Aircraft Accident Investigation Report

Aircraft Fire on Ground
Ethiopian Airlines, Flight ET3739
Boeing 777F, Registration ET-ARH
Pudong International Airport
Shanghai, P.R. China
July 22, 2020

Report No. 20200722YDSQ01
Aviation Safety Committee
Eastern Regional Administration of Civil Aviation Administration of China
December 30, 2021

This report is prepared in accordance with the Regulation on *Investigation of Civil Aircraft Incidents* (CCAR-395-R2) , and the provisions of *Aircraft Accident and Incident Investigation*, the Annex 13 to the Chicago Convention. the objective of aircraft accident and incident investigation is to find out the causes, put forward safety recommendations and prevent similar reoccurrence.

When the report is written in both Chinese and English language, the Chinese version shall prevail in case of any inconsistency in the written expression.

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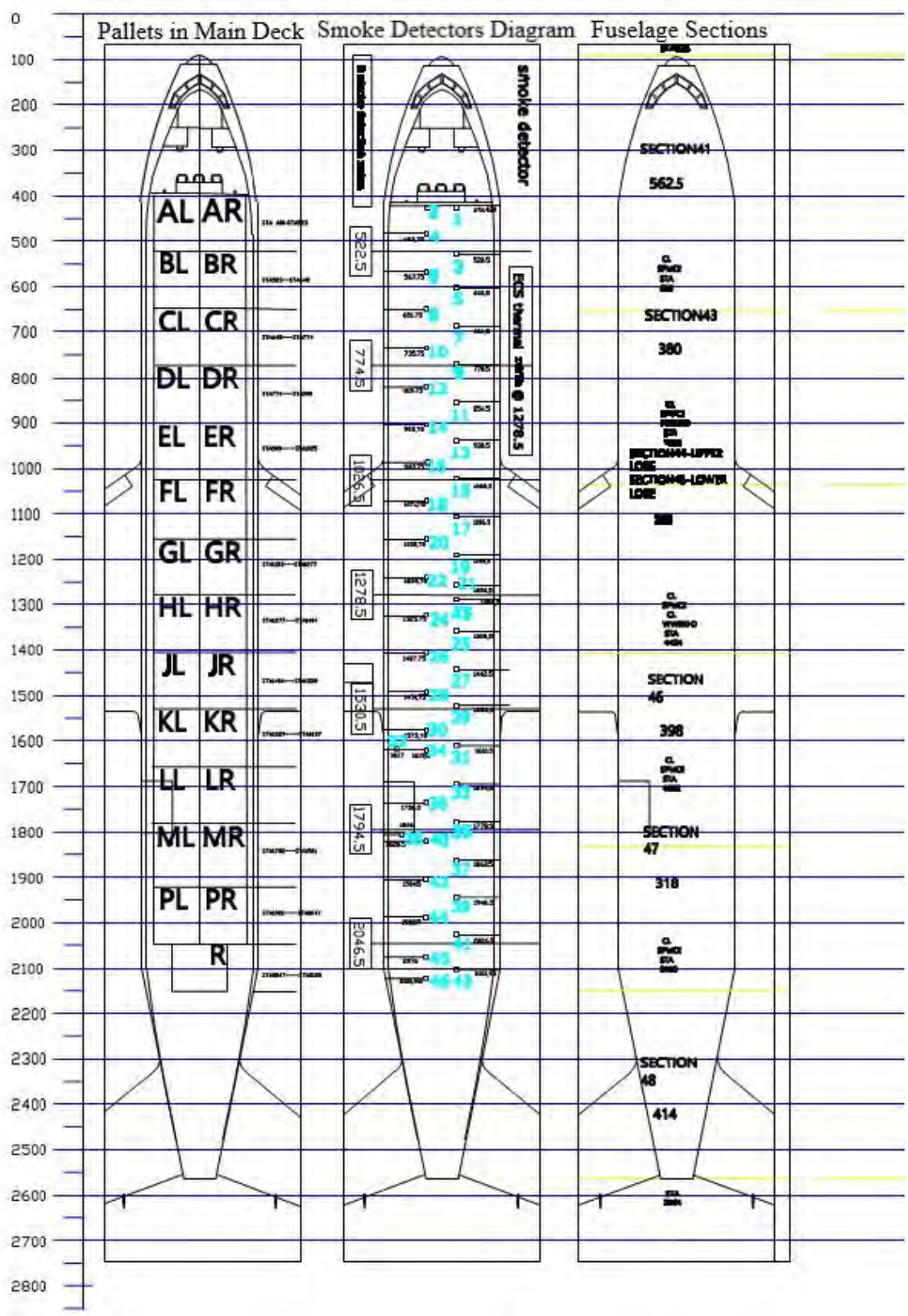
Abbreviations

AOC	AIRPORT OPERATIONS CENTER
AC	ALTERNATING CURRENT
AD	AIRWORTHINESS DIRECTIVE
AMM	AIRCRAFT MAINTANCE MANUAL
APU	AUXILLARY POWER UNIT
BITE	BUILD-IN TEST EQUIPMENT
CAN	CONTROLLER AREA NETWORK
CVR	COCKPIT VOICE RECORDER
DC	DIRECT CURRENT
E/E	ELECTRONIC EQUIPMENT
EICAS	ENGINE INDICATION AND CREW ALERTING SYSTEM
FCOM	FLIGHT CREW OPERATIONS MANUAL
FDR	FLIGHT DATE RECORDER
NOTOC	NOTICE TO CAPTAIN
NVM	NONE-VOLATILE MEMORY
P/N	PART NUMBER
PBE	PROTECTIVE BREATHING EQUIPMENT
PF	PILOT FLYING
PM	PILOT MONITORING
S/N	SERIES NUMBER
SB	SERVICE BULLETIN
SSM	SYSTEM SCHEMATIC MANUAL

Aircraft Configuration[1]



[1] This figure indicates the main deck cargo compartment, smoke detectors and fuselage from section 41 to 48

Executive Summary

On July 22, 2020, an Ethiopian Airlines Boeing777F aircraft with registration of ET-ARH carried out cargo flight ET3739 from Shanghai Pudong to Chongqing to Addis Ababa and finally to Sao Paulo. The aircraft stopped at parking position No.306 of Pudong Airport with 5 people on board (2 captains, 1 co-pilot, 1 flight engineer and 1 load master). At 15:14[2], the flight crew reported fire warning in the main deck cargo compartment after cargo loading accomplished and all aircraft doors were closed. When the main deck cargo door was opened, smoke was visible, and subsequently, fire could be seen in the cargo compartment. The airport firefighting force engaged in the firefighting and was reinforced by Shanghai municipal firefighting force. At 17:01, the open flame was put out without injury. The aircraft main deck cargo compartment was severely damaged by fire. This event is classified as an aircraft accident.

In accordance with the provisions of ICAO Annex 13 to the Chicago Convention, China instituted the investigation, and Eastern Regional Administration of Civil Aviation Administration of China (hereinafter referred to as CAAC) was authorized by CAAC conducting the investigation. Accredited Representatives from the Ministry of Transport of Ethiopia and the National Transportation Safety Board of the United States participated in the investigation.

The investigation team conducted site survey, video footage analysis, test and research, personnel interview etc., to investigate the aspects that may cause the aircraft fire, such as lithium battery, unlawful interference, avionics, cargo transportation, kindling material, and cargo spontaneous combustion etc., and investigated the emergency response process related to the accident.

The investigation team determined that the initial fire area was in the area of STA1790-STA2129 in the aircraft main deck cargo compartment. The Origin of the Fire was on the right

[2] Unless otherwise indicated, all times in this report are Beijing Local Time (UTC+8), and the time referenced is calibrated time base.

part of STA1916-STA2048 (PR position in the main deck cargo compartment), and the highest possible cause of the fire was that the chlorine dioxide disinfection tablets loaded in the main deck cargo compartment in spontaneous combustion in high temperature and humidity, leading to the fire in the aircraft main deck cargo compartment.

1 Factual Information

1.1 History of Flight

On July 22, 2020, a Boeing 777F aircraft, Ethiopian registration ET-ARH, operated as Ethiopian Airlines cargo flight ET3738 (Brussels-Shanghai). The aircraft landed at Shanghai Pudong International Airport (PVG/ZSPD) at 11:51, and the aircraft stopped at parking position No. 306 (Figure 1). Unloading and loading work were completed during the stop-over, and 5 crew members were shifted. The new crew was ready to carry out cargo flight ET3739 from Shanghai Pudong International Airport (PVG/ZSPD) to Chongqing Jiangbei International Airport (CKG/ZUCK) to Addis Ababa Bole International Airport (ADD/HAAB) and finally to São Paulo Guarulhos – Governador André Franco Montoro International Airport (GRU/SBGR). The flight Estimated Time of Departure is 14:30.

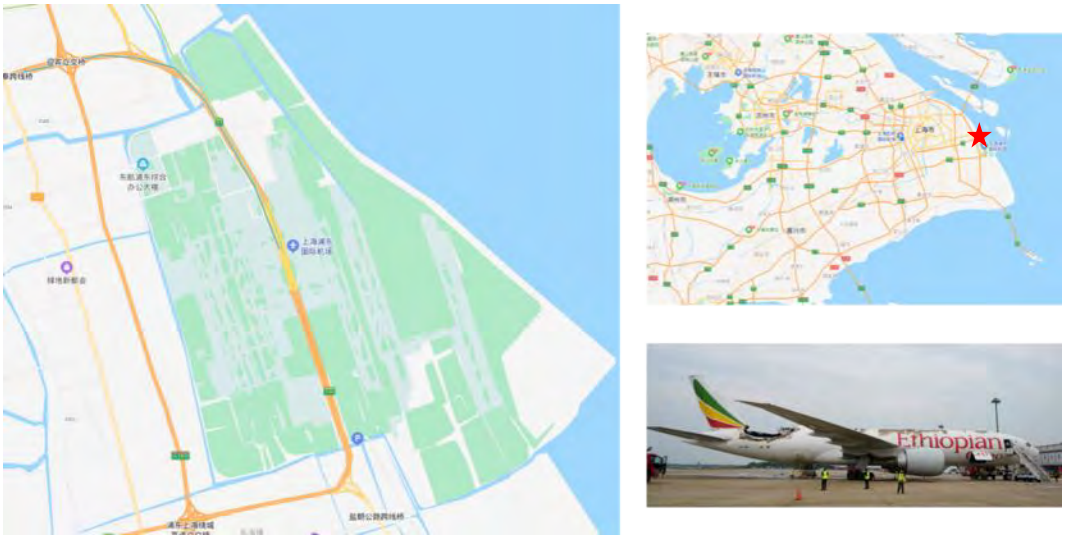


Figure 1 Location of the Accident

At about 13:25, the aircraft started to load cargo, and at about 15:00 cargo loading accomplished, and the cargo door was closed. The manifest indicated that all on board cargo was 69,370kg, and there were no issues with the entire cargo loading process.

At about 14:38, the flight crew boarded the aircraft.

At 15:14:04, the flight crew reported on the Air Traffic Control Tower Delivery frequency

"...Stand 306, we need fire truck. We have fire warning from our cargo compartment please."

At 15:14:32, the ATC Delivery controller informed the Airport Operation Center (AOC) that the fire truck was required by an aircraft on parking position No.306, and informed the apron controller of the situation.

At 15:15:05, the airport AOC confirmed with apron control by telephone, regarding the aircraft on parking position No.306 needing fire truck. Also, the airport AOC asked apron control to confirm whether the flight crew need any further assistance.

At 15:15:53, the ATC Delivery controller informed the flight crew that the fire truck was on the way towards the aircraft, and instructed the flight crew to contact the apron control.

At 15:16:05, the airport AOC confirmed with apron control: "*One fire truck is needed."*

At 15:16:18, The Flight crew made initial contact with apron control "*Please sir, we need fire truck immediately, we have fire warning on our cargo compartment*."

At 15:17:03, the airport AOC contacted the Airport Rescue and Firefighting Department (hereinafter referred to as ARFF): "Firefighting, an Ethiopian freighter on parking position No.306 reported fire warning in cargo compartment. Please initially send one fire truck to the scene and check."

At 15:18:11, The apron controller contacted the flight crew: *"Ethiopian three seven three nine, apron, fire truck is on the way now, and confirm what else service do you need?"* The Flight crew replied, *"For the time, please, we need only fire truck, and if possible, tell them to bring down the passenger stairs immediately."*

At 15:18:37, Fire truck drove out of the No.3 Fire Station.

At 15:19:37, the flight crew contacted the apron control *"Can you tell the fire truck coming immediately, this is an emergency please."*

At 15:20:47, the Apron controller contacted the airport AOC to urge the fire truck.

At 15:21:32, the flight crew declared *"MAYDAY MAYDAY MAYDAY, Ethiopian three seven three nine, Ethiopian three seven three nine, we have fire on board. Please we need fire assistance, fire truck."*

At 15:21:59, the flight crew reported to the apron control *"…… nobody around, nothing in the way."*

At 15:22:12, the apron controller contacted the airport AOC, and once again urged the firefighting force to expedite reaching the site.

At 15:22:26, the apron controller contacted the flight crew to verify whether the passenger stairs had been in place, the flight crew responded no personnel had arrived at the scene.

At 15:23:44, the apron controller contacted the airport AOC to urge the passenger stairs and assist the crew to evacuate.

At 15:25:13, the firefighter reported to the airport AOC that fire truck had arrived at the scene. Meanwhile, the apron controller informed the flight crew of fire truck arrival. At 15:25:24, 4 fire trucks and 1 firefighting command vehicle arrived at parking position No.306.

At 15:25:55, the apron controller informed the flight crew that the fire truck arrived.

At 15:26:45, firefighter reported, no smoke or open flame was detected at the scene.

At 15:28:31, the aircraft 1L door was opened.
At 15:30:36, the main deck cargo compartment door was opened.

At 15:30:54, the flight crew contacted the apron control *"We are about to leaving, we will call*

you when leaving."

At 15:32:15, the airport AOC contacted ARFF. Smoke came out when the main deck cargo compartment door was opened.

At 15:33:22, all 5 crews deplaned the aircraft.

At 15:35:16, open flame was visible inside the main deck cargo compartment.

At 15:35:23, the fire truck began to apply agent.

At 15:38:10, the airport AOC informed ARFF to "Activate emergency rescue now".

At 15:38:56, the field firefighting commander reported that "the aircraft is on fire, all stations come immediately."

At 15:39:11, the firefighting senior command post informed the airport No.1 Fire Station and the airport Special Mission Brigade to reinforce the on-scene firefighting efforts.

At 15:39:13, the airport AOC reported the accident information to Shanghai Safety Supervision and Management Bureau of CAAC.

At 15:39:33, the airport No. 1 Fire Station reported that firefighting force was on the way to the scene.

At 15:41:35, the airport Special Mission Brigade arrived at the scene. Then, the firefighting force from the airport No.1 Fire Station arrived at the scene.
At 17:01, open flame in the aircraft was put out.

At 17:11, smoke was observed at the front of the aircraft fuselage.

At 18:14, the fire on site was brought under control, and the firefighting force continued to cool the aircraft.

During the process, Pudong Airport was closed at 16:40. The operation partially resumed at 17:30 and fully resumed at 18:30. The accident caused 16 inbound flights alternated and 34 outbound flights delayed.

1.2 Injuries to Persons

None.

1.3 Damage to Aircraft

1.3.1 Damage to Upper Fuselage

1.3.1.1 Damage to the Fuselage Structures

The skin, main structural components such as frames and stringers of the upper fuselage from section 41 to 48 were damaged by the fire (Figure 2). Multiple burn-through areas were presented in the crown centerline, of which the most severe area was section 47 (Figure 3) (STA1832-STA2150). The skin, frames and stringers above stringers S24L and S24R were burnt out. There were two large, ablated skin areas above the bulk cargo door of the right fuselage between stringer S24R and S27R (Figure 4). The remaining fuselage structures sustained extensive thermal damage and sooted. The dorsal fin skin and structures of the vertical stabilizer were burnt out (Figure 5). The radial stiffeners, doubler and frame chords of the aft pressure bulkhead were mostly burnt out (Figure 6).

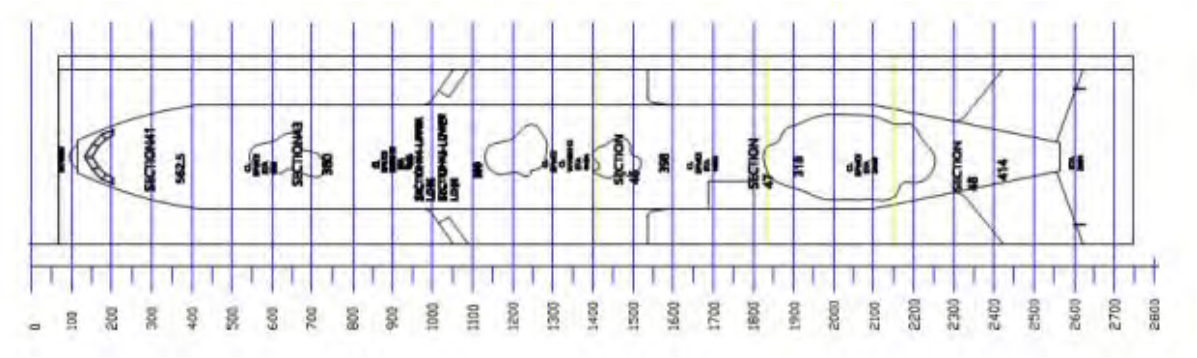


Figure 2 Damage Diagram

Figure 3 Damage to Upper Fuselage

Figure 4 Damage at S24R to S27R

Figure 5 Dorsal Fin Area

Figure 6 AFT Pressure Bulkhead Damage

1.3.1.2 Damage to the Main Deck Cargo Compartment

Components installed on the top of the main deck cargo compartment such as the ceiling panels, heat insulation cotton, smoke/fire detectors, light assemblies, sidewall panels, air condition ducts, wiring harness (including APU main feeder cables), wire mounting brackets, electrical plugs were burnt out (Figure 7). The interior linings of the main deck cargo compartment door were extensively burnt down, and the door structure was severely heated, which was stuck in the open position and could not be manually closed (Figure 8). The main deck cargo compartment floor in front of the aft pressure bulkhead was burnt through (Figure 9). The rigid cargo barrier in the main deck cargo compartment also sustained extensive thermal damage (Figure 10).

