Airplane exploded at gate, Aircraft Accident Report, Thai Airways International Company Limited, Boeing Company 737-400, HS-TDC

Micro-summary: **This 737-400 exploded while parked at the gate.**

Event Date: **2001-03-03 at 1448 local**

Investigative Body: **Aircraft Accidents Prevention and Investigation Branch, Thailand**

Investigative Body's Web Site: **http://www.faa.gov/ats/aat/ifim/ifimthai.htm**

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No. 0507/3392

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29 April B.E. 2548 (2005)

Subject: A Final Report of Accident Investigation

Dear Mr. Robert L. Swaim,

May we refer to an accident of Thai Airways International Public Company Limited aircraft, Boeing 737-400, HS-TDC at Bangkok International Airport, Thailand on 3 March B.E. 2544 (2001). The Aircraft Accident Investigation Committee of Thailand has completed an investigation of this accident and released its Final Report.

In accordance with paragraph 6.4 of Annex 13, the State conducting an aircraft accident investigation shall send the Final Report of the investigation of the accident to the State of Aircraft Design and the State of Aircraft Manufacture with a minimum delay. Therefore, enclosed please find the Final Report of the mentioned accident.

Yours sincerely,

Chaisak Angkasuwan
Director General

Mr. Robert L. Swaim
U.S. Accredited Representative, HS-TDC
Office of Aviation Safety
National Transportation Safety Board
Washington, D.C. 20594
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AIRCRAFT ACCIDENT INVESTIGATION
COMMITTEE OF THAILAND
MINISTRY OF TRANSPORT

AIRCRAFT ACCIDENT REPORT

THAI AIRWAYS INTERNATIONAL COMPANY LIMITED
BOEING COMPANY 737-400, HS-TDC

BANGKOK INTERNATIONAL AIRPORT
THAILAND

3 MARCH B.E. 2544 (A.D. 2001)

The investigation process of the Aircraft Accident Investigation Committee follows the procedures in ICAO ANNEX 13, AIRCRAFT ACCIDENT AND INCIDENT INVESTIGATION, which the objective of the investigation of an accident or incident shall be the prevention of accident and incidents. It is not the purpose of this activity to apportion blame or liability.

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SYNOPSIS

On March 3, 2001, about 1448 local time, Thai Airways International Public Company Limited (Thai Airways) flight 114, a Boeing 737-400, HS-TDC, was destroyed while the airplane was parked at gate 62 of the Bangkok International Airport, Thailand. The airplane was being prepared for a scheduled domestic passenger flight to Chiang Mai, Thailand, when it exploded and was subsequently destroyed by fire. The Aircraft Accident Investigation Committee of Thailand (AAIC) notified aviation authorities in the United States of America (the State of Manufacture) who sent an Accredited Representative to participate in the investigation.

All times in this report are local.

1. FACTUAL INFORMATION

1.1 History of Flight

Thai Airways flight 114 exploded about 14:48 while parked at gate 62 of the Bangkok International Airport, Thailand. Daylight visual meteorological conditions prevailed at the time. Flight 114 was to be a domestic passenger flight from Bangkok to Chiang Mai, Thailand, and was scheduled to depart about 15:15. Flight 114 was to be the fifth flight of the day; the previous flight landed about 14:14.

Figure 1. A Photograph taken Shortly after the Explosion

Immediately after the explosion, witnesses reported smoke in the center cabin and a fire underneath the Center Wing Tank (CWT) area. Photographs taken shortly after the explosion show a large fire beneath the airplane CWT and black and tan smoke coming from the left side forward and aft passenger doors **(See Figure 1)**. Approximately 18 minutes after the initial explosion, a second explosion occurred in the right wing fuel tank.

The accident airplane's Auxiliary Power Unit (APU) was running continuously during ground operations to power the air conditioning system and to provide electrical power for the airplane. All ground operations were routine except that both CWT pump switches were found in the "ON" position. The left and right wing fuel tanks were refueled with approximately 5,440 kilograms (kg) of fuel, resulting in a total fuel quantity of 8,580 kg onboard the airplane at the time of the accident. No fuel was added to the center wing tank, and only residual fuel remained.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Others
Fatal	1	0	0
Serious	3	0	3
Minor/None	1	0	2

1.3 Damage to Airplane

The airplane was destroyed by the explosion and subsequent fire.

1.4 Other Damage

Damage to ground facilities was limited to smoke within the terminal, heat damage to the jetway curtain, and fire damage to the concrete.

1.5 Personnel Information

No pilots were aboard the airplane at the time of the explosion. Five cabin crewmembers and the load control supervisor were in the cabin, and two baggage loaders were in the aft cargo compartment at the time of the explosion. In addition, two caterers were removing galley carts at the R2 passenger door at the time of the explosion. Ten additional personnel were located outside the airplane in close proximity.

1.6 Airplane Information

The airplane, a Boeing 737-400, line number 2113, serial number 25321, was delivered to Thai Airways International on September 10, 1991. It was powered by two CFM56-3C1 engines. The engines were not operating at the time of the accident. According to Thai Airways records, the airplane had accumulated 21,006 hours of operation.

A review of the airplane maintenance logbook revealed that the forward cabin temperature trim control modulating valve and the right outboard main wheel were replaced two flights before the accident flight. A review of applicable Airworthiness Directives (AD) indicated that all applicable ADs were complied with except where the airplane had not yet reached the compliance date. All appropriate fuel system Boeing service bulletins had been incorporated.

After refueling, both left and right wing tanks contained 4,250 kg and 4,250 kg of Jet A fuel each, respectively. No fuel was added to the CWT; however, calculations showed that there was a minimum of approximately 28 gallons (80 kg) of fuel in the CWT at the time of the explosion.

1.7 Meteorological Information

The explosion occurred in daylight conditions. The last airport observation indicated that winds were from 190 degrees at 5 knots, visibility was greater than 10 kilometers, the ceiling was unlimited, the temperature was 36 degrees Celsius (C^o), the dew point was 23 C^o, and the altimeter setting was 29.75 inches of Mercury (in. Hg.), or 1007.5 millibars (mb).

