapsed time of data recording during each respective test flight.

Section V - A TWA800 Emulation

Flight Parameters

As described in the previous section, in the flight test program efforts were made to duplicate as accurately as possible the preflight operations, takeoff and ascent of TWA800. The time of liftoff of the test flight was within 1 minute of the time of day of TWA800, and two days before the anniversary of the accident flight. Exhibit 23F, page 1 compares the altitude and airspeed of this test flight with the **FDR** data from TWA800. As shown in this plot, the test flight elapsed time from rotation to the accident altitude was within ten seconds as compared to TWA800. Slight variations evident during the ascent of the flight test aircraft were necessary to comply with Air Traffic Control (ATC) instructions during the flight tests. However, the overall climb profile matched the accident flight within 1000 feet, and elapsed times to the brief level off at 6000 feet and 12,800 feet during the climb matched within one minute. Additionally, the airspeed throughout the ascent matched the speeds recorded on the TWA800 FDR to within 20 knots for the majority of the FDR recording.

CWT Ullage

Exhibit 23F, page 2 shows the temperature time history in the center (laterally and longitudinally) of the forward bay, between spanwise beams 2 and 3[15]. The temperatures shown are arranged vertically, and consist of an upper thermocouple located 3 inches below the upper skin surface, a thermocouple centered vertically, and a thermocouple 3 inches above the internal lower skin surface of the CWT. Exhibit 23F, page 3 shows the temperature time history in the center of the bay between spanwise

[14] Sub-sampled refers to the process of sampling **data** at **a** lower rate than recorded.
[15] For the purposes of this report, bay number 1 will refer to the b y between **spanwise beams *2*** and ***3.***

beam 2 and the mid spar[16]. Whereas there were measurements made at one inch vertical spacing near the top and bottom surfaces of the center of the two forward bays, only one measurement each near the top and bottom are shown for consistency with measurements at other locations[17]. The temperature measurements shown on pages 2 and 3 are located 3 inches below the internal upper skin surface, 3 inches above the internal lower skin surface, and centered vertically between.

Vertical measurements were also obtained at the left and right sides of the forward two bays. Shown in exhibit 23F, pp. 4 -7 are measurements from the thermocouples placed 4 inches laterally from the respective side walls. The thermocouples installed near the side walls utilized the same vertical spacing as the aft and mid bays.

Shown in exhibit 23F pages 8 and 9 are the ullage temperatures time history in the left mid bay and left rear bay of the CWT, and shown in exhibit 23F pages 10 and 11 are similar plots for the right rear bay and the right mid bay. The position of the measurement locations are centered laterally between the side body rib and the BL 0 rib, and centered between the respective front and rear partition. The measurements in the mid and rear bays are in the same relative vertical positions (3 inches from upper and lower skin surfaces, and centered between) as those shown for the forward bays. Pertinent events of the flight test, such as start of taxi and time of reaching TWA800 event altitude, are noted on the plots.

Evident in all the bays is a steady increase in temperature while the aircraft is stationary on the ground with the **ECS** packs in operation. A vertical gradient of temperatures exists in all of the CWT bays, and most predominantly in the aft and rear bays, is. For all bays, the temperature in the lower part of the tank is warmer than the temperature near the upper skin surface when the aircraft is stationary. However, as the aircraft is pushed back and begins to taxi, there is a change of slope in the temperatures, i.e. the temperatures begin to either level off or decrease slightly. Each bay exhibits a slightly different trend, and the difference between the upper and lower measurement changes in different manners depending on the phase of the flight.

Exhibit 23F, pp. 12 - 14 show a wire frame representation of the CWT, and temperatures within the CWT at certain times during the TWA800 emulation flight test. These plots represent the vertical distributions of temperature at their respective measurement location in each bay. Exhibit 23F, page 12 shows the conditions at start of taxi, page 13 shows the distribution at takeoff, and page 14 shows the temperature when the test aircraft reached the TWA800 event altitude. For both aft and mid bays, the left side of the tank has considerably higher temperature at all vertical levels.

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[16] For the purposes of this report, bay number 2 will refer to the bay between spanwise beam 2 and the mid-spar.
[17] These results will be included in a separate addendum to the Flight Test Group Chairman's Factual Report.