Figure 7 Interior of the Main Deck Cargo Compartment (Front and Rear View)

Figure 8 Main Deck Cargo Comp. Door

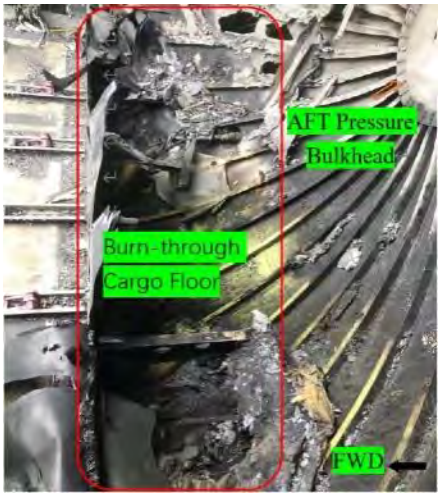


Figure 9 Burn-through Cargo Floor

Figure 10 Rigid Cargo Barrier

1.3.2 Damage to Lower Fuselage

The structures of the forward and aft lower holds in the lower lobe were intact. After removing the side wall panels of the forward lower hold, the structures, ducts and equipment were obviously sooted (Figure 11). Most of the electronic equipment in the E/E bay were also sooted (Figure 12). The APU compartment was intact and no trace of fire or soot.

Figure 11 Inside the Lower Hold Side Wall

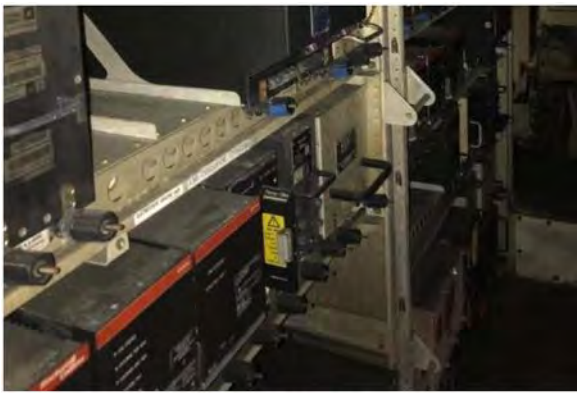


Figure 12 E/E Bay

1.3.3 Damage to Cockpit

The overhead panels in the cockpit and supernumerary area were disengaged due to overheating (Figure 13 and 14). The internal furnishings, linings and components were sooted.

Figure 13 Panel Disengaged in the Cockpit

Figure 14 Panel Disengaged in the Supernumerary Area

The cockpit was obviously sooted. The APU fire switch was not pulled out. All flight crew oxygen masks and portable breathing equipment (PBE) were in place. The protective cover of DEPR/DISCH switch on the CARGO FIRE/ENGINE CONTROL PANEL (P5) was lift, and the CARGO FIRE ARM SWITCH was in armed position. The APU selector was set to ON, and the main battery switch was set to OFF (Figure 15 to 20).

Figure 15 Sooted Cocpit

Figure 16 Central Console

Figure 17 Flight Crew Oxygen Masks (4 Locations)

Figure 18 Cargo Fire/Engine Control Panel

Figure 19 PBE Equipment

Figure 20 Electrical Panel

1.3.4 Circuit Breakers

Circuit breakers in Table 1 were found popped. As the aircraft was powered by APU generator when the event occurred, the circuit breakers related to the APU were particularly examined. The following APU circuit breakers popped:

A17/C28003 (APU FUEL S/O VALVE) on P11 panel (located in the cockpit), B06/C49601 (APUC1), B07/C49600 (APU INLET DR ACTR), F05/C28638 (APU FUEL ISLN VLV), K08/C26640 (APU CRK CTRL) in P310 panel (located in main equipment center), A02/24645 (APU BAT VOLT SENSE), A03/C49602 (APUC2) in P49 panel (located on E10 rack in aft lower hold).

Table 1 Popped Circuit Breakers

P11 OVERHEAD CB PANEL				
Location	Description	CB NO.	ATA Chapter	Remarks
A05	L ENGINE FUEL SPAR VALVE	C28001	28-22-15	Hot battery bus
A17	APU FUEL S/O VALVE	C28003	28-25-11	Hot battery bus
A19	R ENGINE FUEL SPAR VALVE	C28002	28-22-25	Hot battery bus
A23	LDG GEAR EXTD/RETR 2	C32608	32-31-11	Battery bus
B20	RIGHT EDP SUPPLY SHUTOFF VALVE	C29602	29-11-02	CAPT FLT INST BUS, 5A/ 24-61-33SH2 / 91-04-23 AE232
D13	RAT AUTO CONTROL	C29619	29-21-11	CAPT FLT INST BUS 5A/ Connected to P49 Panel
G02	L HF COMM	C23301	23-11-11	HF Transceiver on the E6 Rack , Located 1812/182/R085, possibly

				soaked
P310 POWER MANAGEMENT PANEL- STANDBY				
A08	SNSR EXC 1	C27513	27-51-11	ACE SENSOR EXCITATION POWER 7VAC/1800HZ
B06	APUC 1	C49601	49-61-11	Battery Bus, connected to APUC on E7 rack
B07	APU INLET DR ACTR	C49600	49-15-11	Battery Bus, connected to APU air inlet door
F05	APU FUEL ISLN VLV	C28638	28-25-12	28V DC CAPT FLT INST BUS, connected to APU fuel shutoff solenoid valve
G09	FUEL XFEED VLV AFT	C28612	28-22-24	28V DC CAPT FLT INST BUS, connected to fuel cross feed valve
G11	FLAPS PRI DR CTRL 1	C27604	27-51-15	Flap primary drive control channel 1
G12	SLATS PRI DR CTRL 1	C27606	27-81-15	Slat primary drive control channel 1
H01	LG ANTISKID 1,5,9/3,7,11	C32609	32-42-11	Powered by 28V DC CAPT FLT INST BUS, connected to BSCU on E6 rack
H02	LG ANTISKID 2,6,10/4,8,12	C32612	32-42-14	Powered by 28V DC CAPT FLT INST BUS, connected to BSCU on E6 rack
K08	APU CRK CTRL	C26640	24-31-21	Hot battery bus
L10	NOSE GEAR ISLN VALVE	C29610	29-11-31	Backup AC bus
P49 APU AUXILIARY PANEL (E10 rack)				
A02	APU BAT VOLT SENSE	C24645	24-31-21	2.5A /24-09-37
A03	APUC 2	C49602	49-61-11	10A /49-61-11SH1
A04	RAT AUTO/MANUAL CONTROL	C29621	29-11-03	APU BAT BUS 5A /29-21-11
A05	APU BAT BKUP PWR CVR	C23671	23-71-12	2.5A APU Powered by hot battery bus

1.3.5 Damage to Bulk Cargo Compartment

The ceiling of the bulk cargo compartment was burned through, the APU battery without trace of fire damage (Figure 21 and 22).

Figure 21 APU Battery

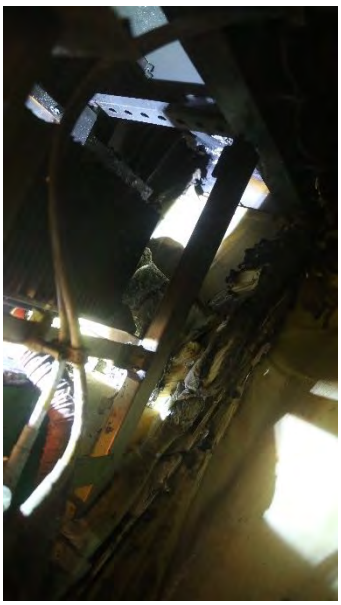


Figure 22 Ceiling of Bulk Cargo Compartment

1.4 Other Damage

There was no other damage.

1.5 Personnel Information

1.5.1 the Flight Crew

1.5.1.1 the Captain

The captain, male, nationality of Ethiopian, age of 42. The flight license is No. AA407. The captain received the first type rating for B777 on March 18, 2016, and has accumulated about 15000 flight hours[3] of total flight experience, including 3000 flight hours on B777. The captain's last line check occurred on January 24, 2020. The captain completed B787 proficiency check on February 5, 2020, B777 proficiency check on August 15, 2019, and dangerous goods training on February 28, 2019. Safety and emergency procedure check on January 3, 2020, valid to January 2, 2021. The captain held a first-class airman medical certificate dated June 9, 2020, with no limitations. The captain's English proficiency is ICAO 5, valid until April 2, 2025.

[3] The operator did not provide flight time information of the crew, and the flight time in the report came from the interview of the crew.

1.5.1.2 the First Officer

The first officer, male, nationality of Ethiopian, age of 30. The flight license number is AC1425. The first officer received the first type rating for B777 type on March 18, 2019, and has accumulated 2500 flight hours of total flight experience, including 1000 flight hours on B777. The first officer's last line check occurred on January 24, 2020. The first officer completed B777 proficiency check on June 12, 2020, B787 proficiency check on December 24, 2019. The first officer completed dangerous goods training on September 4, 2018. The first officer holds a first-class airman medical certificate dated July 13, 2020, with no limitations. The first officer's English proficiency is ICAO 5, valid until June 16, 2022. The first officer's last Dangerous goods training (course) was on August 13, 2020, valid to August 13, 2022. The inspection time of safety and emergency procedures is January 12, 2020, and the validity period is January 11, 2021.

1.5.1.3 the Second Captain

The second captain, male, nationality of Ethiopian, age of 58, the flight license No. AA233. The second captain received the first type rating for B777 on April 25, 2011, and has accumulated 28500 flight hours of total flight experience, including 5000 flight hours on B777. The second captain's last line check occurred on May 8, 2020. The second captain completed B787 proficiency check on June 30, 2020, and B777 proficiency check on December 4, 2019. The second captain completed dangerous goods training on August 13, 2019. The Second Captain held a first-class airman medical certificate dated December 20, 2019, with a limitation to possess glasses for near and distance vision. The second captain's English proficiency is ICAO 6. The second captain's last Dangerous goods training (course) was held on August 13, 2019, valid to August 12, 2021. The second captain'sSafety and emergency procedure check occurred on January 9, 2020, valid to January 8, 2021.

1.5.2 Other Onboard Personnel

1.5.2.1 the Flight Engineer

The Flight Engineer, male, nationality of Ethiopian, age of 29. Maintenance license No. MM-5745, specialty of electronic, with type rating in B777-200/300 aircraft, valid until December 1, 2021.

1.5.2.2 the Load Master

The Load Master, male, nationality of Ethiopian, age of 29. The Load Master completed the dangerous goods training on December 26, 2019, and completed the weight and balance training on May 1, 2019.

1.5.3 the Controllers

1.5.3.1 the Air Traffic Control Tower Controller

The ATC tower supervisor, female, air traffic control license No.612125********1525, obtained on August 28, 2006, the license endorsement valid until December 7, 2020. The medical certificate valid until November 23, 2020. English is ICAO 4, valid until October 15, 2022.

The ATC delivery controller, male, air traffic control license No. 320602********301X, obtained on February 11, 2018, the license endorsement valid until December 7, 2020. The medical certificate was valid to April 3, 2021. English is ICAO 4, valid until June 8, 2021.

The ATC ground controller, male, air traffic control license No. 650102********6519, obtained on October 15, 2015, the license endorsement valid until December 7, 2020. The medical certificate is valid to January 3, 2022. English is ICAO 4, valid until March 29, 2021.

The ATC coordinator, female, air traffic control license No. 341102********0022, obtained on September 4, 2009, the license endorsement valid until December 7, 2020. The medical certificate is valid until November 8, 2021. English is ICAO 4, valid until March 20, 2022.

1.5.3.2 the Airport Apron Controller

The Manager of Airport apron control, male, airport apron control license No. 330702********0414, obtained on February 11, 2018, the license endorsement valid until December 7, 2020. The medical certificate is valid until October 3, 2021. English is ICAO 4, valid until December 22, 2022.
The Airport apron controller, male, airport apron control license No. 320525********1510, obtained on December 3, 2014, the license endorsement valid until December 7, 2020. The medical certificate

is valid until January 5, 2022. English is ICAO 4, valid until October 15, 2022.

The Airport apron coordinator, male, airport apron control license No. 330881********1913, joined the Airport Apron Control of the Airport Apron Management Department of Shanghai International Airport Co., Ltd. in August 2019, obtained the "Airport Apron Controller Certificate" on December 26, 2019. and was valid during the event.

1.5.4 the Airport Firefighters

The duty officer of the firefighting command post, male, age of 33, held a valid correspondent's certificate, certificate number 201901003.

The field firefighting commander, male, age of 49, held a valid civil aviation firefighting commander certificate, certificate number 03118, and was responsible for field command when the first batch of firefighting force arrived.

There were 18 firefighters dispatched in total, holding valid civil aviation firefighting certificates, among which, the commanders held civil aviation firefighting commander certificates; Fire fighters held firefighters' certificate; The on-board correspondent hold correspondent's certificate; The driver held driving license for vehicle in civil aerodrome movement area of Pudong Airport.

During the accident, the Airport ARFF dispatched 116 fire commanders and firefighters.

Shanghai municipal rescue and firefighting corps has reinforced the firefighting efforts by dispatching more than 200 fire commanders and fighters from 20 fire stations in areas of Chuansha, Zhuqiao, Shenjiang, Chuanzhan, Jinqiao and Longyang counties.

1.5.5 Security Inspection Personnel at Pudong Airport

The Security Inspection and Guarding Department of Pudong Airport is responsible for the security inspection of the cargo and mail carried by the accident flight.

X-ray machine operator, male, age of 43, obtained senior security inspection certificate on June 27, 2012, and the latest recurrent training occurred on November 28, 2019. (Recurrent training valid for

3 years). Certificate of Dangerous Goods Training No.352083.

Unpacking staff, male, age of 37, obtained senior security inspection certificate on November 18, 2013, and the latest recurrent training occurred on November 29, 2019. (Recurrent training valid for 3 years). Certificate of Dangerous Goods Training No.351456.

The X-ray machine operator and the unpacking staff accomplished the recurrent training of Dangerous Goods in 2018 and 2020. They attended the Training of Dangerous Goods held by ARFF in September 2019.

X-ray machine operator and unpacking staff were properly certified and qualified.

1.6 Aircraft Information

The Boeing 777F with registration ET-ARH was designed as a freighter with a class E[4] main deck cargo compartment (with a capacity of 518.2 m^3), equipped with rigid cargo barrier and strengthened fuselage. The forward cargo compartment (with a capacity of 70.5 m^3), the aft cargo compartment (with a capacity of 47 m^3) and the bulk cargo compartment (with a capacity of 17 m^3) in the lower lobe area were designed as Class C[5] cargo compartments. The cargo compartment configuration of this freighter is shown in Figure 23.

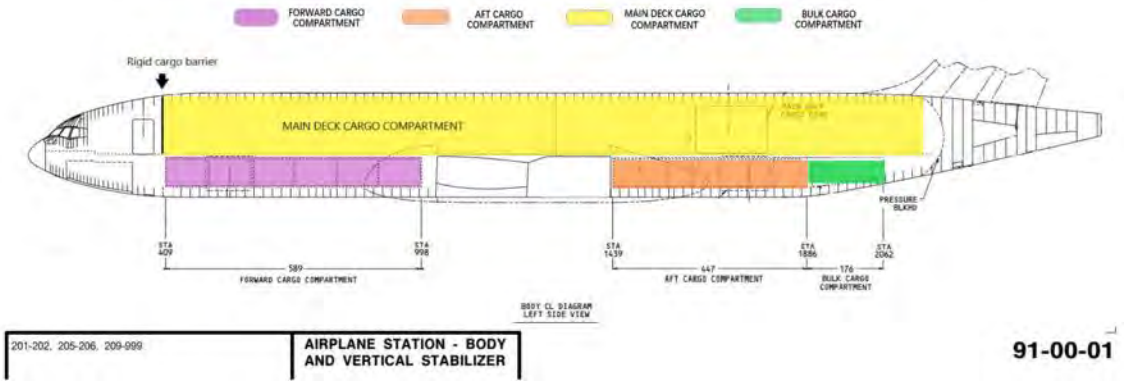


Figure 23 B777F Compartment Configuration

[4] Class E cargo compartments are certified for cargo aircraft only:(1)There is a separate approved smoke or fire detector system to give warning at the pilot or flight engineer station.(2) There are means to shut off the ventilating airflow to, or within, the compartment, and the controls for these means are accessible to the flight crew in the crew compartment.(3)There are means to exclude hazardous quantities of smoke, flames, or noxious gasses from the flight crew compartment. (4)The required crew emergency exits are accessible under any cargo loading condition.

[5] A Class C cargo or baggage compartment is one not meeting the requirements for either a Class A or B compartment but in which—
(1) There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station;
(2) There is an approved built-in fire extinguishing or suppression system controllable from the cockpit.
(3) There are means to exclude hazardous quantities of smoke, flames, or extinguishing agent, from any compartment occupied by the crew or passengers;
(4) There are means to control ventilation and drafts within the compartment so that the extinguishing agent used can control any fire that may start within the compartment.