1.8 Aids to Navigation

The aircraft was not in flight.

1.9 Communications

No communications systems were a factor in the accident.

1.10 Airport Information

The Bangkok International Airport is located at north 13 degrees 54 minutes 45 seconds latitude and east 100 degrees 36 minutes 24 seconds longitude. A primary airport surveillance radar was located about 150 meters behind the accident airplane.

1.11 Flight Recorders

The Digital Flight Data Recorder (DFDR) and Cockpit Voice Recorder (CVR) were located in a pressurized section of the aft fuselage. Both recorders were recovered from the accident site and sent to the U.S. National Transportation Safety Board (NTSB) laboratories in Washington, D.C., where they were downloaded under the direction of the AAIC.

The DFDR was a Sundstrand solid-state digital recorder, part number 980-4700-001 and serial number 1548. The case had severe heat damage; however, the recording medium was in good condition. The DFDR was not operating at the time of the explosion. Review of the previous flights revealed no unusual data or discrepancies that would have had a bearing on the accident.

The CVR was an Allied Signal (Sundstrand) recorder, serial number 53282. The CVR recording was of good quality and starts when the aircraft is on short final for landing at the Bangkok International Airport. The 30-minute recording continues uninterrupted until the time of the explosion. The recording contains an uneventful landing and taxi to the gate, followed by the sounds of the passengers and flight crew departing the aircraft. The ground crew can then be heard in the background during the final minutes of the recording.

A repeating background electrical noise that starts during the landing ground roll and continues until the end of the recording can be heard on several of the CVR channels. The magnitude of the electrical noise saturated the recording capability when the airplane was at gate 62. A comparison recording was made at gate 62 using a portable cassette tape recorder. The comparison cassette recorded an electrical noise that was nearly identical to the noise recorded on the accident CVR. The rotation of the nearby primary airport surveillance radar coincided with the timing of the recorded noise on the comparison recording.

The CVR continued to run for approximately 0.3 second after the initial sounds of the explosion were recorded. Only one explosion was recorded, and the explosion sound had peaked when the CVR stopped recording. A comparison of the explosion sound spectrum to a library of known sounds revealed that the accident sound spectrum corresponded most closely to the two fuel tank explosion sound spectrums.

1.12 Wreckage and Impact Information

The upper fuselage crown was consumed by fire from the cockpit to aft of the wing **(See Figure 2)**. The fuselage had failed both forward and aft of the wing as a result of the explosion and fire. Most of the floor structure, cabin seats, and airplane systems were consumed in the area above and several rows forward of the CWT. The majority of the right wing upper surface was missing and found essentially intact on the left side of the airplane.

Figure 2. Aircraft Wreckage

The cockpit area, including the upper cockpit structure, overhead instrument panel, and surface features of the main instrument panels suffered severe heat damage. Both center wing tank pump switches and the left forward wing tank pump switch were found in the "ON" positions **(See Figures 3, 4, 5 and 6)**. As evidenced by witness statements, people who accessed to the cockpit before the time of the explosion were pilots and mechanics.

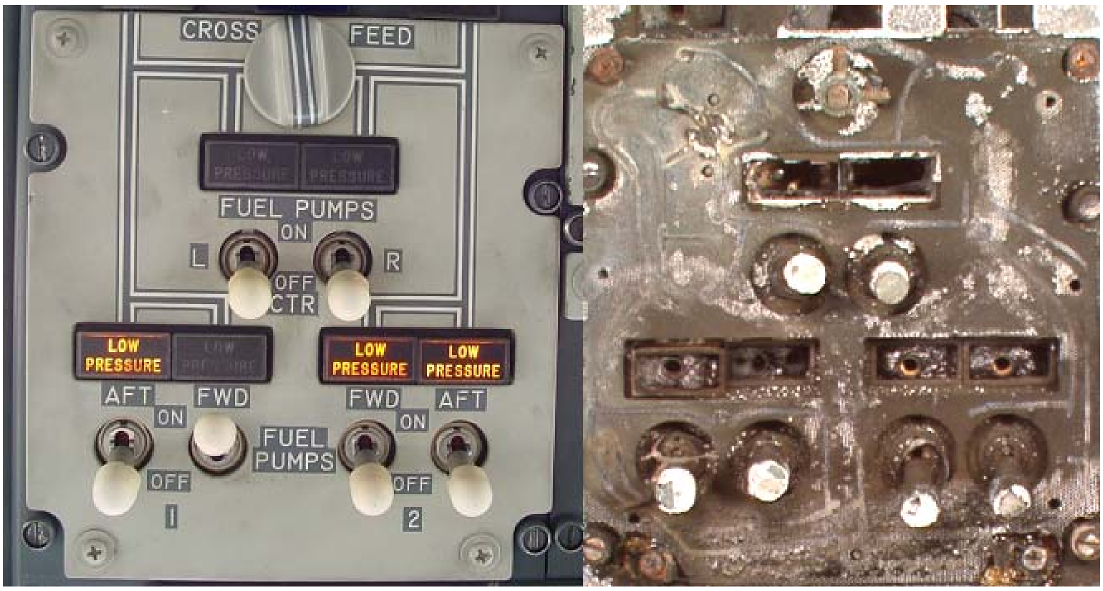

Figure 3. Cockpit Fuel Control Panel Comparison

Figure 4. The Position of Toggle Switches Located on the Left of the Fuel Control Panel

Figure 5. The Position of Toggle Switches Located at the Center of the Fuel Control Panel

The airplane structure exhibited signs consistent with an overpressurization event in the center wing fuel tank. The remaining edges of the upper surface were displaced upward, and the lower surface had been displaced downward between spars. The upper portion of the forward spar was found bowed forward about 7 inches near the centerline of the airplane. The face of the rear spar was displaced aftward and separated from the reinforced structure at the bottom.