As evident in the temperature time history plots, the highest ullage temperatures observed when the aircraft was on the ground and in flight occurred in the left mid and aft bays. The maximum temperature observed in the tank is in the left mid bay, where a temperature of 145" F near the internal lower surface of the tank is observed before taxi commences. In addition, the largest temperature gradient of over -20" from bottom to top is noted in the left mid bay. The left rear bay reaches a maximum temperature of 138" F near the tank internal lower surface, with a -9" F degree vertical gradient evident before taxi.

The forward two bays also exhibit a vertical and spatial gradient of temperatures. Exhibit 23F, pages 2 and 3 showed the time histories of the center array in bay number one and bay number two, respectively. The maximum temperature measured in forward bay #1 is 124" at the internal lower surface, with a -5" gradient from bottom to top. **A** similar gradient is evident in the forward bay #2 between the mid spar and spanwise beam **2.** When the test airplane reached the same altitude as the TWA800 event, forward bay #1 shows a maximum temperature of 117" near the internal lower surface, and the vertical gradient to the upper skin surface has reduced -3". Bay 2 has a maximum temperature of 120" at the center of the internal lower surface, and a -3" gradient to the upper measurement. The sides of the two forward bays show a lower temperature as compared to the center, and the maximum vertical temperature occurred at the center thermocouple.

The temperature time history for the lower internal tank surface of forward bay #1 shows large, short duration increases in the temperatures near the start of taxi. The temperature of the short duration, higher spiked values are consistent with the temperature of the fuel in forward bay #1, measured during the same portion of the flight test. The fuel temperature, measured ½ inch from the lower internal tank surface of forward bay #1 is shown in exhibit 23F page 15, and shows a similar sharp rise in temperature during taxi, when the probe is immersed in liquid fuel.

The liquid fuel temperature measurement ½ inch from the lower internal tank surface at the rear spar is shown in exhibit 23F, page 16. **As** demonstrated in these plots, the liquid fuel can migrate between bays as the aircraft changes pitch attitude, or as the aircraft brakes or turns during taxi. If liquid fuel is heated in one bay of the CWT and then migrates to another portion of the tank, the liquid fuel temperature can be considerably higher than the ullage air temperature in a particular bay.

The temperature time histories in the left and right mid bay ullage, with specific focus on the ascent portion of the TWA800 emulation test flight is shown in exhibit 23F page 17. The data in this exhibit show the data as collected, at one sample per second. During taxi, takeoff, and ascent, all of the ullage temperatures exhibit a decline in temperature. Each vertical position of each bay shows a decrease in temperature as the aircraft ascends. By the time the aircraft reaches the same altitude as the TWA800 event, the temperatures in the warmest part of the CWT (i.e. the left mid bay) have reduced to 128" F in the lower location, with a -14" gradient to the upper location. The temperature in the right mid bay is at 114" F near the lower internal tank surface, and a -7" gradient to the top.

Exhibit 23F, page 18 shows a similar examination of the temperatures in the left and right aft bays during ascent. The aft bays show a similar behavior, with the left aft bay lower location reducing to 120" F and a -6° gradient to the upper location at the event altitude. The right aft bay lower location is 112" F at the TWA800 event altitude, with an -8" gradient to the top location. The temperatures measured in the ullage bays at the TWA800 event altitude are summarized in Table 2 below. As evident in these measurements, the warmest part of the CWT at the TWA800 event altitude is the left mid bay, and the coolest part of the tank is at the side of the forward bays.