1.6.1 Aircraft Basic Information

Aircraft Basic Information			
Aircraft Model	B777-200F	Manufacturer	BOEING
Manufacturer Serial No.	42031	Date of Manufacture	Sept. 2014
Registration No.	ET-ARH	Certificate of Registration No.	NO. R-493
Certificate of Airworthiness	NO. A-493	Radio Station License	NO.C-493
Time Since New	26740.25 Hours	Cycle Since New	4286 Cycles

1.6.2 Engines

Engines		
	Left Engine	Right Engine
Engine Model	GE90	GE90
Serial No.	906-275	907-630
TSN	40264.26	25156.14
CSN	5192	4047

1.6.3 Aircraft Maintenance Records

1.6.3.1 Aircraft Dispatch on JUL 22

On July 22 2020, the Boeing 777-200F aircraft, registered ET-ARH, was filed at Pudong Airport to its next sortie for Chongqing Airport, on a scheduled cargo flight ET3739. Transit check had been performed by the flight engineer according to the job card ETH B777 TRANSIT MAINTENANCE CHECK (LINE DISPATCH). The flight engineer signed the log book for aircraft dispatch since there was no fault or deferred defect found during the check.

1.6.3.2 Line Maintenance Records

Maintenance records within three months prior to accident on the AIRPLANE MAINTENANCE RECORD LOGBOOK and the ACCEPTABLE DEFERRED DEFECTS history had been reviewed. There was no deferred defect beside 8 open defects relating to the cargo handling subcomponents such as pallet locks.

1.6.3.3 Scheduled Maintenance Records

Last scheduled maintenance records of A Check (accomplished on June 29th 2020) and C Check (accomplished on October 9th 2017) of the aircraft, along with the AD/SB compliance reports (including the work packages) since its first service provided by Ethiopian Airlines, had been reviewed as well. There were 134 job cards performed during the A Check, including 2 cards related to the fire-damaged area， and 412 job cards performed during the C Check, including 4 cards related to the fire-damaged area. All the foresaid scheduled maintenance records were reviewed and no questionable issue was found. There were 20 ADs and 21 SBs which were applicable and complied to this aircraft, including 3 ADs and 1 SB related to the fire protection, electrical power and wiring harness. The review of these compliance records found no questionable issue either.

1.6.4 B777F Freighter Main Deck System

1.6.4.1 Main Deck Cargo Compartment Smoke Detection System

According to the applicable aircraft maintenance manual (AMM 26-16-00，REV. May 05/2020), smoke detection system in the main deck cargo compartment consisted of 46 area-type smoke detectors and a cargo smoke detection system (CSDS) controller. The smoke detectors located in eight different zones, 22 on the left and 24 on the right. All the detectors connected to the CSDS controller via controller area network buses (CAN bus), and the diagram is shown in Figure 24. Each smoke detector contained a dual channel photoelectric sensing chamber and two thermal sensors. The smoke alarm and overheat alarm channels transmitted their signals separately without mutual interference. Whenever the detector got electrical power supply, it can automatically come into detection after its built-in-test equipment (BITE) finished the continuous test. Fault signal would

illuminate the red LED on the enclosure of the detector, in the meantime, it would be also sent to the CSDS controllers.

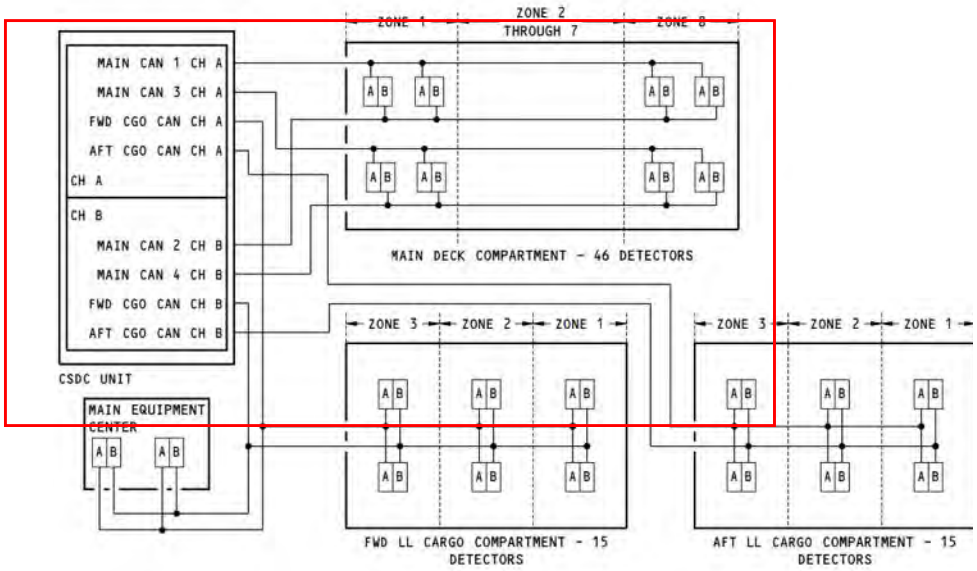


Figure 24 Smoke Detection System Diagram

The cargo smoke detection system controller was comprised of a dual channel electronical monitoring and control unit with automatic continuous built-in-test equipment (BITE). There were 3 processors in the controller, included 2 operational processors and 1 maintenance processor. Every operational processor had 2 channels, that were CHA and CHB, with the same capability of detecting and reporting smoke or overheating.

The forty-six detectors in the main deck compartment were divided into 17 groups (Table 2). When smoke or significantly elevated ambient temperature was detected by any single group, a main deck fire alarm would be triggered with cockpit indications of:

a) The red master warning lights come on, and

b) The fire warning aural in the cockpit operates

c) The MAIN DECK CARGO FIRE WARNING LIGHT on P5 panel comes on (Figure 25)

d) AIMS shows a red FIRE CARGO MAIN DECK warning message on upper EICAS.

Table 2 Main Deck Compartment Detection Groups

DETECTION GROUP	MAIN DECK DETECTOR IDENTIFICATION (CAN ADDRESS)	
	LEFT	RIGHT
1	0.1.2.3.4	0.1.2.3.4
2	2.3.4.5	2.3.4.5
3	3.4.5.6	3.4.5.6

4	4.5.6.7	4.5.6.7
5	5.6.7.8	5.6.7.8
6	6.7.8.9	6.7.8.9
7	7.8.9.10	7.8.9.10
8	8.9.10.11	8.9.10.11.12
9	9.10.11.12	9.10.11.12.13
10	10.11.12.13	10.11.12.13.14
11	11.12.13.14	11.12.13.14.15
12	12.13.14.15.16	12.13.14.15
13	13.14.15.16.17	13.14.15.16
14	14.15.16.17.18.19	14.15.16.17
15	15.16.17.18.19.20	15.16.17.18
16	17.18.19.20.21	16.17.18.19
17	18.19.20.21.22.23	17.18.19.20.21

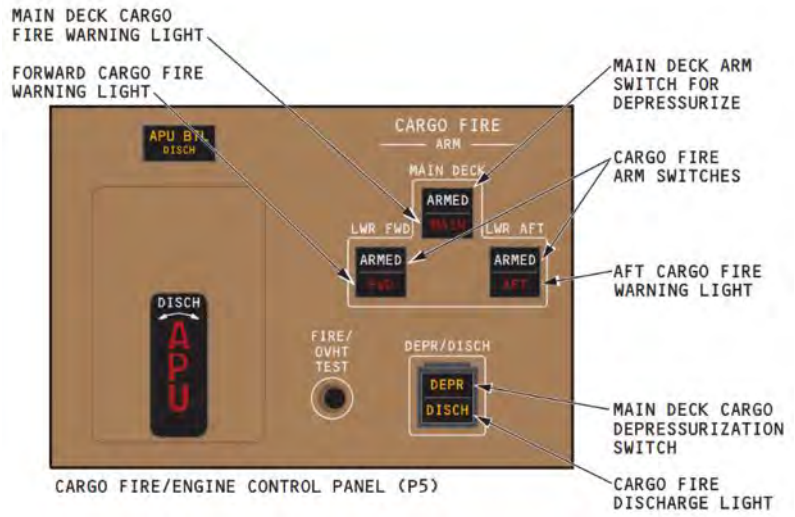


Figure 25 Cargo Fire/Engine Control Panel (P5)

1.6.4.2 Main Deck Fire Extinguishing

The main deck cargo compartment was designed as a class E cargo compartment, which had no guidance of ground fire operation in existing manuals published by the aircraft manufacture. In case of in-flight fire condition, according to the Flight Crew Operations Manual (FCOM, REV. June 15, 2020), pushing the MAIN DECK CARGO FIRE ARM switch would config one pack off and the other to a low flow mode. Subsequently pushing the CARGO DEPR/DISCH switch would initiate a controlled depressurization to a cabin altitude of approximately 23,000 feet with the airplane altitude at 25,000 feet.

1.6.4.3 Main Deck Cargo Door Power Supply

According to System Schematic Manual (SSM 52-32, REV. Feb 19/2020), there were 2 cargo door control panels located in the supernumerary area (P408 panel) and the forward area of the main deck cargo door (P409 panel), Figure 26. Each panel equipped with one control switch of the main deck cargo door. The cargo ground support control unit (CGSCU) (located at electronic bay E1-4) operated the main deck cargo door by three AC Motors via the control switches. The ground handling bus (GND HDLG BUS) of P320 panel supplied 28V DC power to the CGSCU, while the AC motors were powered by 115V AC from the ground handling bus (GND HDLG BUS) of P330 panel. When the freighter was powered by APU on ground, the ground handling bus (GND HDLG BUS) received electrical power from the APU[6].

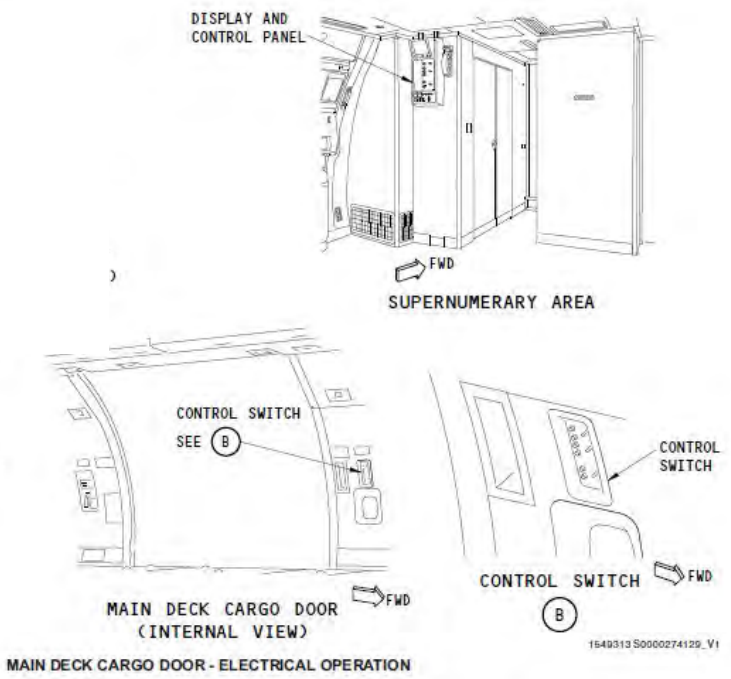


Figure 26 P408 and P409 Panels

1.6.4.4 Main Deck Cargo Lights Power Supply

Two toggle switches controlled the main deck cargo illuminating lights. They were located at P408 panel in the supernumerary area and P441 panel at the aft of the main deck cargo door. The main deck cargo lights received 115V AC power from the ground handling bus (GND HDLG BUS) or the ground service bus (GND SVC BUS) of P320 panel.

[6] According to the AIRCRAFT MAINTENANCE MANUAL (SDS 24-40-00-007, Rev. May 05/2020)

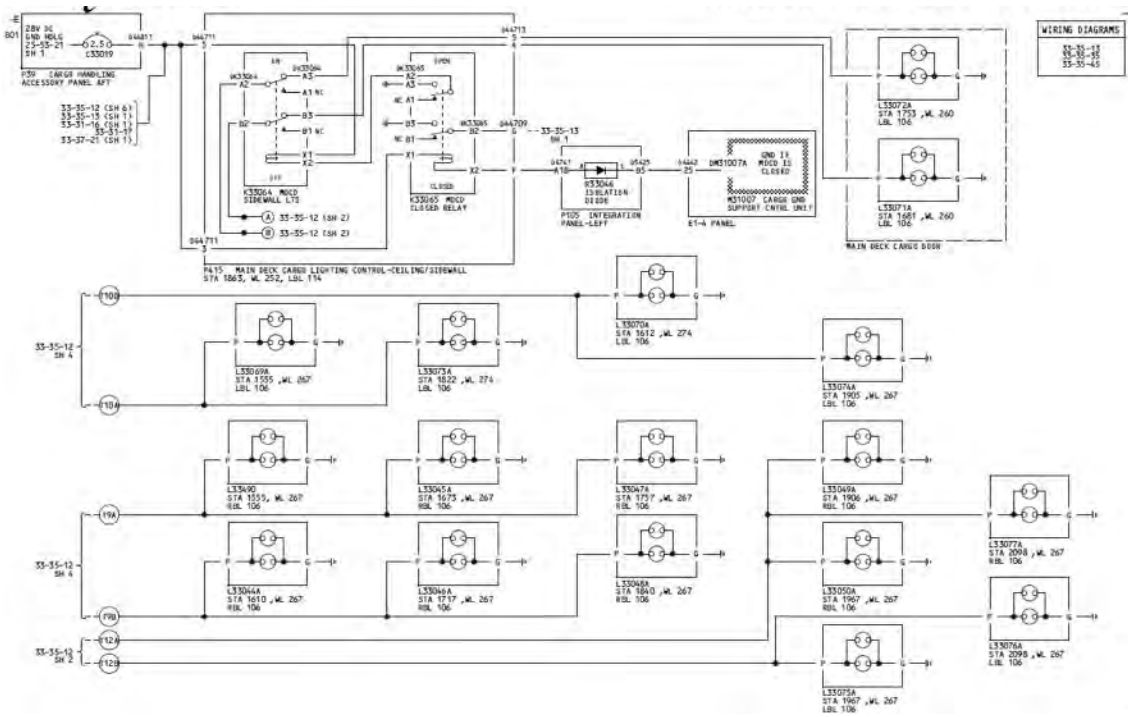


Figure 27 Main Deck Cargo Lights Schematic

1.6.4.5 Rigid Barrier Doors

According to the FCOM chapter 1.47.20, the rigid cargo barrier separated the main deck cargo compartment from the supernumerary area. If there was smoke in the main deck cargo compartment, the rigid cargo barrier helped to prevent the smoke from entering the supernumerary area. Two rigid cargo barrier doors were used for access between the main deck cargo compartment and the supernumerary area. The doors were to remain closed except when entering and exiting the cargo compartment. Occupancy of the main deck cargo compartment was prohibited during taxi, takeoff, and landing. Main deck cargo compartment access was limited to caring for live animals or cargo requiring special attention. Portable oxygen must be carried by occupants in the main deck cargo compartment.

Operate limitations and cautions were specified on the rigid cargo barrier doors (Figure 28):

(1) In-Flight Access Is Limited: Max 3 persons for cargo operations, no animals

(2) Max 11 persons for animal carriage operations,

(3) Occupancy of the cargo compartment is prohibited during taxi, takeoff, and landing

(4) Each occupant must carry portable oxygen bottle with full face mask when entering the cargo compartment

(5) In the event of lights flashing, return to the supernumerary area

(6) In the event of aural warning don oxygen mask and return to the supernumerary area

(7) No smoking in the cargo compartment

(8) Keep door closed except during entrance and egress

(9) In the event of smoke or cargo fire, Do Not Open.

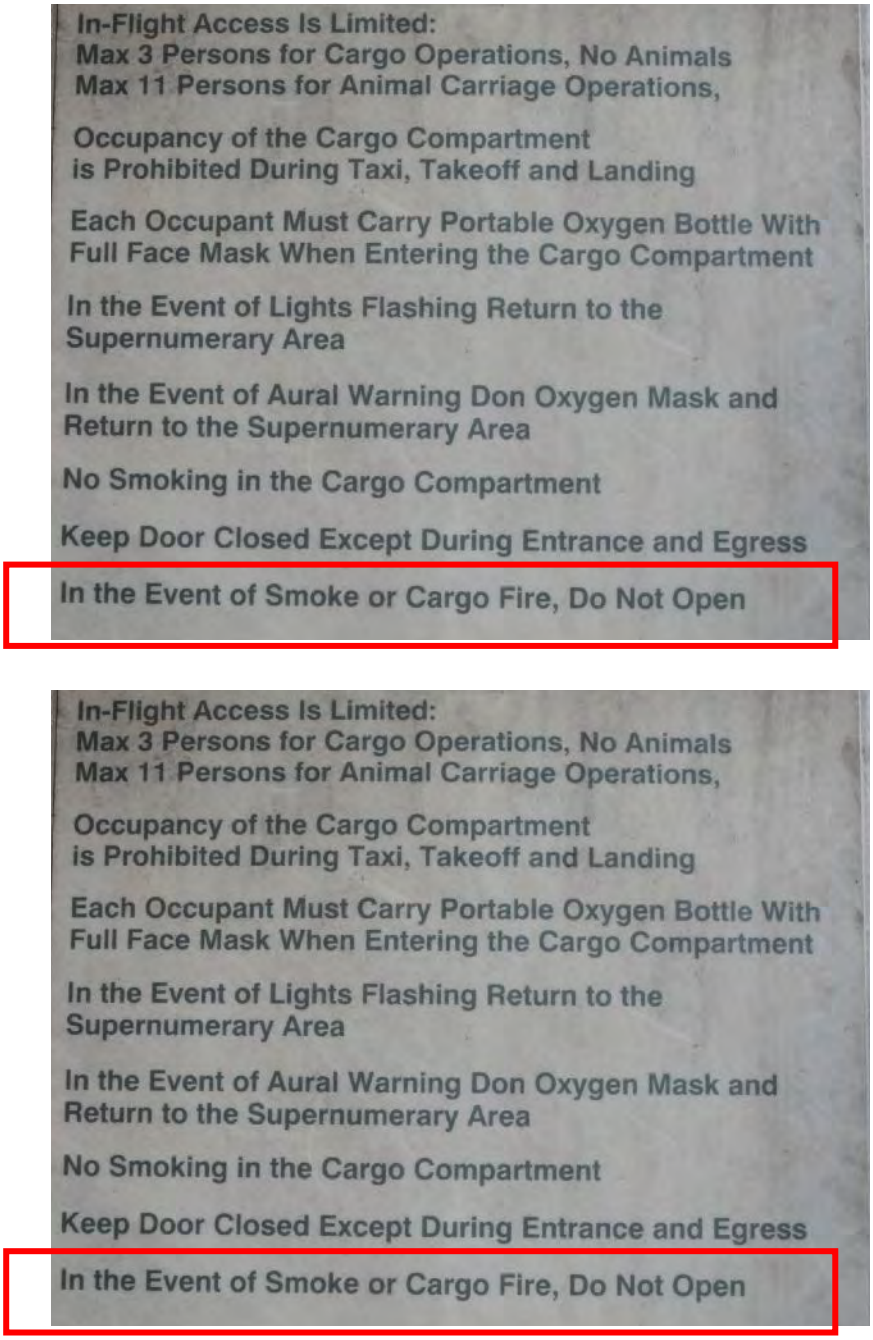


Figure 28 Rigid Barrier Doors Limitations of ET-ARH

1.6.5 Emergency Equipment

The emergency equipment of the aircraft included halon extinguishers, water extinguishers, oxygen masks with smoke goggles, portable oxygen bottles with smoke mask, portable oxygen bottles, portable breathing equipment, exits with escape slide/raft, exit paths with slide, exit paths with rope, first aid kit, life vests, infant life vests, protective gloves, megaphone, crash axe, flashlights and emergency locator transmitter (The symbols and locations are Figure 29 and 30).