Figure 6. The Position of Toggle Switches
Located on the Right of the Fuel Control Panel

1.13 Medical and Pathological Information

According to the medical examiner, the decedent was found approximately five rows aft of the forward passenger doors. The postmortem examination of the decedent by the Royal Thai Police Forensic Medicine Institute attributed the cause of death to smoke inhalation. The decedent's carboxy-hemoglobin concentration in the blood was 33 percent. The decedent suffered flash burns on his right side and a ruptured right eardrum. In addition, soot was found in the trachea and upper airways. The decedent sustained a blunt force traumatic injury to the left side of the head, with a corresponding brain lesion. He also sustained a blunt force traumatic injury to the left chest area with corresponding fractures of ribs 5 and 6 and corresponding hemothorax of the left lung.

1.14 Fire

The Bangkok International Airport is served by two airport fire stations, the Rescue and Fire Fighting Department (RFFD) of an Airports Authority of Thailand located between two runways and a Royal Thai Air Force (RTAF) fire station located on the east of the Bangkok International Airport. According to the air traffic control (ATC) transcript, RFFD was initially notified of the fire at 14:41:15 and the first equipment arrived at the scene at 14:45:01. The RFFD responded with a total of 10 vehicles (including 3 aircraft fire fighter tenders, 3 water supply tenders, 1 boom ladder vehicle, 1 rescue vehicle, and 2 command post vehicles) and 36 firefighters, and the RTAF responded with 5 vehicles (including 2 primary aircraft fire fighting tenders, 1 rapid intervention vehicle, 1 water supply tender, and 1 rescue vehicle) and approximately 25 firefighters. In addition to vehicle-mounted nozzles, the RFFD used four "handlines" and the RTAF used three "handlines." The RFFD applied about 230 barrels (5 gallons each) of Aqueous Film-Forming Foam (AFFF) concentrate on the fire. The fire was brought under control (that is, it ceased to grow and no longer threatened the terminal or adjacent airplanes) about 15:20 and was completely extinguished about 15:45.

1.15 Survival Aspects

At the time of the explosion five Cabin Attendants (CA) and the load control supervisor were in the cabin: two CAs were near the first two passenger rows, one CA (responsible for the overwing exits) was about six passenger rows aft, and two CAs and the load control supervisor were near the aft galley. After the explosion, the two forward CAs called out and attempted to look for the CA responsible for the overwing exits. The two forward CAs then exited the airplane through the partially blocked 1L passenger door to the jetway. The two aft CAs and the load control supervisor exited the airplane by jumping to the tarmac from the 2R doorway. The 2R door was not armed for slide deployment prior to it being opened.

1.16 Test and Research

All testing and research was conducted by NTSB, detailed as follows.

1.16.1 Jet A Flammability

To approximate the temperature of the fuel in the CWT at the time of the explosion, the Boeing Commercial Airplane Group conducted a survey of Boeing 737 fuel temperatures. The investigation found that the CWT fuel temperature could be as high as

48 C° (118.4 degrees Fahrenheit; F°) approximately 30 minutes after landing with the air conditioning packs being operated by the onboard APU.

An analysis of the Jet A fuel uploaded to the accident airplane wing tanks, prior to the explosion, determined that the lower flammable temperature limit was 40 C° (104 F °). No fuel was recovered from the CWT for testing.

1.16.2 Fuel Pumps

Initial examination of the four wing tank fuel pumps and the two CWT pumps (Fuel Pump Type 8240-5) was conducted at FR-HiTemp facilities in Titchfield, England, and continued at the NTSB materials laboratory in Washington, D.C. The pumps were designed to operate at a nominal 12,000 rpm, with the fuel passing through two rotating stages: an axial-flow inducer and a centrifugal-flow impeller. Both stages are mounted on a common rotor shaft, which also mounts the armature for the electric motor. At a normal ground attitude, the left CWT pump inlet would be higher than the right inlet and would run dry first.

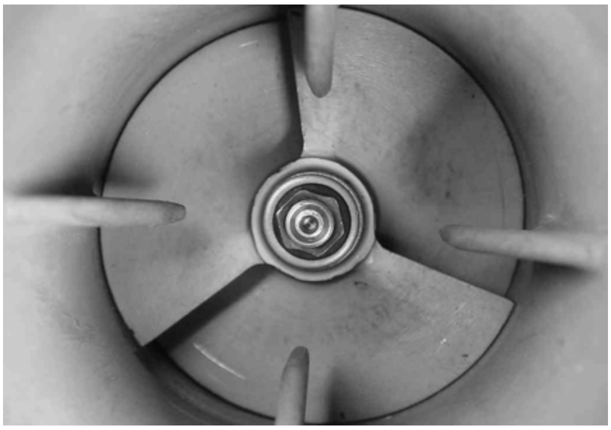

Figure 7. Scratches on Inducer Blades of the Left CWT Pump

Both left wing tank pumps contained foreign material that consisted of trapped lint and a small amount of aluminum flakes.[1] The right forward wing tank pump contained

[1] In 1957, the U.S. Naval Ordnance Laboratory documented that it was possible to create an ignition by striking even non-ferrous metals.

foreign materials that consisted of small metallic flakes, fibrous material and crystalline material. No foreign material was found in the right aft wing tank pump; however, several scratches and nicks were observed on the inducer.