TABLE 2
SUMMARY OF FLIGHT TEST MAXIMUM ULLAGE TEMPERATURES
AT TWA800 EVENT ALTITUDE

Ullage Bay Location	Maximum Temperature (F)	Minimum Temperature (F)
Bay 1 Center	117"	114"
Bay 1 Left Side	111"	107"
Bay 1 Right Side	110"	101"
Bay 2 Center	120"	117"
Bay 2 Left Side	110"	102"
Bay 2 Right Side	109"	102"
Left Mid Bay	127"	114"
Right Mid Bay	114"	106°
Left Aft Bay	120"	113"
Right Aft Bay	112"	103"

CWT Lower Tank Skin External Surface Temperatures

Exhibit 23F, pages 19 and 20 show the time histories of the CWT external lower skin surface temperature measurements on the left and right side of the keel beam, at the BL22[18] location. As described in a previous section, each of the surface thermocouples is centered longitudinally below each bay at the BL22 lateral location. Similar to what was measured in the ullage, the surface below the left mid bay maintains the warmest temperature throughout the ramp-hold portion of the flight test. **As** shown in exhibit 23F, page 19 for the left side of the tank, the maximum external surface temperature obtained below the left mid bay was 203" F. Immediately before start of taxi, the

[18] In this context BL22 refers to the butt line 22 location, i.e. 22 inches laterally (left or right) from the centerline of the airplane.

temperature was steady at 200" F. The surface below the left aft bay maintained an approximate 9" F lower temperature than the left mid bay during the ramp hold.

A substantial spatial gradient from rear to front is evident from the left side surface measurements. A 60" F spatial gradient between the left mid bay and the dry bay BL22 location is evident during the ramp-hold. On the right side of the keel beam, at BL22, the surface temperature is significantly lower than the corresponding position on the left side of the keel beam. The maximum temperature observed on the right side of the keel beam at the BL 22 location is below the *dry* bay, where a temperature of close to 150" F is observed immediately before taxi. However, at taxi start, a much smaller surface spatial temperature gradient (-16" F) existed between the maximum and minimum temperature at the right BL22 location.

The BL58 location surface temperatures on the left side of the keel beam are shown in exhibit 23F, page 21 and 22. The number label on each time history trace represent the thermocouple locations as described in the previous instrumentation section, and are numbered sequentially from front of the tank to the rear (i.e. 1 is the most forward, 10 is the most aft). In a similar fashion to the BL22 location, the left side BL58 is the warmest near the rear of the tank. Near the time of taxi start, the rear of the tank at BL58 had reached over 180" F, and spatial gradients of over -40° F existed from rear to front. On the right side of the keel beam, shown in exhibit 23F, page 23 and 24, the temperatures near the center (i.e. near the mid spar) of the tank reach a maximum of close to 150" F before taxi. When taxi commenced, all of the bay surfaces reduced temperatures, although at significantly different rates and magnitudes. The rates of temperature change also varied considerably upon liftoff. At the TWA800 event altitude, all of the CWT lower skin external surface temperatures are in the range of 120" to 145" F.

<u>ECS Pack Bay Air temperatures</u>

The air temperatures measured **4** inches below the CWT lower skin surface (i.e. in the ECS pack bay) are shown in exhibit 23F, pp. 25 - 28. The air temperatures display a similar trend as the surface temperatures, with large spatial gradients evident. The warmest measurements in the ECS pack bay occurs on the left side of the keel beam, below the left mid and left aft bays at the BL 22 location. Below these left bays, the air temperature reached to close to 238° F before taxi. The measurements show cooler air temperatures on the right side of the keel beam in the ECS pack bays, with the maximum air temperature measured of close to 190" F. On both sides, the BL22 location air temperatures are warmer than the BL58 air temperatures, and show higher temperature measurements towards the rear of the ECS pack bays.

Upon taxi and liftoff, changes in the trend and distribution of air temperatures in the ECS bays are apparent. During the ascent, all of the ECS pack bay air temperatures reduced as the altitude increased. Additionally, the spatial gradients diminished during the climb, and a different distribution of temperatures is evident after the test aircraft leveled off at 19,000 feet-msl.

ECS Pack Component Surface Temperatures

As described previously, surface temperatures were measured on several components of the ECS components. Measurements were made to determine the upper (facing towards the CWT lower skin) surface temperature of some of the hotter components of the ECS units. Exhibit 23F, page 29 shows the surface measurements on the top surface of the inlet to the heat exchanger, and at the compressor outlet for all three packs. During the on ground portion of the test, the inlet to the heat exchanger for the packs in operation (packs 1 and 3) reached temperatures between 330" F and 350" F. The compressor outlets of the packs in operation were approximately 280" F. For the pack not in operation, the heat exchanger inlet still reached a temperature of 270" F before pushback. During taxi and ascent, the temperatures of these components varied considerably, especially during portions of the taxi when the units were turned off for engine start and liftoff. Moderately steady temperatures for the heat exchangers and compressor outlets are observed after the aircraft leveled at 19,000 feet and had all three packs in operation.