Figure 29 Emergency Equipment Symbols

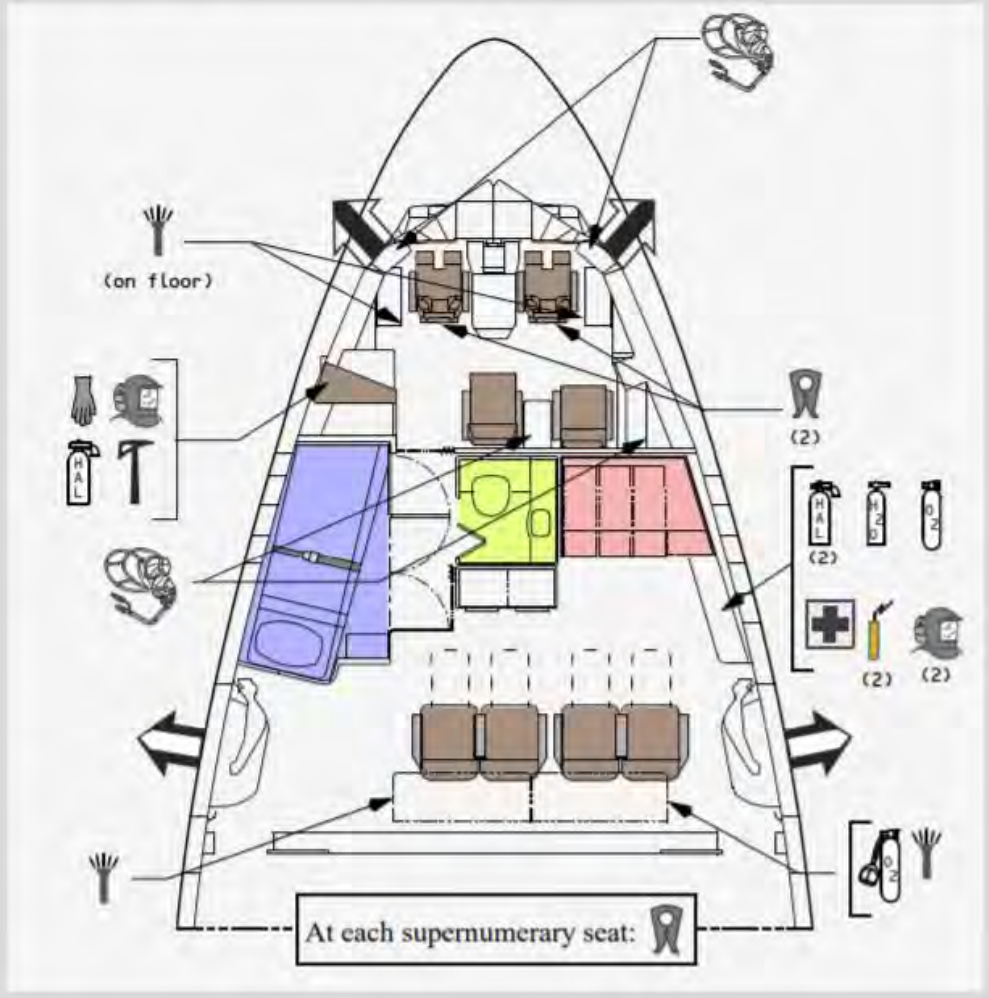


Figure 30 Emergency Equipment Locations

1.7 Cargo Onboard

1.7.1 General Information of Goods

A total of 69,370 kg of cargo were loaded on the aircraft, 85 bills in total. According to the waybills, the goods included masks, thermometers, protective clothing, machinery equipment, medicines and clothes. According to the documents, there were 4 bills containing electronic products with lithium batteries, no other dangerous goods were declared.

There were 22 pallets at 27 loading positions in the main deck cargo compartment, among which 5 positions of LL, FR, FL, GR and GL were empty, 1750 kg of empty pallets were loaded in LR (Figure 31 shows pallet positions involved), and the remaining 21 pallets carried goods of 56,910 kg in total. The forward and the aft cargo compartments carried 6 pallets, carrying a total of 10,170 kg of cargo, and the bulk cargo compartment carrying 540 kg of goods.

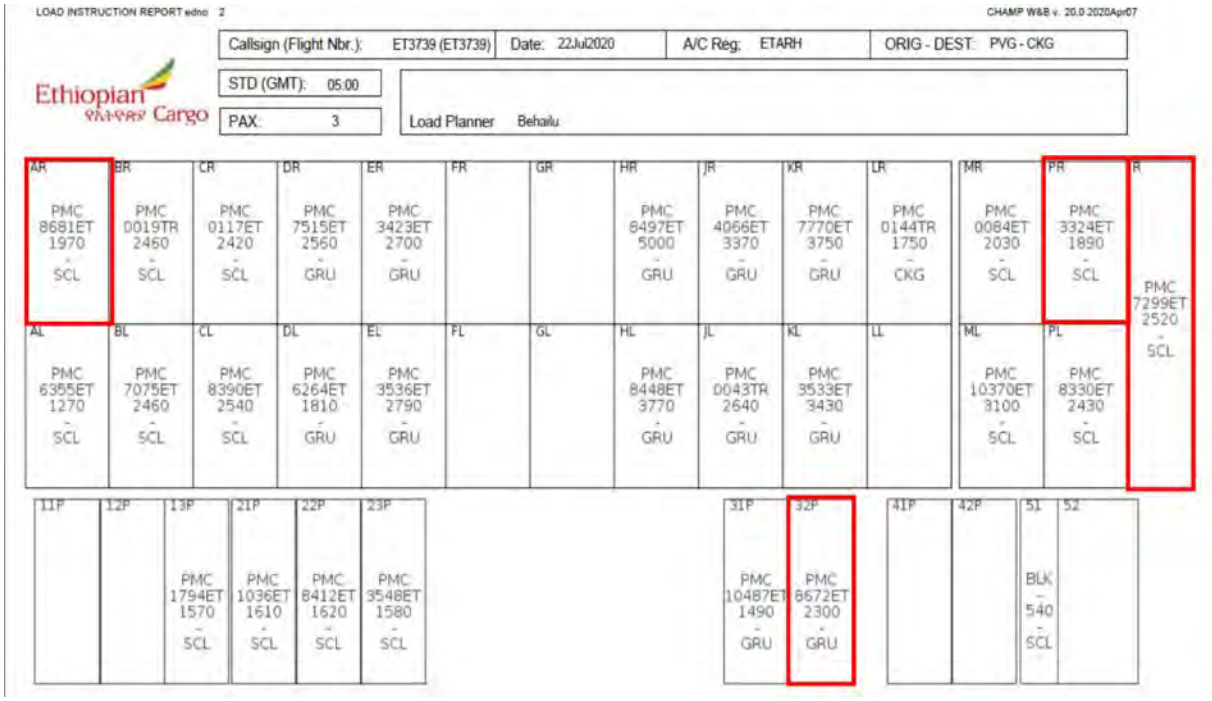


Figure 31 Load Instruction Report

1.7.2 Goods Containing Lithium Batteries

There were four pallets containing cargo with lithium batteries, pallet numbers were PMC3324ET, PMC7299ET, PMC8672ET and PMC8681ET. See the red mark in Figure 31 for the specific locations.

15 pieces of Hisense cash register containing lithium batteries were loaded on pallet PMC3324ET (Figure 32), 15 pieces of mesh nebulizer installed with lithium batteries were loaded on PMC7299ET board (Figure 33), 66 pieces of vehicle-mounted hard disk video recording equipment installed with lithium batteries were loaded on pallet PMC8672ET (Figure 34), and 2 pieces of facial massager containing lithium batteries were loaded on pallet PMC8681ET (Figure 35).

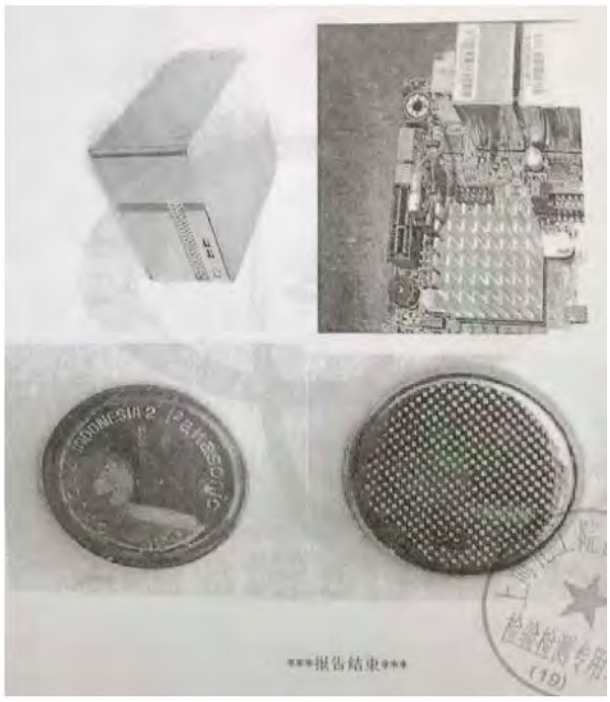


Figure 32 Hisense Cash Register in Appraisal Certificate

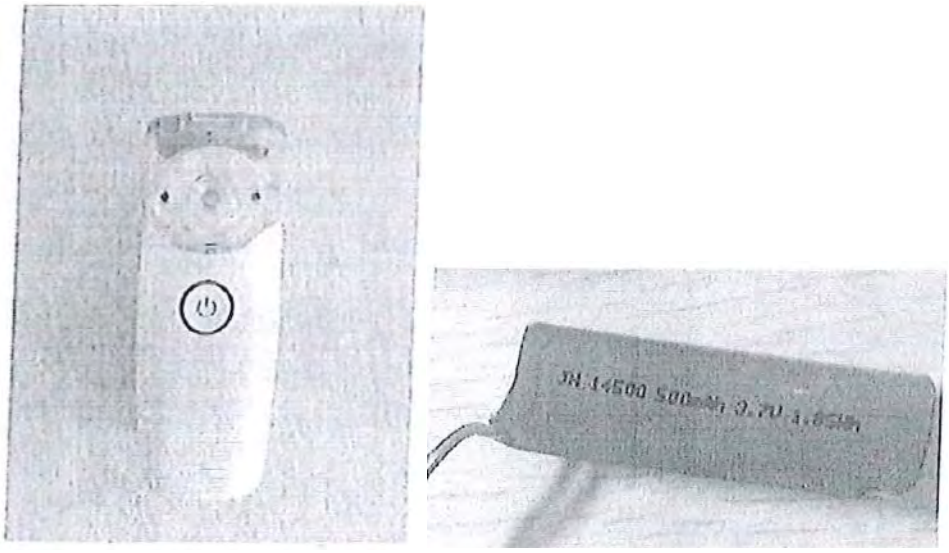


Figure 33 Mesh Nebulizer and Lithium Battery in Appraisal Certificate

Figure 34 Lithium battery Carried by the Vehicle-mounted Hard Disk Video Recording Equipment in the Appraisal Certificate

Figure 35 Lithium Battery Carried by the Facial Massager in the Appraisal Certificate

1.8 Meteorological Information

1.8.1 Weather condition of the Cargo Storage

From July 20 to July 22, the temperature in Pudong Airport was between 24-34℃ and the relative humidity was between 60% and 98%.

On July 20, there was light fog and light showers. It was mainly cloudy and overcast. The wind direction was northwest, then turned to northeast wind in the morning and southeast wind at night. On July 21, there was light fog with haze. The weather condition was cloudy to sunny. On July 22, there was intermittent light fog. The weather condition was scattered to sunny. The wind direction was northeast, then turned to southeast in the early morning and southerly in the morning.

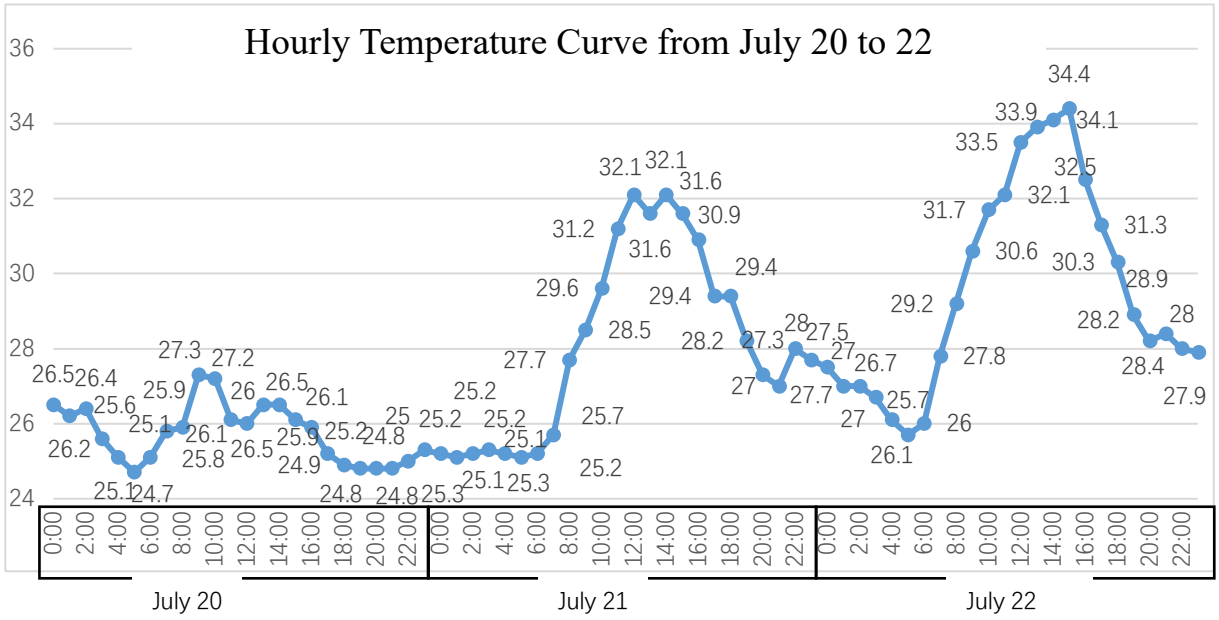


Figure 36 Hourly temperature from July 20 to July 22 (Celsius)

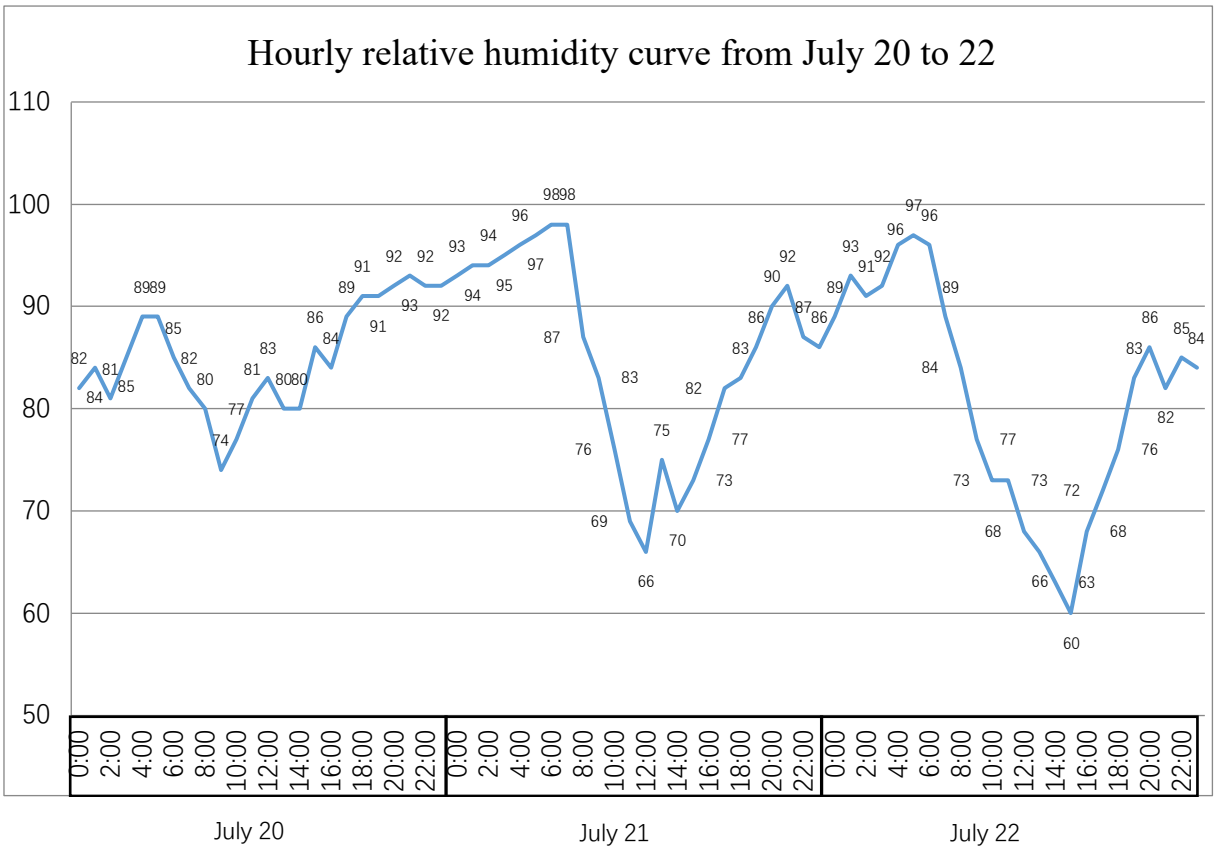


Figure 37 Hourly humidity from July 20 to July 22 (%)

1.8.2 Weather Condition During Fire

Pudong Airport weather condition at 15:00: surface wind was 150 degrees 5 meters per second, visibility was more than 10km, temperature was 34℃, dew point was 24℃, QNH 1006 hectopascals.