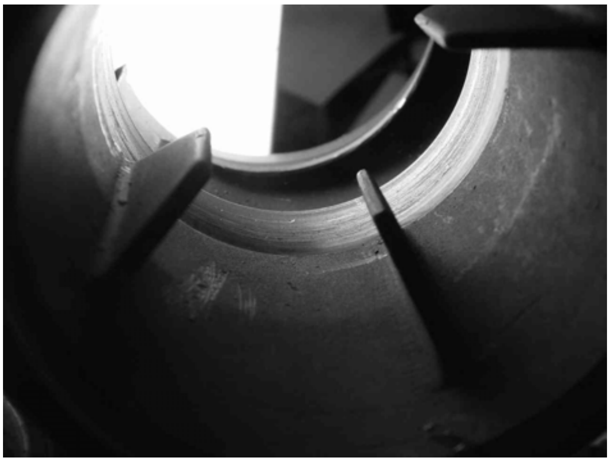

Figure 8. Galling in Aluminum Housing around Inducer and Impeller of the Left CWT Pump

Figure 9. Scoring and Metal Adhered to Outer Diameter of the Impeller of the CWT Left Pump

The left CWT pump inducer had circumferential scratches on all three blades and moderate scoring was observed on the inducer-housing bore **(See Figure 7)**. The impeller was galled and scratched along the entire periphery, and the bore of the housing was found scored along the area that aligned with the inducer **(See Figure 8)**. The interior of the housing contained numerous metal shavings. The outer diameter of the impeller had numerous foreign metallic-like particles smeared along the circumference **(See Figure 9)**.

Carbon bearing material was found transferred to the rotor shaft **(See Figure 10)**. The face of the aluminum housing where the impeller was contained was recessed, and a 0.054-inch gap existed between the housing and the impeller face (the normal gap between the housing and impeller face is 0.02 to 0.03 inches) **(See Figure 11)**. The housing at the gap had been further opened by up to an additional 0.08 inch at the periphery of the impeller. Microscopic examination found numerous grinding and impact marks in the housing and the face of the impeller.

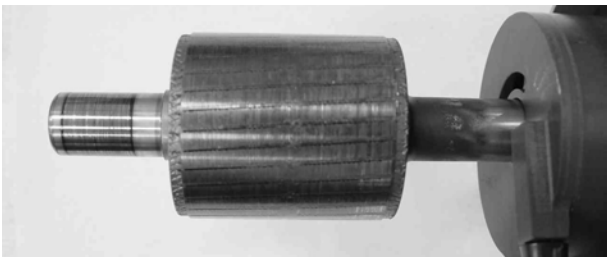

Figure 10. Carbon Bearing Material on Shaft

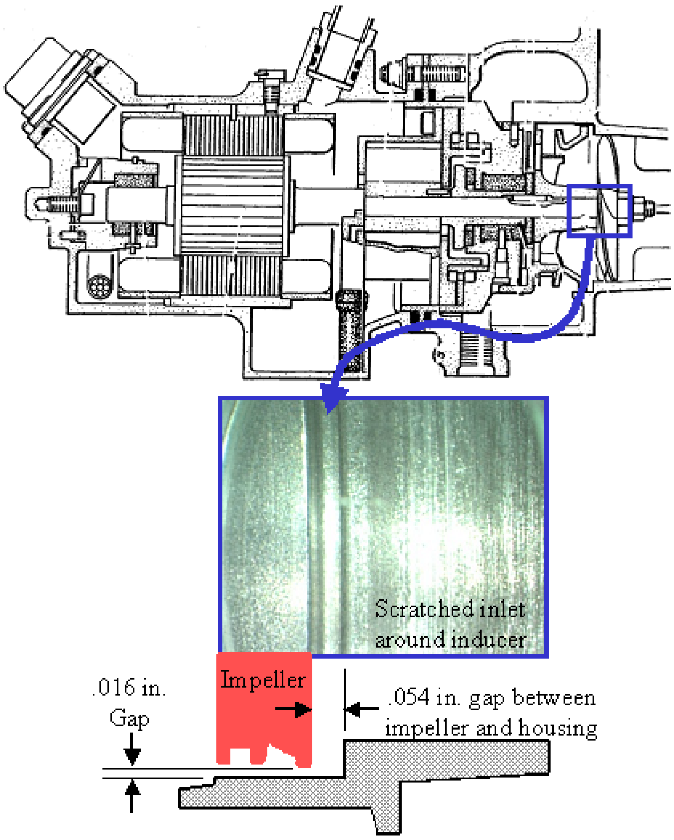

Figure 11. A Gap between Impeller and Housing

The right CWT pump inducer had a circumferential scratch on one blade, and several marks were observed on the inducer-housing bore. The pump contained no metal shavings. Less carbon bearing material was found transferred to the rotor shaft than was found on the shaft of the left pump.

After disassembly and removal of debris during initial inspection, the CWT fuel pumps were run in an explosive chamber. The flammable environment testing was conducted at 160 F^{o} (71.1 C^{o}) ambient, with n-hexane fuel metered to provide a stoichiometric fraction of 1.8, in accordance with the conditions specified in Boeing Specification DWG 10-62049 (using MIL-STD-810F, dated 01 Jan 2000). Neither of the CWT fuel pumps ignited the explosive environment during 35-minute tests. A second test of each was conducted to evaluate the internal flame traps in the pumps. The initial spark ignition was fired 3 minutes after the pump was started, with three additional firings at 3-minute intervals. Operation of the pump in the test fixture did not cause an ignition of the environment.

1.16.3 Metallic Debris and Engine Fuel Filters

Metallic and non-metallic debris was recovered from both wing fuel tanks. The debris included loose particles of tank sealant, aluminum rivet heads, and portions of steel fasteners. Depending on the size, some of this debris would have been able to pass through the fuel pump inlet screens.

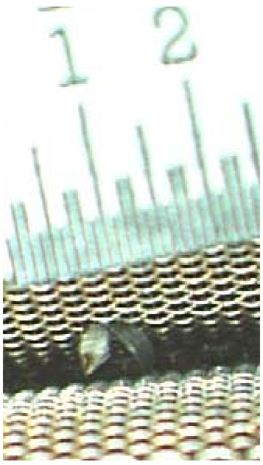

Figure 12. Steel & Aluminum Shavings Found in Engine Fuel Filter

Examination of the engine and APU fuel filters, which are downstream of the fuel pumps, was conducted at the NTSB materials laboratory facility in Washington, D.C. Small fragments of steel, titanium, and aluminum were found in the left engine fuel filter pleats **(See Figure 12)**. Microscopic examination found numerous strike marks on the debris surfaces.