Exhibit 23F, page 30 shows the top surface temperature measurements of the pneumatic bleed control valves, which control the bleed air from the compressor section of the engines into the ECS units. The bleed control valves for packs 1 and 3 warmed to 360" F and 340° F respectively before pushback. The control valve for Pack 2, which was not in operation prior to liftoff, reached approximately 310" F before pushback. **All** control valve temperatures fluctuated during taxi and takeoff. When the airplane leveled at 19,000 feet and all three packs were in operation, the valve components for all packs ranged between 220" F and 250" F.

Exhibit 23F, page 31 shows the temperatures measured at the exhaust louvers of the ECS units. **As** described in the instrumentation section, the exhaust louvers are located on the bottom of the aircraft, at the location where the heat removed from the bleed air is expelled to the atmosphere. However, instrumentation installment difficulties precluded the measurements being directly in the exhaust flow, and were mounted to the side louver support. Hence, the potential existed for the temperature measured at this location not being the desired temperature, or influenced by other factors. **As** seen in this exhibit, the temperature traces for the packs in operation do not match during the ground portion of the test. When the aircraft reached altitude, the other component time histories imply the three pack operating well within comparable temperature ranges. However, in this plot the temperature at the exhaust louver of pack 3 shows an approximate -70" to -80" offset. This offset first appears within the first 60 minutes of the test, and continues during portions of the flight test when all three packs were operating and other component temperature measurements were consistent.

Shown in exhibit 23F, page 32 are the surface temperatures of the ECS water separators. The water separators remove water from the cooled air before it is ducted into the cabin compartment. The surface temperatures of the water separators for packs 1 and 3 remain relatively low for the duration of the entire flight. The surface of the water separator for pack 2 follows closely the ambient air temperature in the ECS pack bay (pack 2 is on the left side of the keel beam) until lift off, when pack 2 is turned on. After liftoff, all three water separators have the similar surface temperatures for the rest of the flight until touchdown, when the units are turned off.

Wing Tip Vent Surge Tanks and Tank 3

The temperature measurements in the right wing tip surge tanks and vent stringers are shown in exhibit 23F, pp. 33 - 35. Exhibit 23F, page 33 shows the temperature centered in the CWT vent stringer, at the point where the CWT vent joins the collector can[19]. As demonstrated in these plots, the temperatures in the vent stringer and collector reach quasi-equilibrium with the outside ambient temperature during the ramp-hold portion of the test. Soon after liftoff occurred, the temperature in the CWT vent exit and collector reduced considerably as the aircraft increased altitude. This is also shown in exhibit 23F page 34, which shows the ascent portion of the trajectory in detail. A similar trend is shown in the vent exits from main tank number **3** and **4,** shown in exhibit 23F page 35. At the TWA800 event altitude, the temperatures in the all the vent stringers and in the surge tank have reduced to approximately 68" F.

Main wing tank #3 ullage temperature is shown in exhibit 23F, pages 36 and 37. Temperature measurements were made at the vent inlets and near the fuel pump power conduits as described in the instrumentation section. Tank 3 exhibits a similar behavior as that of the wing vents, in that a relative constant temperature of approximately 88" F is obtained, with the exception of the temperature in the outboard vent opening. This temperature exhibits a different trend during ramp hold, but obtains a similar quasi-equilibrium before taxi commenced. After lift-off, all of the measured tank 3 ullage temperatures show a decrease with increasing altitude. When the test airplane reached the TWA800 event altitude, the ullage temperatures in Tank 3 had reduced to the range 75° F to 85" F.

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[19] The collector can is a structure that collects the vent flow from the CWT, tank **3** and tank **4** (CWT, tank 1 and tank 2 on the left side). The flow from all vents then enters a single tube leading to the atmosphere at the underside of the wing surface.