Pudong Airport weather condition at 15:30: surface wind was 170 degrees 4 meters per second, visibility was more than 10km, temperature was 33℃, dew point was 26℃, QNH 1006 hectopascals.

Pudong Airport weather condition at 16:00: surface wind was 140 degrees 6 meters per second, visibility was more than 10km, temperature was 33℃, dew point was 26℃, QNH 1006 hectopascals.

1.9 Communications

The flight crew used VHF to communicate with air traffic control tower (121.95MHZ) and the airport apron control (121.65MHZ). The airport AOC communicated with the ATC Tower, ARFF and the airport apron control by telephone and 800-megabit walkie talkie. All equipment functioned normally during communication.

1.10 Airport Information

1.10.1 General Information of Airport

Shanghai Pudong International Airport (PVG/ZSPD), located at Pudong New Area, Shanghai, China, about 30 kilometers away from the center of Shanghai, is a class 4F airport. The latest certified date of the airport was April 4, 2018, valid until April 3, 2023.

The airport apron control is divided into four areas (APN01, APN02, APN03 and APN 04). Aircraft parking position No.306 is under control of APN01 (Figure 38), and the communication frequency of which is 121.65Mhz (122.125Mhz).

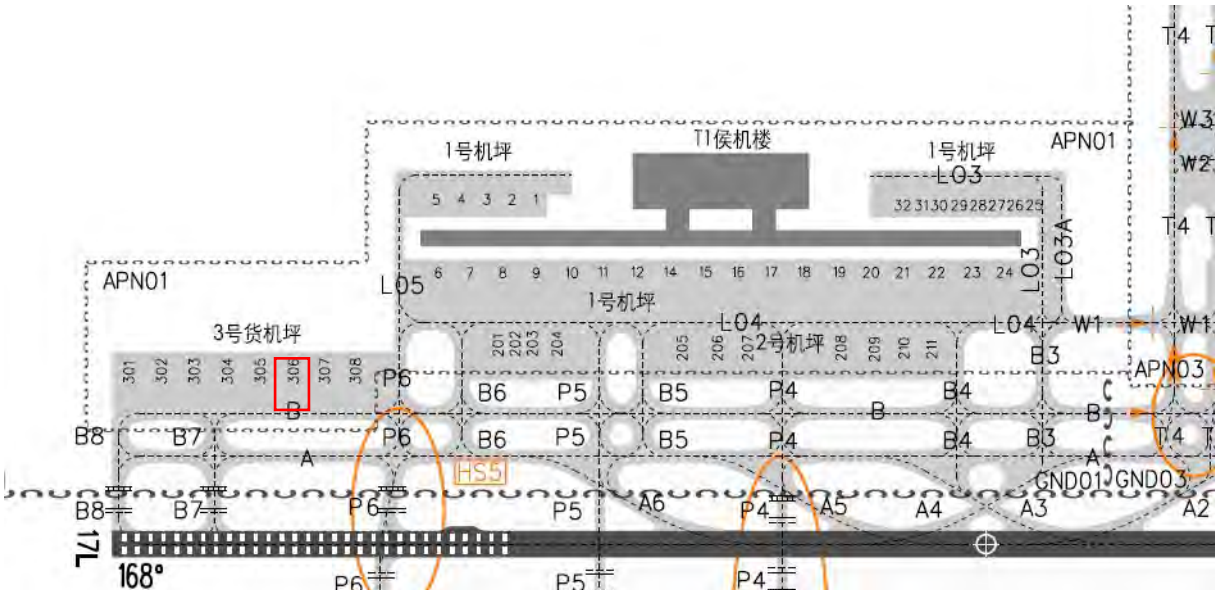


Figure 38 Parking Position No.306

1.10.2 Responsibilities of Relevant Departments

The Airport AOC is the commanding, supporting, coordinating and control center in airport operation. It is mainly responsible for various tasks, such as: collecting and releasing flight information, organizing flight operation support, aircraft stands allocation, airport comprehensive information processing and releasing, crisis handling, flight punctuality management, aircraft ground operation management. In case of emergency, as the airport emergency response command center, it is responsible for initial command and information relay before the arrival of the chief commander.

The apron control of Pudong Airport is responsible for instructing aircraft pushback, engine start, taxiing, engine ground test and the towing aircraft.

The Pudong ATC Tower provides air traffic service within the Pudong area, including air traffic control service, flight information service, alerting service.

1.10.3 Distribution of Airports Firefighting Forces

The firefighting at Pudong Airport is category 10[7], and the personnel, vehicles and equipment are equipped correspondently.

According to the distribution of firefighting jurisdiction in Part II of Article[8] , General Rules, *Emergency Response Plan of Airport Firefighting Department,* parking position No.306 is within the jurisdiction of West Apron Brigade (including No.1 and No.3 Fire Stations) (Figure 39)

[7] According to the *Aerodrome Category for Rescue and Fire Fighting*, Annex 14 to Chicago Convention, category 10 corresponds to the aeroplane overall length of 76 ~< 90 m, the maximum fuselage width of 8 meters.

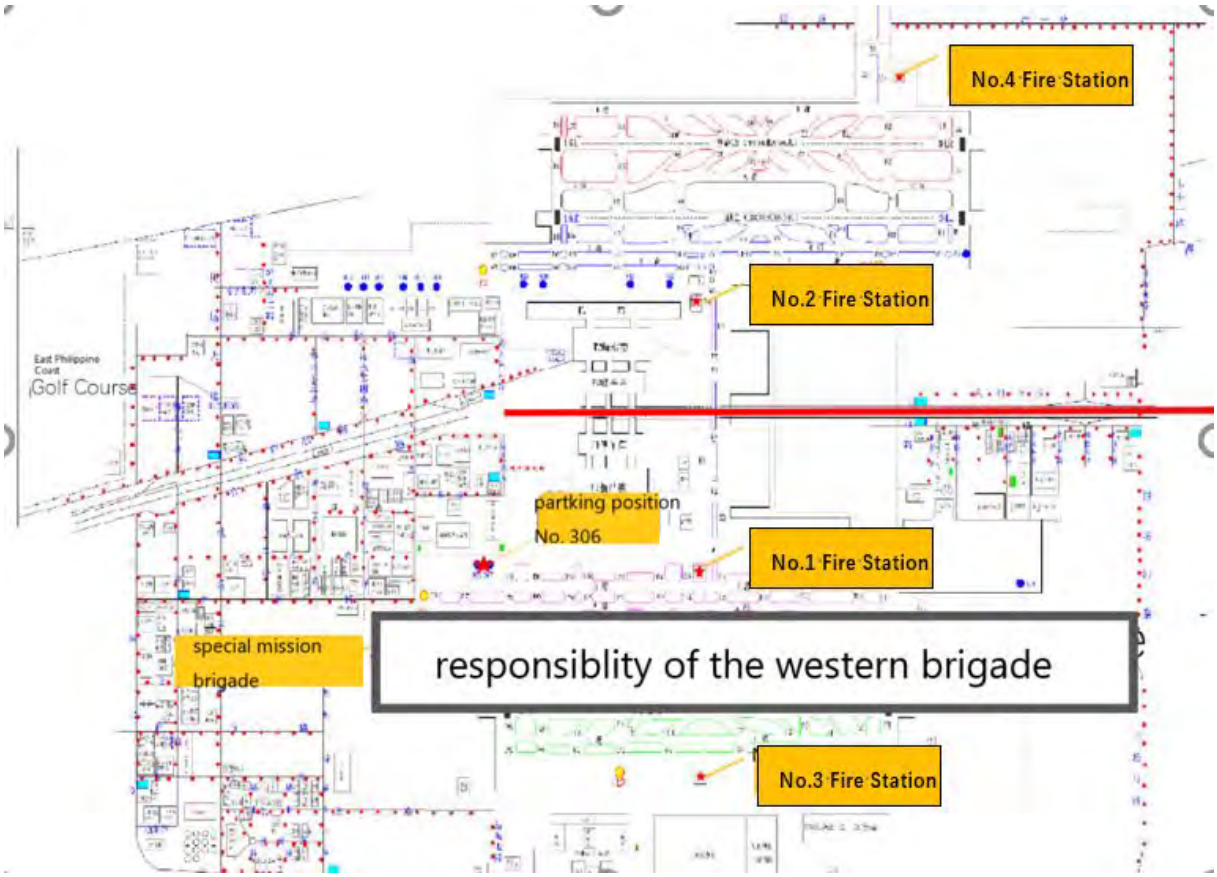


Figure 39 Distribution of Firefighting Forces

1.10.4 Airport Emergency Plans/Procedures and Drills

According to the Emergency Response Plan of Pudong Airport, Pudong Airport has set up an emergency response leading group and an emergency response command center. The emergency response command center is the permanent office of the emergency response leading group, responsible for organizing, coordinating and implementing emergency responses under the authorization of the emergency response leading group. The emergency response command center is composed of senior management of the Airport and heads of the supporting stakeholders. The emergency response command center reports to the emergency response leading group. The emergency response command center locates in the airport AOC.

In accordance with the *Regulation of Management of Emergency Response in Civil Transport Aerodrome* (CCAR-139-II-R1), Pudong Airport conducted 44 various subjects emergency response trainings in 2017, 42 in 2018 and 56 in 2019.

The ARFF has documented trainings and emergency drills. According to the *Training Syllabus of Full-time Firefighters of Civil Air Transport Aerodrome*. It has carried out trainings on the subjects of Airport Emergency Plan, real fire simulation and aircraft engine fire fighting; During 2017-2020, a total of 15 firefighting drills and desktop exercises were conducted, including drills on aircraft emergency response (wing fires) and the drills on satellite hall emergencies.

1.11 Flight Recorders

1.11.1 Flight Data Recorder (FDR)

The aircraft was equipped with a solid-state FDR, manufactured by L-3 company with part number 2100-4045-22, serial number 000967493. The recorder exhibited no damage except that the outer shell was partly sooted. The data were extracted normally from the recorder. The FDR operates when any of the following occurs[9]:

(1) Any engine is in start mode (starter air valve switch in START position or fuel cutoff lever not in CUTOFF position)

(2) Any engine is in the RUN mode (N1 RPM>20% or N2 RPM>20%)

(3) The airplane is airborne.

Since the aircraft met none of the above conditions at the time of the fire, there was no data of the accident recorded in the FDR.

[9] According to B777 AIRCRAFT MAINTENANCE MANUAL (AMM 31-31-00，REV. May 05/2015)

1.11.2 Cockpit Voice Recorder (CVR)

The aircraft was equipped with a solid-state CVR, manufactured by L-3 company with part number 2100-1025-22, serial number 001035689. The recorder exhibited no damage besides the outer shell was partly sooted. The data were extracted normally from the recorder. The CVR operates when any of the following occurs[10]:

(1) At least one engine is on when the switch is spring-loaded to the AUTO position or,

(2) The CVR AUTO/ON switch is set to ON position.

Since the aircraft met none of the above conditions at the time of fire, there was no data of the accident recorded in the CVR.

1.11.3 Quick Access Recorder (QAR)

QAR data included the starting information of the APU from 14:38:05 to 14:39:17 on JULY 22. The recorded data showed that the rotating speed of the APU began to increase at 14:38:05, and reached full speed at 14:39:00. At 14:39:17, the data recording stopped. The airline modifiable information (AMI) software with the part number of 3167-BSM-758-03 in the airplane condition monitoring function (ACMF) of the aircraft, was installed by accomplishing the job card EO(M)-777-AMM31-41-04-420-804-003 on June 11, 2018. The APU data during the start-up of the APU will be collected and recorded by this AMI software.

Advised by the Boeing: The ACMF AMI software stored the pre-programmed operating principles which controlled the beginning and the ending of the QAR recording. ACMF AMI software included an option to start the QAR recording for a short time during the APU starting, which was used to diagnose failures in the process of starting. QAR would begin to record 20

[10] According to B777 AIRCRAFT MAINTENANCE MANUAL (AMM 23-71-00，REV. Sep 05/2016)

frames (4 seconds per frame) of data for 80 seconds since the APU starts. Therefore, the last set of QAR data recorded was the starting information of APU.

1.12 Wreckage and Accident Scene

Ethiopian Airlines B777F freighter, registration ET-ARH, docked at parking position No.306 of Pudong Airport with its nose heading east. The fire only damaged the aircraft, while the airport cargo terminal to the east, the taxiway B to the west, the parking position No. 307 to the south, and the parking position No. 305 to the north were not affected (Figure 40). The aircraft sustained several burn-through damages in the upper fuselage, and the interior linings of the main deck cargo compartment was seriously burnt out. The main frames and components of the lower fuselage remained intact but got partially sooted, which could be suffered from thermal damage. No obvious fire or soot trace were found in the areas of wings, engines, landing gears, stabilizers and APU. The details were described in section 1.3.

The freighter was towed to parking position No.411 of Pudong Airport on Sep 24, 2020.

Figure 40 Damaged Aircraft

1.13 Survival Aspects

1.13.1 Deplaning

15:14:04, the crew reported fire warning in the main deck cargo compartment of the aircraft at the ATC delivery frequency, and requested for fire truck.

15:18:11, the flight crew requested for passenger stairs.

15:28:31, door 1L, the left front boarding gate of the aircraft was opened, and 5 crew members deplaned via 1L using the passenger stairs.

15:33:22, all crew members deplaned without injuries. (Figure 41)

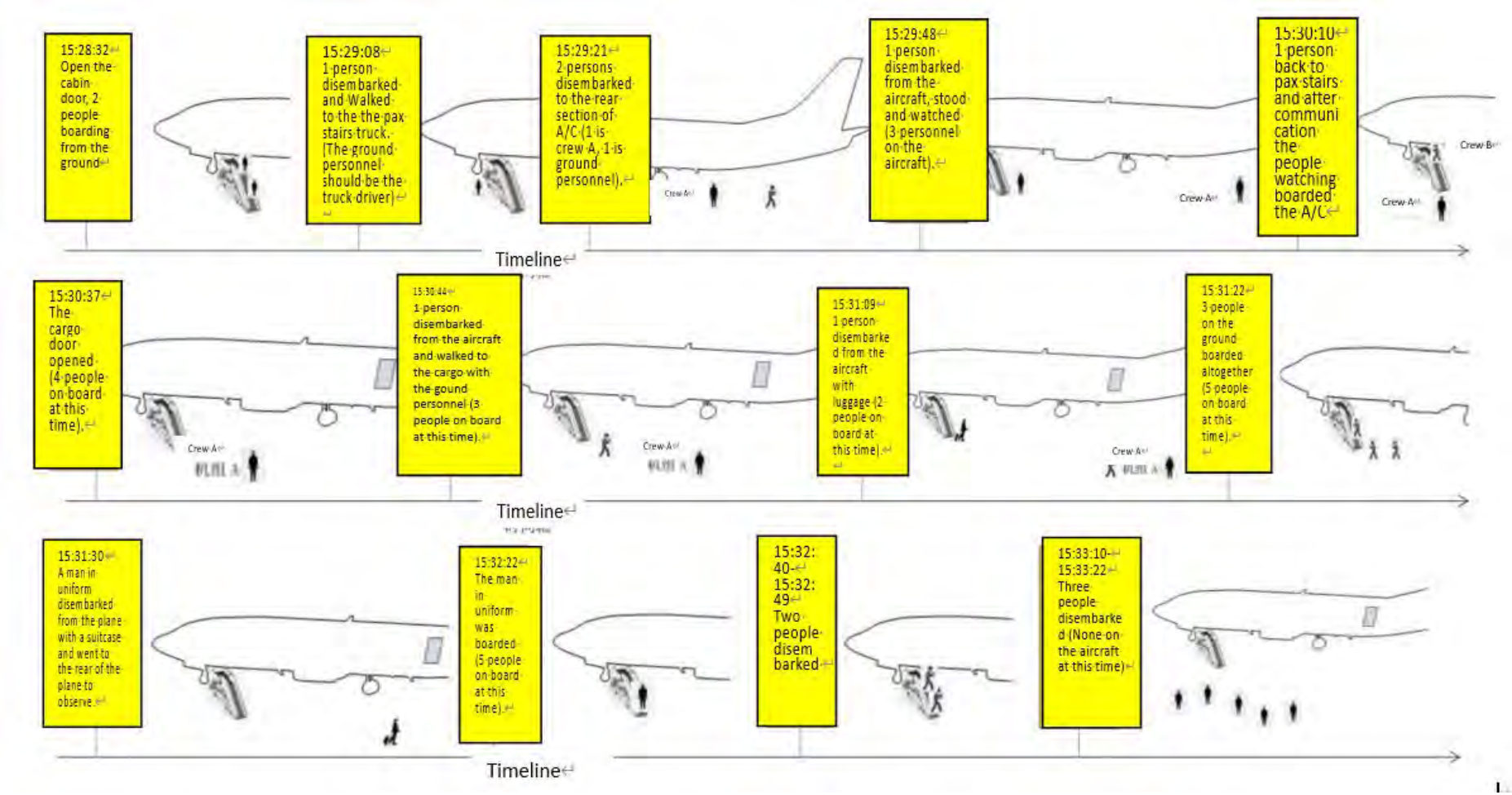


Figure 41 Crew deplaning

1.13.2 ARFF

1.13.2.1 ARFF Response

The ARFF was notified by AOC at 15:17 to dispatch fire truck to verify a fire warning situation at parking position No.306. At 15:18, three fire trucks from No.3 Fire Station were sent to parking position No.306 via the airport service lane. On the way to parking position No.306, they were joined by fire truck F302 which was exercising at parking position No.316. At 15: 25, the first batch of firefighting force reached parking position No. 306 (Figure 42).