1.16.4 Fuel Quantity Indication System Electrical Wiring

The wire bundles containing the Fuel Quantity Indication System (FQIS) wiring and the CWT FQIS repeater wiring were examined or recovered from all areas where the bundles had not been consumed by the fire that followed the explosion. Examination of the wire bundle design noted that 115 Alternating Current Voltage (VAC) were co-routed with the FQIS wires, although it was not determined if the powered wires were directly adjacent to the FQIS wires in the bundles.

Figure 13. The Condition of the Center Wing Tank in-tank FQIS Wire

All the removed wiring from these bundles was inspected at the NTSB materials laboratory in Washington, D.C., by personnel from the NTSB, the Federal Aviation Administration (FAA), and the Boeing company. Molten ends of wires were consistent with the surrounding fire damage. No other potential evidence of arcing was found in the recovered wire bundles. However, wire strands with nicks and cuts in the insulation and strands of uninsulated wire were found **(See Figure 13)**. In addition, contaminates of aluminum shavings, grease, and dirt were found in the bundles.

1.16.5 Fuel Quantity Gauges

The three cockpit fuel quantity indicators, three refueling fuel quantity indicators, and three digital control units were examined at the laboratory facilities of Smiths Industries in Malvern, Pennsylvania, on May 10, 2001, by personnel from the NTSB, FAA, and the Boeing company.

Figure 14. Fluid Tracks and Corrosion in Left Cockpit Gauge

After replacement of fire-damaged parts, the three cockpit indicators functioned normally and allowed for the readout of the solid-state memory. The gauge design includes an internal 1-kilohm (1kΩ) resistor that, if failed, would render the gauge inoperative. None of the gauges recorded an error code that would have indicated an internal error in the respective gauges, and each respective resistor was found intact. Maintenance codes for all three gauges indicated that before losing power, short circuits had developed between the compensator plates or the wires leading to each tank. In addition, the left gauge indicated leakage resistance between the two-compensator lines, the center gauge indicated that plates of a tank unit had shorted, and the right gauge indicated tank probe leakage resistance **(See Figures 14, 15 and 16)**.

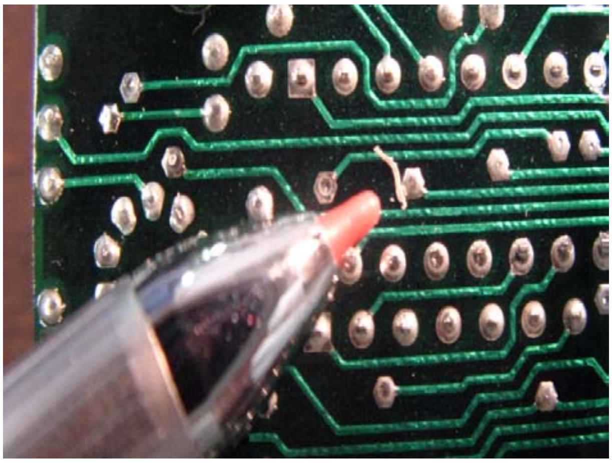

Figure 15. Conductive Debris between Tracks in CWT Gauge

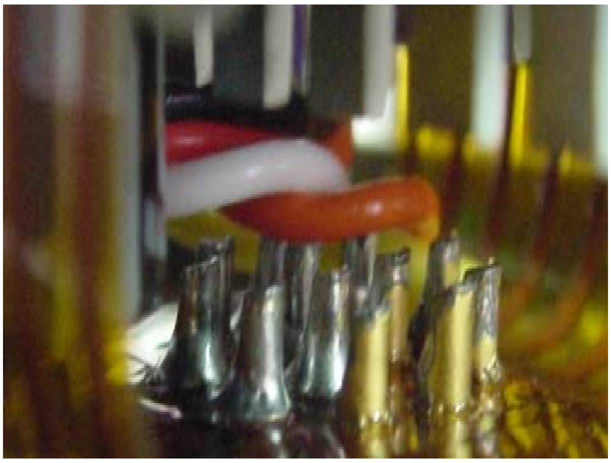

Figure 16. Wires Resting on Sharp Solder Cups in Right Gage

1.16.6 CWT Refueling Float Switch

Most of the CWT float switch was recovered and examined at the laboratory facilities of the Air Force Research Laboratory in Dayton, Ohio, by personnel from the NTSB, FAA, and the Boeing company. The switch was found broken and extensively fire-damaged **(See Figure 17)**. The glass from the reed switch enclosure was found shattered and resolidified globules of metal were found adhering to the reed **(See Figure 18)**. Molten aluminum was also found in the tubular switch enclosure.

Figure 17. The Condition of the Float Switch

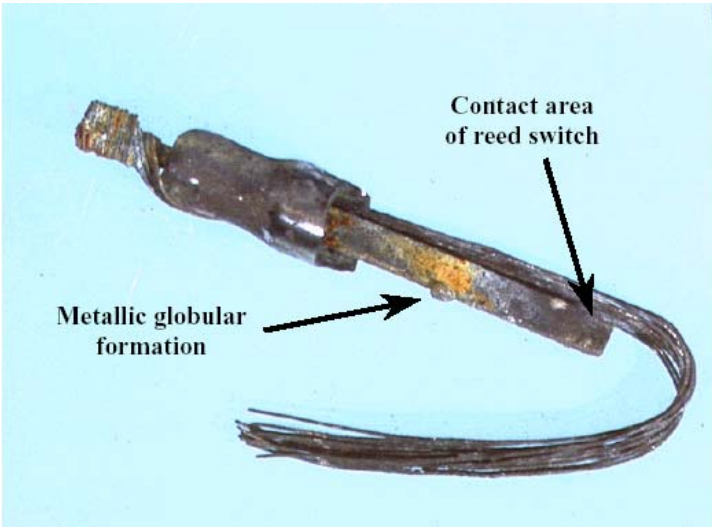

Figure 18. Remaining Section of the Glass Encapsulated Reed Switch

The float switch circuit is connected to a 28 Direct Current Voltage (VDC) power source when the wing refueling panel is open. The refueling panel located under the right wing leading edge was found open after the explosion, however, two of the three door latches found in the latched (closed) position and photographs showed the panel was in the closed position during the fire fighting operations. Wiring from ahead of the forward spar was consumed by fire. The recovered portions of the wire bundles containing the float switch wiring were examined at the NTSB laboratory facilities in Washington, D.C., by personnel from the NTSB, FAA, and the Boeing company. No evidence of a short circuit was found in the recovered float switch wires or any other remaining wires contained in the bundles.