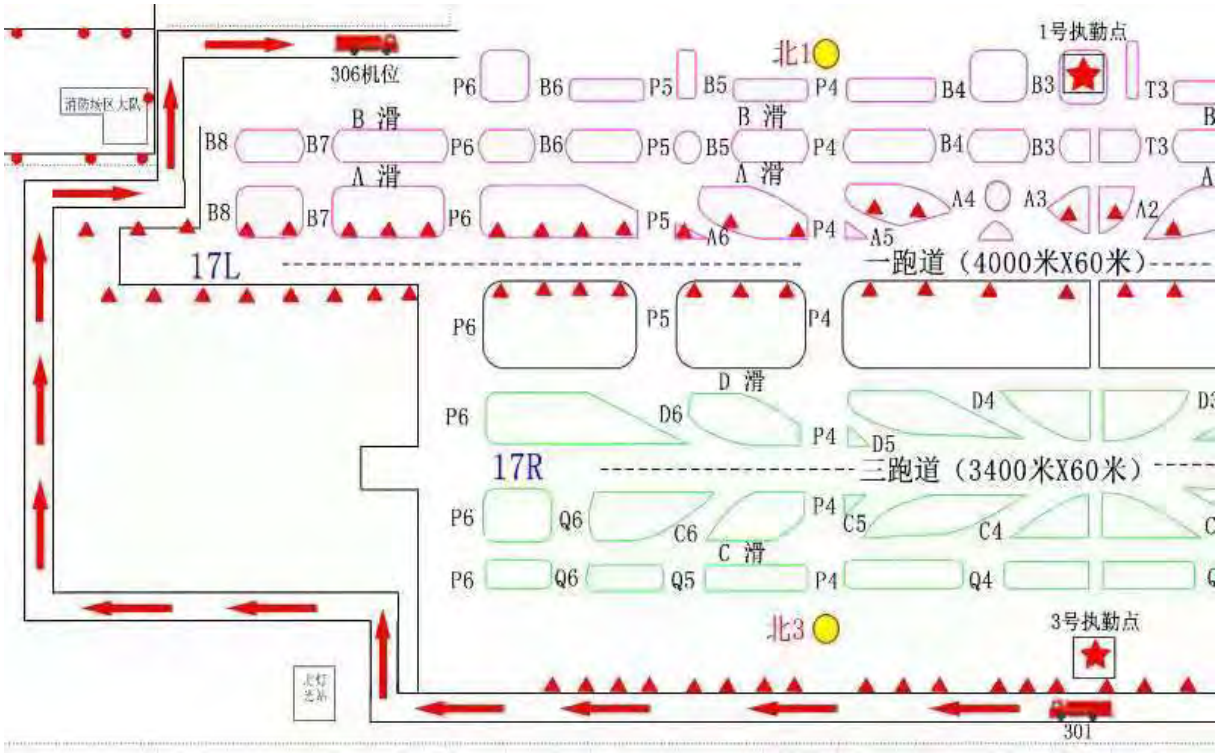


Figure 42 The First Batch of Firefighting force Trajectory

1.13.2.2 On site Operation of ARFF

(1) Field Command

Upon arriving at parking position No. 306, the first batch of 4 fire trucks and 1 command vehicle deployed in a Ready mode, positioned at the left front side, right front side and right rear side

of the aircraft and adjacent to agent supply of parking position No.307 respectively. The field commander acquainted himself with the situation from the on-site personnel. Knowing that there was a fire warning in the rear section of main deck cargo compartment and observing the aircraft external at a close distance, the field commander adjusted the deployment of the force at once, and mobilized the major fire truck had previously positioned at the left front side of the aircraft to the left rear side, aimed the top turret to the main deck cargo door, and requested for passenger stairs to approach the main deck cargo compartment of the aircraft to assess the fire situation. While ready to mobilize the major foam tender to the left rear side of the aircraft, the field commander noticed that the main cargo compartment door was opened and a small amount of smoke was emitted. The field commander repositioned the major foam tender immediately to the left rear side and established a water distribution deployment about 20 meters away from the fuselage. When the flame was visible, the agent was discharged immediately to extinguish the fire.

At 15:32, based on the current situation, the ARFF convened Special Mission Brigade and No.1 Fire Station to be standby, meanwhile, relayed the site information via radio.

At 15:38, upon receiving the instruction from AOC to activate the emergency plan, the firefighting senior command post issued instruction to Special Mission Brigade and No.1 Fire Station, requiring them to scramble to the aircraft, and the No.2 and No.4 Fire Stations were also mobilized for reinforcement. At 15:57, the firefighting senior command post requested for external rescue and firefighting to support, and informed the reception personnel to go to the apron Gate 2A to receive them. At 16:13, the first batch of external RFF reinforcement were guided to the scene.

(2) Usage of HRET/SPN

The ARFF mobilized four fire trucks with HRET/SPN (High-Reach Extendable Turret with Skin-Penetrating Nozzle), namely a Rosenbauer Panther 6x6, an Oshkosh stiker 3000, a Rosenbauer Panther and an Oshkosh new striker. During the firefighting efforts, the fire trucks with HRET/SPN approached the leading edge and trailing edge of both wings. The extendable

arms of which were used to carry out targeted firefighting tasks. A large amount of vaporific agent was formed at the designated position, which soaked the cargo surface, effectively slowed down and prevented the growth of the fire, at the same time, played a role in protecting the empennage and central fuel tank.

In the first batch of RFF force, fire truck F303, equipped with HRET/SPN (from No.3 fire station), approached main cargo deck door with the skin-penetrating nozzle at about 15:39, suppressing the fire closely. It effectively prevented the fire from spreading to the empennage.

The reinforcing fire truck F203 with HRET/SPN (from No.2 Fire Station) arrived at the scene at about 15:56, and stopped at the right rear side of the aircraft, applied foam via the extendable arm hitting the burn-through flame at the crown centerline, then repositioned to pierce the skin of the fuselage from the left rear side of the fuselage, and applied agents to hit the burn-through flame at the rear part of the fuselage, effectively preventing the fire from spreading to the empennage.

At about 15:56, the reinforcing fire truck F202 (from No.2 Fire Station) with HRET/SPN, arrived at the scene, and applied foam from the right rear side of the aircraft, hitting the burn-through flame, then repositioned and pierced the skin of the fuselage in front of the starboard engine, to hit the burn-through flame at the front of main deck cargo compartment, effectively preventing the fire from spreading to the cockpit.

Reinforcing fire truck F404 (from No.4 Fire Station) with HRET/SPN arrived at the scene at about 16:05, and applied foams to the burn-through at the top of the fuselage at the wing position, from the right rear side of the fuselage. effectively preventing the fire from spreading to the front of the fuselage and protecting the fuel tank.

(3) Water Supply

The first batch of firefighting trucks applied Aqueous film forming foam (AFFF) to extinguish the fire. Water supply was completed at the fire hydrant located at an intersection of the road

outside apron gate 2A. When the reinforcement arrived, a unit made use of the drainage ditch on the west of the apron to supply the water by connecting the pump vehicle in series, another unit made use of the water supply of underground fire hydrant at parking position No. 301-308 at the West Cargo Area, pressurized by the pumps in airport water works to ensure the water supply of firefighting.

(4) Command and Communication

Firefighting communication recordings and ARFF interview indicated that ARFF had established an integrated command and communication system. Firefighting senior command post communicated with the field commander through radio of 800Mhz frequency. Field commander directly instructed firefighting force in person or via radio of 400Mhz frequency.

1.13.3 Municipal Firefighting Reinforcement

At 15:56, following the airport AOC instruction, the firefighting senior command post requested the Center of Emergency Response Coordination of Shanghai for assistance. Upon receiving the request, Shanghai Firefighting and Rescue Corps dispatched the firefighting forces from 20 local fire stations including Chuansha, Zhuqiao, Jiang Shen, Chuanzhan, Jinqiao and Longyang etc., with 38 vehicles for firefighting operation, command, communication and support, more than 200 commanders and firefighters engaged in the efforts. Three vehicles from Chuansha Fire Station, the first batch of supporting force, arrived at the accident scene at 16:12.

1.14 Tests and Research

1.14.1 Test on Suspected Chlorine Dioxide Disinfection Tablets

The investigation team sent the Articles of "suspected chlorine dioxide disinfection tablets" packed in transparent plastic bags and aluminum foil bags retrieved from the PR position from the site survey to qualified appraisal institutions for analysis and test, refer to Table 3 for the details.

Tianjin Fire Evidence Identification Center of Fire Bureau of Ministry of Emergency Management issued

- "Analysis and Appraisal Report on Evidence Identification of Ethiopian Airlines Ground Fire at Pudong Airport (Appendix 1),
- Appraisal Report (20201412)" (Appendix 2)
- Appraisal Report (20201743)" (Appendix 3);
- Analysis Report (SHA20090108-01) issued by Ingeer (ICAS) Testing Technology Service (Shanghai) Co., Ltd (Appendix 4);
- Qualitative Test Results of "Suspected Chlorine Dioxide Disinfection Tablets" issued by Testing Co., Ltd. of Shanghai Research Institute of Chemical Industry (hereinafter referred to as SRICI) (Appendix 5).

Table 3 Details of Related Articles Containing Chlorine dioxide at PR location

Number	Name	Package	Appearance	Source	Photo	Appraisal/Test Institution	Appraisal/Test Result
Article 1	Disinfection Tablets	aluminum foil bags	Tablets	The owner claimed from Shandong Zhaoguan		Tianjin Fire Evidence Identification Center of Fire Bureau of Ministry of Emergency Management (referred to as Tianjin in this Table)	The sample has the characteristics of chlorine dioxide effervescent tablets: may contain sulfate or hydrogen sulfate, possible to absorb moisture in the air when the product is not tightly packed. Risk of spontaneous combustion exists when the sample is damp at normal temperature. The spontaneous combustion temperature of the tablets packed in aluminum foil bags (Article 1) is about 150℃, and the risk of spontaneous combustion is extremely high. In the case of unfavorable heat dissipation, it is possible to accumulate heat in a short time to reach spontaneous combustion temperature, that is, it is possible to spontaneously combust at this temperature.
Article 2	Disinfection Tablets	Plastic bag	Tablets	The owner claimed from		SRICI	the components of "Suspected Chlorine Dioxide Disinfection Tablets" are similar to those of commercially available disinfection products which can release chlorine dioxide, and the

				Shandong Zhaoguan			sample will produce chlorine dioxide when it reacts with water.
						ICAS	The results showed that the available chlorine and chlorine dioxide in the sample accounted for 21.1% and 4.66% respectively. The components of the sample mainly included sodium dichloroisocyanurate (71-72%), sodium sulphate (20-21%) and magnesium sulphate (7-8%).
						Tianjin	The sample had the characteristics of chlorine dioxide effervescent tablets; as the sample may contain sulphate or hydrogen sulfate, there is a possibility of moisture absorption in the air when the product is not tightly packed. The sample damped at normal temperature moisture poses risk of spontaneous combustion.
Article 3	Virus shield	aluminum foil bags	Particle	Crownfortune		SRICI	Hazards identification: None Suggestion according to IATA DGR: The substance is not subject to IATA DGR Packaging requirements: None

Article 4	Disinfectant powder	Foil bag	Powder particle	Crownfortune		SRICI	Hazards identification: Oxidizer (main), Corrosive (Sub) Suggestion according to IATA DGR: Shipping Name: Oxidizing solid, corrosive, n.o.s. (Chlorine dioxide absorbed in nano material) Class or Division:5.1 Subsidiary Hazard:8 UN Number:UN3085 Packaging requirements: Packing Group II.

(1) Article 2 was sent to SRICI for qualitative test. SRICI conducted 2 kinds of tests: "UV-VIS Spectrophotometry Test" and "Raman spectroscopy". When using UV-VIS Spectrophotometry Test, the Article was dissolved in water to form a solution, and the gas generated by the reaction was statically absorbed by distilled water. The UV-VIS spectrum received from the test was consistent with the UV- VIS absorption spectrum peak characteristics of chlorine dioxide, that was, the maximum absorption peak is near 360nm, so it was judged that the solution produced after the sample reacted with water and the absorption solution of the releasing gas containing chlorine dioxide. The Raman spectra of the samples sent for Raman spectroscopy scanning and that of chlorine dioxide on the market were compared and the results showed that the two substances had high similarity. According to the analysis of the above two qualitative test results, the components of "Suspected Chlorine Dioxide Disinfection Tablets" are similar to those of commercially available disinfection products which can release chlorine dioxide, and the sample will produce chlorine dioxide when it reacts with water.

(2) Article 2 was sent to Ingeer (ICAS) Testing Technology Service (Shanghai) Co., Ltd. for chemical composition analysis. The results showed that the available chlorine and chlorine dioxide in the sample accounted for 21.1% and 4.66% respectively. The components of the sample mainly included sodium dichloroisocyanurate (71-72%), sodium sulphate (20-21%) and magnesium sulphate (7-8%).

(3) Article 2 and Article 1 were sent to Tianjin Fire Evidence Identification Center of Fire and Rescue Department of Ministry of Emergency Management for spontaneous combustion risk analysis, and compared with 6 kinds of commercial effervescent tablets purchased in the market.

In the exothermic analysis test under constant temperature, the self-heating power (about 100,000μW) of Article 1 under moisture absorption was extremely large, which was far greater than that of commercial effervescent tablets of different brands in the market, and the risk of thermal spontaneous combustion was extremely high. Under the condition of unfavorable heat dissipation, the object itself can be rapidly heated up in a short time to reach the spontaneous combustion temperature, and the spontaneous combustion temperature of the article is

relatively low, which is about 150℃, that is, it is possible to spontaneously combust when it reaches this temperature.

In the analysis and test of thermal instability, there was obvious exothermic reaction in the process of heating up, and the exothermic temperature was the spontaneous combustion temperature of the Article, which indicated that the spontaneous combustion temperature of the Article was low, and there was a fire danger at about 150℃.

In the combustion experiment, Article 2 was ignited with open flame, a small amount of white smoke came out, and the sample foamed continuously after removing the fire source, and no open flame was generated in the whole process; Article 1 was ignited with an open flame, with more white smoke coming out, the sample foamed, and an open flame was generated. After the fire source was removed, the fire continued burning.

In ion analysis test in aqueous solution, Chlorite ion, chloride ion and sulphate ion were detected in Article 1 and Article 2. There was sulphate ion indicated that Articles may contain sulphate or bisulphate, which had the characteristics of moisture absorption. It is possible to absorb the moisture in the air when the product is not tightly packed. The research results of "exothermic analysis under constant temperature" showed that the Article was able to spontaneously release heat under the condition of moisture absorption. Therefore, the existence of sulphate or bisulphate in the Article component increases the risk of exothermic spontaneous combustion of the substance.

Investigation team concluded that both the tablets packed in aluminum foil bag (Article 1) and the tablets packed in plastic bag (Article 2) conform to the characteristics of chlorine dioxide effervescent tablets. Because the two Articles may contain sulphate or bisulphate, it is possible to absorb moisture in the air under the condition of loose product packaging. Both Articles have a certain risk of spontaneous combustion when they are damp at normal temperature. Among them, the spontaneous combustion temperature of the tablets packed in aluminum foil bags (Article 1) is about 150℃, and the risk of spontaneous combustion is extremely high. In the

case of unfavorable heat dissipation, it is possible to accumulate heat in a short time to reach spontaneous combustion temperature, that is, it is possible to spontaneously combust at this temperature.

1.14.2 Verification of Goods Storage Conditions

On July 21, 2020, from 20:30 to 21:38, the goods were loaded on the pallet. There was a film at the bottom, which wrapped up the lower goods (the 3 layers from the bottom) and wrapped the winding film for 6 turns. After loading on the pallet, it was covered with a film, with a net over the film (the net was locked and fixed). There was one more film covered the net and wrapped with winding film for 3.5 turns. At 23:20 on July 21, 2020, the goods were transported from the warehouse of the cargo station to position ADR-103-2 of warehouse outer area of Shanghai Pudong International Airport Cargo Terminal Co., Ltd. (hereinafter referred to as "PACTL") and stored in the open air. At 10:48 on July 22, the goods were transported from the cargo terminal to the apron. At 13:59 on July 22, the goods were loaded in the aircraft main deck cargo compartment. According to the meteorological data, on July 22, the temperature in Pudong Airport was 27℃-34℃ (33℃ at 12:00), humidity 62%-98%.

On August 20, 2020, the investigation team simulated the process of the transport by using stack packaged in the same way as the goods mentioned above. The simulated stack was exposed to the sun. On the day of the simulation, the temperature at Pudong Airport was 26℃-34℃ (33℃ at 12:00), and the humidity was 59%-95%. At about 13:00, the temperature of the stack was measured, and the ambient temperature inside the stack reached 80℃. At the same time, the condensation was found in the plastic film.

It was possible that chlorine dioxide disinfection tablets of the goods were exposed to high temperature and humid environment. (Figure 43 and 44).

Figure 43 Stack internal temperature

Figure 44 Condensation in the plastic film

1.14.3 Tests of smoke detection controller in cargo compartment

The cargo compartment smoke detection controller of the aircraft (ET-ARH), P/N 905701-04, S/N 0351, was manufactured in August 2014, and had accumulated 26740.25 hours /4286 cycles after installation, which was an original part of the aircraft. On September 2, 2020, the investigation team sent the component to its manufacturer (Meggitt Safety Systems) for decoding. On October 9, 2020, the manufacturer submitted the third version of the Test Report (ER 15081, Version C).

According to the Test Report: the external nameplate and antistatic label of the smoke controller showed signs of sooted, with discoloration and blackening. the handle of the smoke controller showed signs of discoloration and thermal corrosion. The rear plug was not damaged. Some components of the smoke controller were damaged due to fire, and the function test failed. See the following table for the readout data from NVM related to the event (UTC time):

Table 4 NVM Fault Record Table

(This table was taken from the Meggitt Technical Report)

Block #	Time	Failure (LRU fault ID)	Detector	Channel	Zone
15	7:17:24	Right Main Deck Detector Failure (262)	43	CH-A	8
14	7:17:24	Right Main Deck Detector Failure (262)	43	CH-B	8
13	7:18:01	Right Main Deck Detector Failure (254)	35	CH-A	6
12	7:34:35	Right Main Deck Detector Overheat Failure (570)	41	CH-B	7
11	7:34:45	Right Main Deck Detector Overheat Failure (570)	41	CH-A	7
10	7:34:51	Right Main Deck Detector Overheat Failure (568)	39	CH-B	7
9	7:34:55	Right Main Deck Detector Overheat Failure (568)	39	CH-A	7
8	7:34:58	Right Main Deck Detector Failure (260)	41	CH-B	7
7	7:35:08	Left Main Deck Detector Overheat Failure (571)	42	CH-A	8
6	7:35:09	Left Main Deck Detector Overheat Failure (574)	45	CH-A	8
5	7:35:11	Right Main Deck Detector Overheat Failure (572)	43	CH-A	8
4	7:35:11	Right Main Deck Detector Failure (260)	41	CH-A	7
3	7:35:12	Right Main Deck Detector Failure (258)	39	CH-A	7
2	7:35:12	Right Main Deck Detector Failure (258)	39	CH-B	7
1	7:35:15	Right Main Deck Detector Overheat Failure (572)	43	CH-B	8

The above fault records show that the detectors located in the rear zones 6, 7 and 8 of the aircraft (stations STA1778.5 to STA2122) (Figure 45) failed first, and a detector overheat failure is triggered when the smoke detector recognizes a temperature either significantly less than -50 ℃ or greater than about +225℃. There were 15 detector failure records, of which 13 were from the right side, accounting for 87%. All failed detectors were located at the right side of the rear main deck cargo compartment. In addition, since NVM only recorded the failure of smoke detector function, and did not record the information of smoke warning, therefore, the first time when the fault information occurred was 15:17:24, which was later than the time of 15:14:04 when the crew reported fire warning.

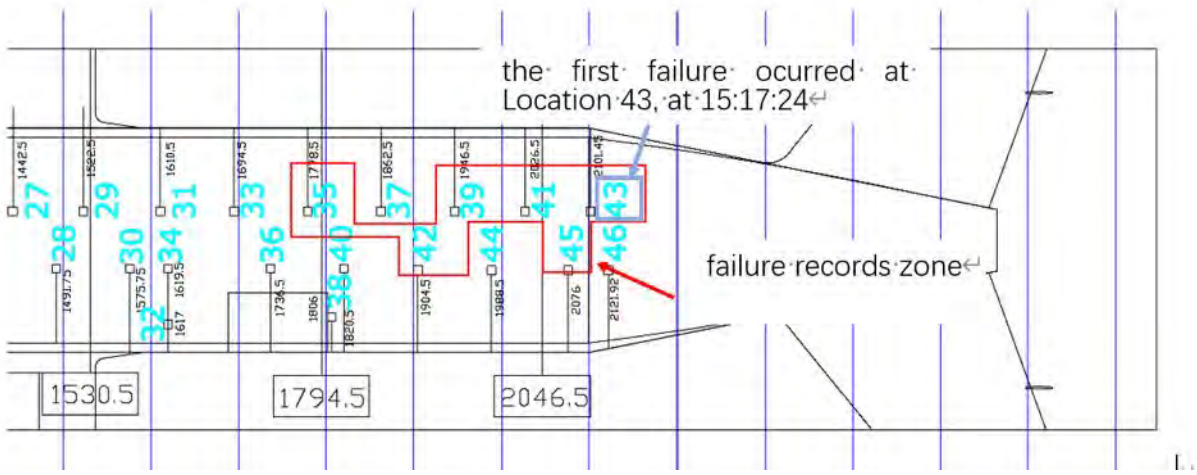


Figure 45 Locations of Failed Smoke Detectors

1.14.4 Test of APU Feeder

The investigation team sent 7 wires (Table 5) from different fused parts of APU feeder (see Figure 46) to Tianjin Fire Material Evidence Identification Center of Fire Bureau of Ministry of Emergency Management for testing. In accordance with GB/T 16840.1-2008 (Technical Determination Method for Electrical Fire Evidence Part 1: Macroscopic Method), GB/T 16840.4-1997 (Technical Determination Methods for Electrical Fire Cause Part 4: Metallographic Method), GB/T 19267.6-2008 (Physical and Chemical Examination of Trace Evidence on Forensic Sciences Part 6: Scanning Electron Microscope/X Ray Energy Dispersive Spectrometry), the laboratory conducted the appraisal and analysis of the wires received for testing. All 7 wires were aluminum wires identified by macroscopic inspection, and the melted marks were extracted. The microstructure characteristics of the melted marks were analyzed through metallographic method. Surfaces between the melted marks, melted beads and the wires had no transition zone characteristic, and the microstructure of the melted marks is all equiaxed grain. Then the laboratory submitted the Material Evidences Analysis and Identification Report on Accident of Ethiopian Airlines B777F Aircraft (Appendix 6). The conclusion of the test was that, all the melted marks on 7 wires were the melted marks due to fire burning.

Figure 46 APU Feeder

Table 5 Extraction Parts

Material	Extraction Part	Label Color	Photo
Material 1	STA1979	yellow	 
Material 2	STA1979	green	

			
Material 3	STA1979	Red	 
Material 4	STA2150	Blue	 
Material 5	STA2150	Black	 

Material 6	STA1434	Yellow-black	 
Material 7	STA1434	Blue-green mark	 

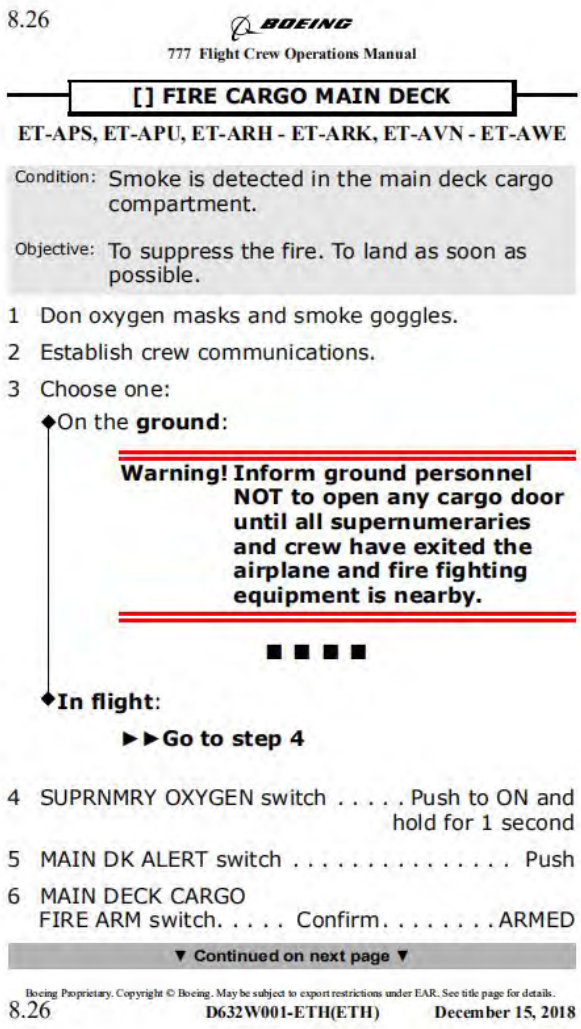
1.15 Organizational and Management Information

1.15.1 Manuals and Procedures of Ethiopian Airlines

1.15.1.1 Procedure of fire warning in Main Deck Cargo Compartment

Fire Cargo Main Deck section of Boeing 777 Flight Crew Operation Manual (FCOM) states: *Don oxygen mask and smoke goggles; Establish crew communications;* If the aircraft is on the ground, the FCOM states: *inform ground personnel NOT to open any cargo door until all supernumeraries and crew have exited the airplane and firefighting equipment is nearby.* (Figure 47).

(Note: The contents of the above manual are directly quoted from the quick reference handbook of Ethiopian Airlines)



8.26

BOEING

777 Flight Crew Operations Manual

[ ] FIRE CARGO MAIN DECK

ET-APS, ET-APU, ET-ARH - ET-ARK, ET-AVN - ET-AWE

Condition: Smoke is detected in the main deck cargo compartment.

Objective: To suppress the fire. To land as soon as possible.

1 Don oxygen masks and smoke goggles.

2 Establish crew communications.

3 Choose one:

◆On the **ground**:

Warning! Inform ground personnel NOT to open any cargo door until all supernumeraries and crew have exited the airplane and fire fighting equipment is nearby.

■ ■ ■ ■

◆**In flight**:

►►**Go to step 4**

4 SUPRNMRY OXYGEN switch . . . . . Push to ON and hold for 1 second

5 MAIN DK ALERT switch . . . . . Push

6 MAIN DECK CARGO FIRE ARM switch. . . . . Confirm. . . . . ARMED

▼ Continued on next page ▼

Figure 47 FCOM --- FIRE CARGO MAIN DECK

1.15.1.2 Emergency Radio Communications

Ethiopian Airlines Flight Operation Manual, 7.3.1 *International Distress Signal "MAYDAY*" in Section 3.8 *Emergency Radio Communications* states:

a) A distress message concerns an aircraft in grave and imminent danger and in need of immediate assistance. It has the highest priority. The distress message content should include as much of the following as time permits or is appropriate:

I. "MAYDAY, MAYDAY, MAYDAY."

II. Radio call sign (repeated three times)

III. Nature of the emergency

IV. Intentions

V. Position or estimated position (stating which).

b) A distress call may not be immediately acknowledged transmission should be made initially on the primary frequency. If the distress call is not acknowledged within 15 seconds, it should be repeated on the secondary frequency. If there is still no response, the message should be repeated alternatively on the primary and secondary frequency until it is acknowledged.

c) After establishing communications with any station, all transmissions should be directed to that station until the primary guard is assumed by another station.

d) When an emergency occurs, the pilot who cannot otherwise establish communications without delay may alert a ground radar facility to the emergency by setting the transponder to Mode A, Code 7700 (distress). Thereafter, radio communications should be established with ATC as soon as possible.

1.15.1.3 FCOM – Emergency

Ethiopian Airlines Flight Operation Manual, 7.6.3 in Section 3.1 Crew Duties and Responsibilities in – Emergency " states: *When an emergency occurs, the following items must be considered, in sequence:*

a) FLIGHT MANAGEMENT

One pilot must fly the aircraft. Usually, this is the pilot flying at the time, but the Captain may elect either to fly the aircraft himself or to have the other pilot fly it. Assuming control of the aircraft does not relieve the captain of the responsibility for directing crew action.

b) IDENTIFYING THE EMERGENCY

The crewmember who first recognizes the emergency should announce it in a firm, clear voice,

for example, "Engine Failure," or "Wheel Well Fire." If the fire bell is ringing, it should be silenced promptly without command. The Captain should confirm the condition and then direct the required crew action.

c) EMERGENCY EVACUATION ASSIGNMENTS

The duties specified in the evacuation assignments are to be accomplished when ordered by the Captain. Each crewmember must be able to accomplish from memory the duties specified in the evacuation assignments for his or her stations and also be familiar with the assignments of other crewmembers.

d) CHECKLIST MEMORY ITEMS

When a non-normal situation is evident, at the discretion of the Captain/ Pilot flying, both crewmembers systematically and without delay accomplish all recall items in their area of responsibility. When executing abnormal/emergency procedures specified in the type specific FCOM, flight crew should verbally confirm (dual response) before the execution of any critical aircraft system controls. Such procedures should at a minimum address:

I. engine thrust levers;

II. fuel master or control switches;

III. engine fire handles or switches

IV. engine or APU fire extinguisher switches or cargo fire arm switch;

V. IDG/CSD disconnect switch;

VI. Auto throttle arm switch.

1.15.1.4 Fire or Smoke

Ethiopian Airlines Flight Operation Manual, 7.2 *Cabin Fire or Smoke* in Section 3.7*Fire and Smoke* states: *Any fire inside the fuselage is to be considered as emergency and treated as such until it is certain that it has been extinguished. The Captain is to be notified of any such fire, regardless of its origin. The most common of these fires are electrical and grease fires in the*

galley and fires resulting from careless use of cigarettes and matches. In the event of fire or smoke in the cabin, appropriate procedure stated in the Aircraft Operation Manual should be followed.

1.15.1.5 On Ground Emergency

It is described in 3.10 "On Ground Emergency" of Ethiopian Airlines B777/787 Standard Operating Procedure:

- During on Ground Emergency, stop the Aircraft immediately, notify ATC & Cabin Crew then perform the required NON-NORMAL CHECKLIST. If evacuation is required follow evacuation procedure.

- For engine fire use opposite side doors for evacuation.

- For APU fire use all doors for evacuation

- For Cargo Smoke consider remote parking stand and deplane the passengers as quickly as possible using all available stairs.

1.15.1.6 Normal Deplane and Evacuation

(1) Procedure and Checklist of normal deplane for crew

Procedure of normal deplane:

Ethiopian	ETHIOPIAN AIRLINES ENTERPRISE FLIGHT OPERATIONS	REV. No. 5 01-JAN-2020
	B777/787 STANDARD OPERATING PROCEDURES	

2.23. PARKING, SHUTDOWN AND SECURE

NOTE: Approaching the parking position check for APU running and Brake Pressure normal (B777). Check for the EXT PWR AVAIL light and transfer power or use APU as required.

CAPTAIN	FIRST OFFICER
PARKING BRAKE SET	ELECTRICAL POWER SET
FUEL CONTROL switches OFF FLIGHT DIRECTOR switch OFF EFB CLOSE FLIGHT SELECT	SEATBELT sign OFF HYDRAULIC panel SET FUEL PUMP switches OFF BEACON light switch OFF FLIGHT DIRECTOR switch OFF TRANSPONDER MODE selector STANDBY and SET 2000 EFB CLOSE FLIGHT SELECT STATUS MESSAGES CHECK *
Communicate with ground crew and ensure that chocks are in position before releasing parking brakes.	
PARKING BRAKE RELEASE	APU selector as needed
Call "SHUTDOWN" Checklist.	Read "SHUTDOWN" Checklist.
Pass Landing and Block-in time to company radio. Take the time from ACARS.	

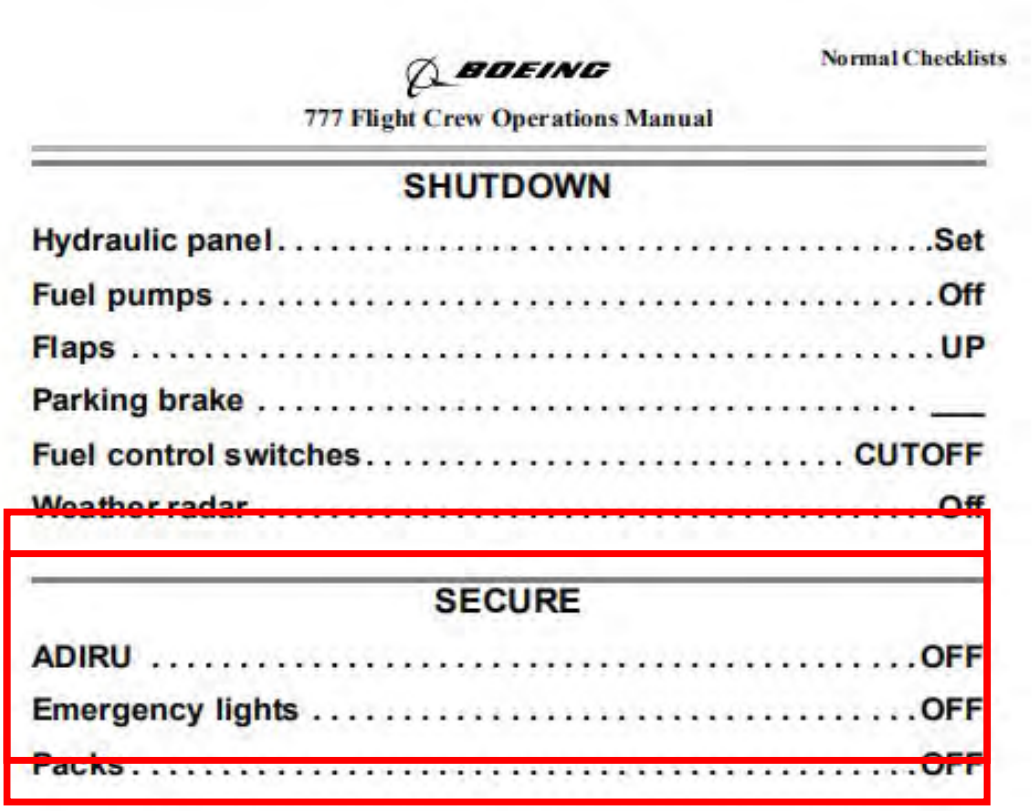
*Disregard EICAS alert and status messages displayed during the PFC self-test after hydraulic shutdown. Wait approximately 3 minutes after HYD PRESS SYS L+C+R message is shown before recording status and alert messages in the maintenance log.