A diode that was installed in the float switch wiring near the refueling station was examined at the Naval Research Laboratory in Washington, D.C. The diode was found to be electrically intact and not shorted or open.

1.16.7 Electromagnetic Interference (EMI)

Energy emissions from the airport surveillance radar were strong enough at the accident gate to be recorded on the CVR and a test tape recording. The potential coupling of energy to the CWT FQIS wiring was calculated using four different methods by specialists from the FAA and the Boeing Commercial Airplanes Group. The results of the calculations ranged from 0.0024 milliJoulses (mJ) to 0.024 mJ. The FAA regards 0.25 mJ as the minimum ignition energy level for fuel tank hazard analysis.

1.16.8 Static Electricity

The fuel uploaded to the accident airplane contained an additive to dissipate static charges during refueling. However, previous testing showed that dripping fuel with the additive could still impart a static charge to isolated metal components, so the possibility that an electrostatic discharge ignited the CWT vapors was examined. The vent valve installations from the CWT were destroyed, but the similar valves in the wing fuel tanks were found to be nearly electrically isolated. The frame and sealing disc from the wing tank valves were examined at the electrostatic laboratory at the Air Force Research Laboratory, and testing determined that the maximum energy buildup would be approximately 0.01 mJ.

1.17 Organizational and Management Information

No organizational or management policies or practices were identified as factors in the accident.

1.18 Additional Information

1.18.1 Activities of Concerned Organizations

Several similar airplane accidents had occurred in the past, for example center wing fuel tanks exploded in a Philippine Airlines 737 accident occurred on May 10, 1991 and a Trans World Airlines, Inc. (TWA) Boeing 747-131 accident occurring on July 17, 1996. The investigation results of these accidents indicate that there are various factors, which may cause the ignition of fuel/air mixture in fuel tanks, such as heat transfer from external heat-generating sources located around the fuel tanks, short circuit or induced current in a FQIS wiring system, dry running of fuel pumps in almost empty fuel tanks, use of steel impellers that may produce sparks if debris enters fuel pumps, etc. Only one of these factors or combinations of them may cause the ignition of fuel/air mixture in the fuel tanks.

Investigation organizations, regulatory organizations, airplane manufacturers and airlines have researched, experimented and issued recommendations, rules, requirements, regulations, and advices concerning these factors in order to prevent the ignition of fuel/air mixture in fuel tanks such as the following:

- The NTSB has issued safety recommendations numbered A-90-70, A-91-71, A-91-72, A-96-174, A-96-175, A-96-176, A-96-177, A-00-105, A-00-106, A-00-107 and A-00-108 regarding general wiring, FQIS wiring, the installation of temperature probes in fuel tanks and the reduction of heat transferring to fuel tanks as a result of the operation of heat-generating devices located near fuel tanks by means of the modification of aircraft design or the installation of additional insulation between the heat-generating devices and fuel tanks, etc.

- The FAA has issued Airworthiness Directives (AD) numbered 99-03-04, 2001-08-24 and 2001-01-13 pertaining the FQIS wiring and the ground operation prohibition of the Boeing 737 CWT fuel pumps if fuel quantity is less than 1,000 pounds (454 kg). In addition, the FAA has created new regulations and issued Advisory Circulars (AC) under 14 Code of Federal Regulations Part 25.981 that have been issued to provide guidance for concerned people about the prevention of ignition sources and the minimization of flammability within fuel tanks.

Furthermore, the FAA has set up the Aging Transport Systems Rulemaking Advisory Committee (ATSRAC) which incorporated Boeing representatives to provide recommendations on airplane system safety issues. In addition, FAA developed the Enhanced Airworthiness Program for Airplane Systems (EAPAS), which is a program that addresses the safety of wiring systems, including through the implementation of the ATSRAC recommendations. Currently, the ATSRAC and EAPAS are still in progress.

- The Boeing company has issued a Service Letter (SL) numbered 737-SL-21-053 advising airlines of the use of external air conditioning systems, whenever available, for servicing airplane when it is on ground.

- Just after this accident, Thai Airways revised several operational procedures to reduce the flammability and the potential ignition sources in the CWT. Flight crews have been advised to minimize the use of air-conditioning packs while on the ground and to use the external ground sources for conditioned air whenever possible. In addition, flight crews have been required to maintain the fuel level in the CWT at 1/2 tank or greater

1.18.2 High Explosive Device

RTAF and Explosive Ordnance Disposal (EOD) personnel from the Royal Thai Police, along with NTSB and FAA specialists, examined the wreckage for physical evidence normally associated with the detonation of a high-explosive device. No remnants of an explosive device were found in the wreckage. No gas washing, erosion of metal surfaces, or pitting of metal surfaces was found on any of the wreckage. In addition, no characteristic penetrations or indentations of materials caused by projectiles or curled or petaled fracture surfaces were found on any of the wreckage.

Material samples of wreckage, clothing, and cotton swabbings of surfaces from the wreckage were collected and shipped to the Explosives Unit Laboratory of the U.S. Federal Bureau of Investigation (FBI) in Washington, D.C., at the request of the AAIC. The FBI laboratory used a combination of visual examination, gas chromatography with chemiluminescence detection, gas chromatography/mass spectrometry, liquid chromatography/mass spectrometry, and ion chromatography in its analysis of these evidence samples. No organic explosives or explosive residues were found on any of the evidence.

2. ANALYSIS

2.1 General

The airplane was certificated, equipped, and maintained according to regulations and approved procedures. None of the ground or cabin crewmembers in or near the airplane were associated with the cause of the accident.

After the initial explosion, all but the injured flight attendant were able to evacuate the airplane. The injuries sustained by the one crewmember fatality suggest that he was incapacitated by the initial explosion and could not have evacuated the airplane.

The emergency response of the RFFD and RTAF personnel was adequate. Although the RFFD and RTAF personnel were delayed by a landing airplane, an earlier arrival would not have affected the success of the fire fighting or rescue of the fatal crewmember. The fire fighting was effective in containing the fire and preventing it from spreading to the terminal or adjacent airplanes.

Witnesses statements and photographs show that the airplane was intact after the explosion and that the fire was located beneath the CWT, emanating from a pool of burning fuel. Breaks in the side of body structure from the explosion allowed fuel from the left and right fuel tanks to pour into the CWT and then onto the ground through openings created in the forward and rear wing spars. This supply of fuel fed the fire and prevented fire fighting personnel from rapidly extinguishing the fire. The initial explosion also breached the cabin structure above the CWT and quickly overwhelmed the fire resistant cabin materials, as indicated by the two colors of smoke exiting from the forward and aft passenger doors immediately after the explosion. Explosion of the right wing tank that occurred about 18 minutes after the initial explosion was likely the result of ignition of the fuel vapors through the vent system that allows for communication between all three tanks.

Analysis of the CWT structure indicates that an overpressure event occurred in the tank from the inside outwards. Because of the circumstances surrounding the accident (airplane parked at the gate, engines not running, etc.), the initial conjecture was that a high explosive device had caused the explosion. However, the absence of physical evidence and the lack of explosive residues on any wreckage indicate that a high explosive device was not involved in the accident.

The conclusion that no high explosive device was detonated on the airplane is also supported by the analysis of the CVR sound spectrum. Only one explosion was recorded on the CVR, and it peaked when the recorder quit operating. The accident CVR signature was compared to the signatures of several other fuel tank explosions (specifically, the TWA flight 800 accident, which occurred on 17 July 1996 and the accident involving a Philippine Airlines Boeing 737, which occurred on 11 May 1990), as well as those made during tests with high-energy explosives (conducted during the TWA flight 800 investigation). The comparisons indicated that the accident CVR signature closely matched the signatures from the CWT explosions rather than those of the high-energy explosives.

2.2 Jet A Flammability

The fuel and fuel/air mixture in the CWT would have been heated as the airplane sat at the gate. The ambient temperature was 36 C^o (96.8 F^o), which would have been compounded by the radiant heat from the tarmac and the lack of a cooling wind at the gate. In addition, the air conditioning packs are located directly below the CWT and were operating the entire time the airplane was on the ground. Testing performed by the Boeing company for this accident and during the investigation of the TWA flight 800 accident showed that heat produced from operation of the air conditioning packs can significantly heat the contents of the CWT, resulting in a more flammable fuel/air mixture in the CWT. Therefore, the temperature of the contents of the CWT was most likely higher than the flash point for the Jet A fuel on board the airplane of 40 C^o (104 F^o).

2.3 Possible Ignition Sources

2.3.1 Fuel Pumps

Records and interview statements indicate that only residual fuel remained in the CWT at the time of the explosion, which would have resulted in at least the left (and possibly the right) CWT fuel pump inlet being above the fuel level. Since both CWT fuel pump switches were found in the "ON" position, at least the left pump would have been operating in the flammable fuel/air vapor that was present in the CWT ullage prior to the explosion (that is, "dry running"). As evidenced by witness statements, people who accessed to the cockpit before the time of the explosion were pilots and mechanics. However, there is no evidence, which indicates that who turned both CWT fuel pump switches on. Normally, the switches should be in the "OFF" position so that the CWT fuel pump did not operate.

All six fuel pumps showed signs that they had ingested foreign materials at some point while operating. Both right wing tank pumps and the left aft wing tank pump contained scratches and metallic flakes in their housings when examined. The left forward tank pump contained only scratches. Both CWT fuel pumps revealed scratch marks on the stainless steel impeller blades and metal shavings in the housing of the left pump. Because the pumps do not produce sufficient flow to lift debris in a "dry" environment, the metallic debris had to have been carried to the pumps by fuel movement when the inlets were submerged. Ingesting the debris while the inlet is submerged in fuel would not produce a hazardous event. However, if debris lodged in the inlet and the fuel level decreased to a point where the inlet was above the fuel level, a sparking event could occur.

Rotational scoring on the face of the CWT left pump impeller shows that at least some debris was held against the spinning impeller for an extended period. Further, the ground out condition of the housing at the impeller face suggests that the debris was captured in the impeller/housing gap until the debris was ground small enough to pass through the edge gap. As the U.S. Naval Ordnance Laboratory documented in 1957, it is possible to create an ignition by striking even non-ferrous metals. Therefore, a sparking event caused by debris ingestion of the operating “dry running” left CWT fuel pump is a potential ignition source of the flammable fuel/air vapor.

Certification documents and testing done during this investigation show that “dry running” the fuel pumps in a flammable environment did not produce an explosion. However, no testing was completed, nor was there a certification requirement to do so, to determine the effects of ingesting steel or titanium debris in a flammable vapor environment.

2.3.2 Fuel Quantity Indication System

The voltage to the FQIS wiring is limited to prevent a discharge of sufficient energy to ignite the fuel/air vapor. Therefore, in order for the FQIS to have played a role in igniting the fuel/air vapor, a higher voltage must have transferred onto FQIS wiring from outside of the fuel tank then have been discharged from that FQIS wiring into the inside of the tank in a way that could ignite the fuel/air vapor in the tank.

Maintenance error codes for the three cockpit fuel gauges indicated that before power was lost, the FQIS system had experienced a short circuit. Because there is no time code stamp recorded with the error codes, the codes may have been triggered by either a crushing of the FQIS components in the tanks because of the explosion, or from damage to the FQIS wiring before or after the explosion. In addition, the gauges themselves did not experience a hardware failure because a hard failure error code was not recorded. The gauges also had not been subjected to 28VDC or greater since the internal 1-kΩ resistor were still intact. Although analysis of the recovered FQIS wire bundles found no evidence of a short circuit event, about 20 percent of the FQIS wiring was extensively burned or consumed by fire and could not be examined for short circuit indications. Therefore, a high voltage transfer to the FQIS was unlikely but could not be ruled out as a potential ignition source.

2.3.3 Refueling Float Switch

The CWT float switch is mounted on the end of an electrical conduit tube that contains electrical wiring for the switch. The float switch is only powered when the wing refueling door is open in order to limit the time that the switches are connected to a 28VDC power source. Photographic and physical evidence indicate that the accident airplanes refueling door was closed prior to the explosion.

Analysis of the CWT refueling float switch found metal splatter inside the reed switch that could be an indication of an arcing event. However, since the material was contained within the wall of the aluminum conduit material and the refueling door was closed before the explosion, any arcing probably would have occurred as a result of wires short circuiting while being destroyed by the explosion and subsequent fire and was most likely not the ignition source.

2.3.4 Electromagnetic Interference

NTSB examined the possibility that energy might have been transferred to the FQIS by Electromagnetic Interference (EMI) from the airport surveillance radar that was located nearby. Analysis of the energy levels that could possibly couple to the FQIS determined that the maximum energy transfer to the FQIS was about an order of magnitude less than the commonly accepted minimum ignition energy of 0.25 mJ. Therefore, the emissions from the nearby radar were most likely not the ignition source.

2.3.5 Static Electricity

NTSB also examined the possibility that electrically isolated parts could create a discharge of sufficient energy to ignite the fuel/air vapor in the tank. Analysis of the vent valve components determined that the resistive path through the valve hinge was sufficient to dissipate static charging. In addition, a static dissipative agent was present in the fuel. Therefore, an electrostatic discharge was most likely not the ignition source.

3. CONCLUSIONS

3.1 Findings

3.1.1 Airframe, engines and other aircraft systems were maintained in accordance with the procedures and regulation set forth by the Department of Civil Aviation of Thailand and had valid certificate of airworthiness.

3.1.2 RFFD response was adequate and prevented the fire that followed the explosion from spreading to the terminal and adjacent airplanes.

3.1.3 The injures sustained by the fatally injured cabin crewmember as a result of the initial explosion prevented him from evacuating the airplane.

3.1.4 The estimated residual fuel level in the center wing fuel tank was about 80 kg when the explosion occurred.

3.1.5 At the time of the accident, the outside air temperature was 36 C^o (96.8 $F^{\,o}$), excluding the radiant heat from the tarmac.

3.1.6 The operation of the air conditioning packs increased the temperature of the fuel/air vapor in the ullage of the center wing fuel tank while the aircraft was serviced at gate.

3.1.7 The fuel/air vapor in the ullage of the center wing fuel tank was flammable at the time of the explosion.

3.1.8 Deformation of the surfaces of the center wing fuel tank structure away from the center indicates that an overpressure event occurred.

3.1.9 The CVR sound spectrum of the explosion was similar to other center wing fuel tank explosions (for example, the TWA flight 800 accident, which occurred 17 July 1996, and the accident involving a Philippine Airlines Boeing 737, which occurred 11 May 1990).

3.1.10 No evidence was found to indicate that the center wing fuel tank explosion was initiated by a high-energy explosive device.

3.1.11 The left and right center wing tank fuel pumps were operating at the time of the explosion as their switches were found in the "ON" position and at least the left pump was not submerged in fuel.

3.1.12 It is very unlikely that the flammable fuel/air mixture in the center wing fuel tank was ignited by the center wing fuel tank float switch, electromagnetic energy from the nearby airport radar transmitter, or electrostatic discharge energy from the vent valve.

3.1.13 A high voltage transfer to the FQIS could not definitively be ruled out as a potential ignition source.

3.1.14 The left and right center wing tank fuel pumps had ingested metallic debris at some point while operating.

3.1.15 The scoring signatures and metallic debris found in the left center wing tank pump indicates that debris was held against the spinning impeller for an extended period and was also trapped at the periphery of the impeller.

3.1.16 The ability of ignition to come from striking of even non-ferrous metals was documented by the U.S. Naval Ordnance Laboratory in 1957.

3.1.17 A sparking event caused by trapped debris in the "dry running" left center wing tank fuel pump is a potential ignition source of the flammable fuel/air vapor.

3.2 Probable Cause

The AAIC determines that the probable cause of this accident was an explosion of the CWT resulting from ignition of the flammable fuel/air mixture in the tank. The source of ignition energy for the explosion could not be determined with certainty, but the most likely source was an explosion originating at the CWT pump as a result of running the pump in the presence of metal shavings and a fuel/air mixture.

4. RECOMMENDATIONS

4.1 State of Design should accelerate projects involving researches on the prevention of the ignition and protection of vapors within fuel tanks. Rules, regulations or ordinances, which may be issued in accordance with the results of these researches, should also be accomplished as soon as possible.

4.2 RFFD should achieve response times of two minutes, and not exceeding three minutes in accordance with table 9-2 of Annex 14 to the convention on International Civil Aviation done at Chicago on 7 December 1944. Response time is considered to be the time between the initial call to the rescue and fire fighting service, and the time when the first responding vehicle(s) is (are) in position to apply foam at a rate of at least 50 per cent of the discharge rate.