On the LAST LEG of the flight

CAPTAIN	FIRST OFFICER
CALL " SECURE CHECKLIST"	ADRU/IRS selectors OFF BATTERY switch OFF FLIGHT DECK DOOR POWER switch OFF EMERGENCY LIGHTS switch OFF PACK switches OFF
EFB Power switch OFF HUD Combiner STOW (B787)	
Dim all instrument, panel and display lights using Master Brightness Switch.	
Call SECURE CHECKLIST	Read SECURE checklist
Check and Sign the aircraft Log Book and CFP.	Complete the aircraft Log Book and CFP.
OPEN the FLIGHT DECK DOOR	

SOP Page 70

Checklist of normal deplane: (in the red box)



BOEING

Normal Checklists

777 Flight Crew Operations Manual

SHUTDOWN

Hydraulic panel.....Set

Fuel pumps.....Off

Flaps.....UP

Parking brake.....___

Fuel control switches.....CUTOFF

Weather radar.....Off

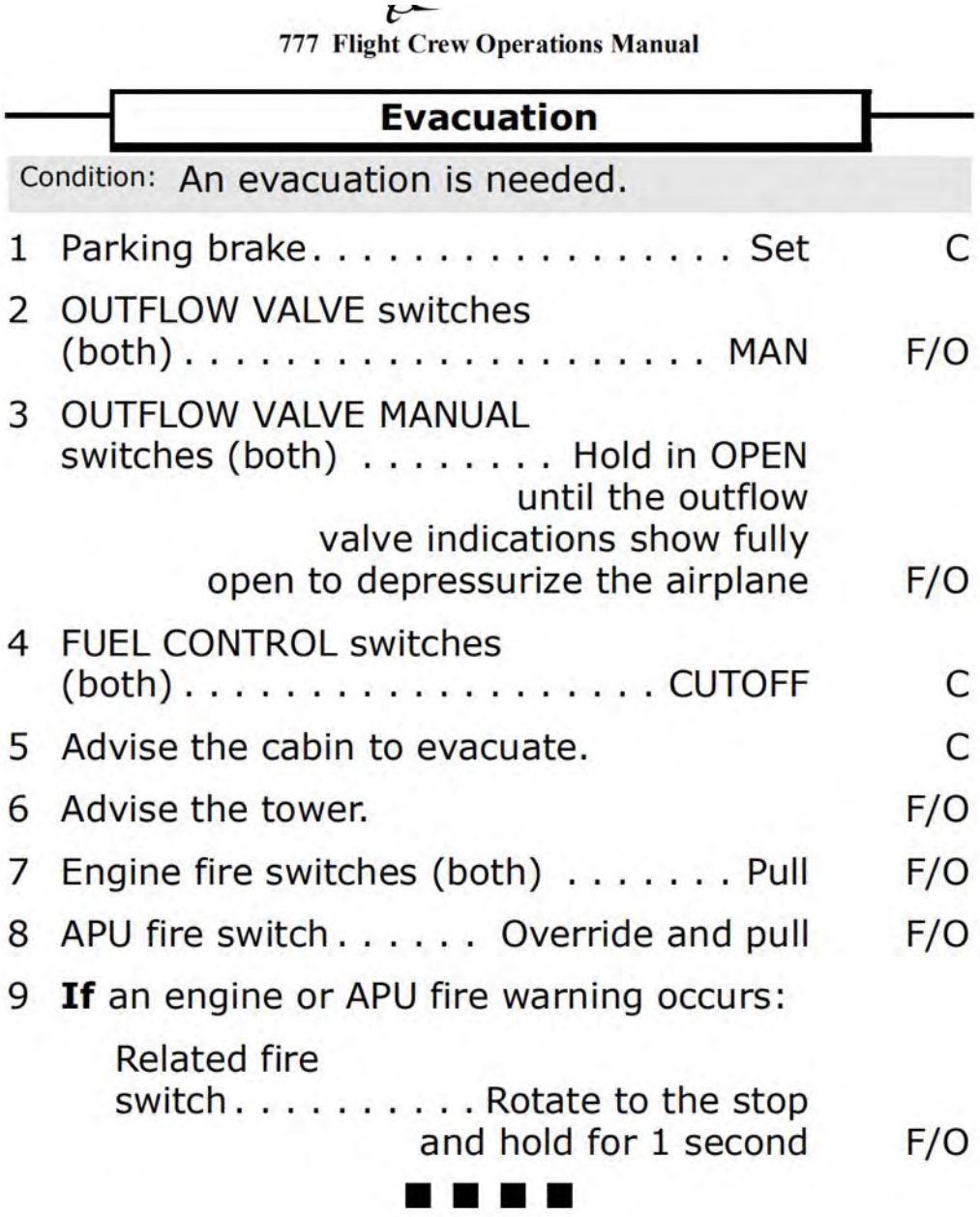
SECURE

ADIRU.....OFF

Emergency lights.....OFF

Packs.....OFF

(2) Procedures of emergency evacuation



777 Flight Crew Operations Manual

Evacuation

Condition: An evacuation is needed.

1	Parking brake . . . . . Set	C
2	OUTFLOW VALVE switches (both) . . . . . MAN	F/O
3	OUTFLOW VALVE MANUAL switches (both) . . . . . Hold in OPEN until the outflow valve indications show fully open to depressurize the airplane	F/O
4	FUEL CONTROL switches (both) . . . . . CUTOFF	C
5	Advise the cabin to evacuate.	C
6	Advise the tower.	F/O
7	Engine fire switches (both) . . . . . Pull	F/O
8	APU fire switch . . . . . Override and pull	F/O
9	**If** an engine or APU fire warning occurs:	
	Related fire switch . . . . . Rotate to the stop and hold for 1 second	F/O

■ ■ ■ ■

The procedure of normal deplane requires ADIRU selectors OFF, emergency lights off, PACK off.

The checklist of emergency evacuation requires APU OFF before the emergency evacuation.

1.15.2 Agreement between the Airport and Ethiopian Airlines

The agreement between Ethiopian Airlines and Pudong Airport was signed in 2014, in which

Section 14.4 described the relevant responsibilities in case of emergencies.

Article 14.4.1 clarifies the emergencies event including:

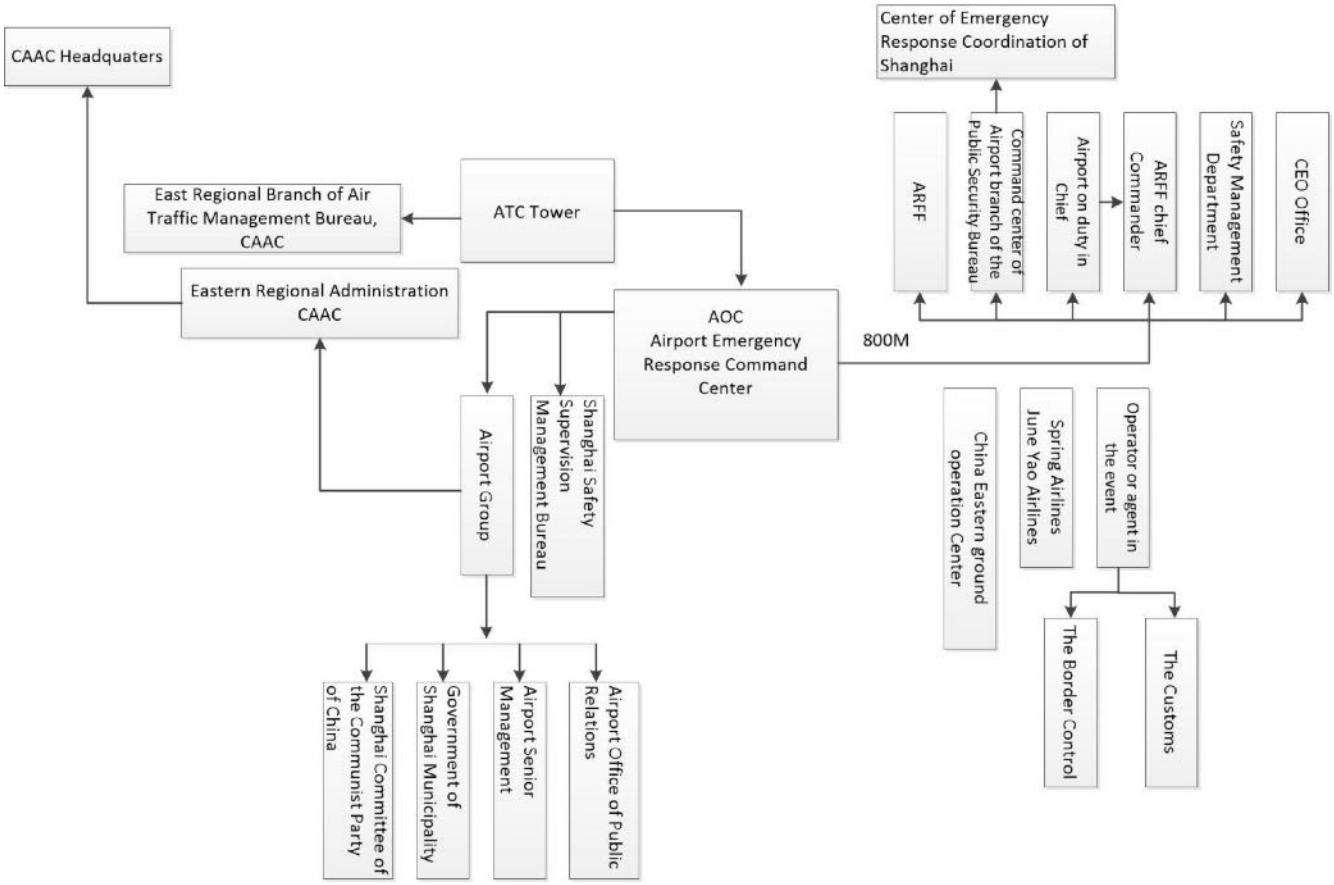
- Aircraft accident;
- Aircraft in-flight malfunction;
- Aircraft is under unlawful interference, including hijacking and explosive threat;
- Air collision;
- Other emergencies involving aircraft.

In Article 14.4.3, an agreement being reached of respective responsibilities in case of emergency, that is, "the emergency response shall be in line with the relevant provisions of the Pudong Airport Manual."

1.15.3 The Organization of the Pudong Airport Emergency Response

The Pudong Airport established the Airport Emergency Response Command Center, located at the Airport Operation Center (AOC), responsible for general organization and coordination of emergency response, organizing the development and rectification of the Airport Emergency Plan.

Airport Emergency Plan *of Pudong Airport* stipulated the information flow chart in emergency response, as the follows:



1.15.4 The Requirement on Emergency Response in the Pudong Airport Manual in Case of Fire

a) In case of an emergency involving an aircraft or non-aircraft, under the coordination of the Airport Emergency Rescue Team and Emergency Response Command Center (AOC), all airport departments and units shall handle it according to Pudong Airport Emergency Plan.;

b) In case of an emergency involving equipment and facility failure, the management department of the jurisdiction shall be responsible for organizing, and notifying the airport AOC based on the severity of the event.

c) In case of a minor fire event, the ARFF shall dispatch vehicles and personnel according to the location of the emergency without affecting the airport operation.

1.15.5 ARFF Emergency Plan

The requirements on the activation and methods of emergency response in Emergency Plan:

(1) The first-level response: aircraft accident, explosion, fire, substantial damage, etc.; The Red-level of social emergency; Class I and II public health events; emergency could be upgraded to first-level response; other matters decided by the ARFF.

Response mode: the ARFF chief commander or designated person shall be on site to coordinate and command. Upon receiving the instruction, all stations scramble to the scene and carry out the rescue and firefighting tasks.

(2) The secondary-level response: aircraft in-flight emergency such as aircraft malfunction, could be resulting in aircraft accident, explosion, fire, substantial damage; or aircraft is encountering unlawful interference; Orange-level of social emergency; Class III public health event; emergency could be upgraded to secondary-level response; other matters decided by the ARFF.

Response mode: the ARFF chief duty officer or firefighting/medical commander shall be on site to coordinate and command; the firefighting and rescue team, field communication team, triage team and medical team assemble at the predetermined standby area as quickly as possible, other relevant rescue teams shall be fully ready for launching at any time.

(3) The third-level response: aircraft in-flight emergency such as aircraft malfunction, could only be resulting in any difficulty in effecting a safe landing; Yellow-level of social emergency; Class IV public health events; other emergency dispatches and other matters decided by the ARFF.

Response mode: The firefighting/medical department on duty personnel shall be on site to coordinate and command, firefighting team and medical team shall be standby.

1.15.6 Management for Emergency Rescue in Civil Transport Airport

Chapter II "*Emergency Classification and Emergency Rescue Response Level*" of *Management for Emergency Rescue in Civil Transport Airports* (CCAR-139-II-R1) stipulates:

Article7 Airport Emergency includes aircraft emergency and non-aircraft emergency.
Aircraft emergencies include:
(1) Aircraft accident;
(2) Aircraft encountering in-flight distress, such as in-flight failure, encountering dangerous weather, and dangerous goods leaking, etc;
(3) Aircraft under unlawful interference, such as hijacking and explosive threat;
(4) Aircraft collided with another aircraft or with obstacle, resulting in casualty or fuel leakage;
(5) Runway safety events, such as short landing, runway excursion, veering off runway, etc.;
(6) Aircraft fire;
(7) Other emergency involving aircraft.

Article 8 Aircraft emergency response level
(1) Local Standby: in the case of an in-flight emergency, that could only result in the difficulty of safe landing, all rescue units shall be full ready for scramble.
(2) Assembly Standby: in the case of in-flight emergency, could be resulting crash, explosion, fire, substantial damage, or encountering unlawful interference, all rescue units shall be instructed to be standing by at assigned position.
(3) Scramble: in the case of aircraft accident, explosion, fire or substantial damage, etc. on or in the vicinity of the airport, all rescue units shall be immediately instructed to the accident scene as quickly as possible.

Article 12 The airport authority shall set up an airport emergency response command and management department --- Airport Emergency Response Command Center (hereinafter referred to as the Command Center), as a permanent office of the Airport Emergency Response Leading Group, as well as a management department of airport emergency response and

command department in case of emergency. The Command Center specific responsibilities include:

(a) to organize, summarize, revise and manage airport emergency plan.

(b) to regularly check the relevant departments and units of emergency plan, personnel training, drills, material reserves, equipment maintenance and other work to ensure the implementation of the emergency plan. Regularly revise the list of chief, contact details and telephone numbers of relevant departments and units in the emergency plan;

(c) in line with requirements of this regulation, formulate the annual drill plan and perform the implementation;

(d) in case of emergency, according to the instructions of the chief commander, as well as the requirements of the emergency plan, issue emergency response instructions and perform the implementation;

(e) to organize or participate the disable aircraft removal according to the agreement;

(f) to summarize the airport emergency response management work periodically or aperiodically, and report to the Airport Emergency Response Leading Group.

1.15.7 Regulation on the Transport of Dangerous Goods by Air

Article 75 of *Regulation on the Transport of Dangerous Goods by Air* (CCAR-276-R1) stipulates:

The operator, entrusting cargo sales agent and ground handling agent to engage in the relevant job on the cargo transport by air, shall request in the agency agreement the agent to make examination of the cargo accepted or take effective measures to prevent dangerous goods from being hidden or concealed in the cargo. The operator shall authorize the cargo examination and relevant measures taken by the agent as well as conduct inspection at regular intervals.

1.16 Cargo Loading and Transport

1.16.1 Cargo at PR position

The pallet number of goods loaded at PR position is PMC3324ET. There were 6 air waybills loaded on this pallet. The information of air waybills is as follows:

Master Airwaybill No.	Description of Goods
071-37694436	Rapid diagnostic test paper, Rapid test buffer, Novel coronavirus (2019-nCoV) IgM/IgG Antibody test kit
071-37695173	Hisense POS products (including lithium battery)
071-37696046	Chlorine dioxide air disinfection machine, sealing machine, nano slow-release disinfection material (containing 1% chlorine dioxide adsorbed on nano material), packaging bag
071-37698430	Non-medical, brand free MZ-02 mask
071-37698640	scented tea
071-37702910	Game controller, live broadcast lamp

1.16.2 Goods of Air waybill No. 071-37696046

According to the transportation documents, the goods with the air waybill number of 071-37696046 were loaded at PR position, with the declared names "packaging bags, sealing machines, disinfection machine and nano slow-release disinfection material (containing 1% chlorine dioxide adsorbed on nano material)". The goods were delivered with a Certification for safe Transport of Chemical Goods (NO.2020072245) (Appendix 7) issued by SRICI. The name of the Article sent for inspection was "nano slow-release clean material (including 1% chlorine dioxide adsorbed on nano material)", and the conclusion was "unrestricted goods". The consignor was Jietong Overseas Trading Co., Ltd. (hereinafter referred to as "Jietong Overseas"), which is an offshore company registered in Hong Kong, China by Zhejiang Jietong International Freight Forwarding Co., Ltd. (hereinafter referred to as "Zhejiang Jietong").

1.16.3 Transport of Goods of Air Waybill No. 071-37696046

The goods with the air waybill No. 071-37696046 were related to the following entities:
the manufacturers, include Guangdong Crownfortune Equipment Co., Ltd. (hereinafter referred

to as " Crownfortune ") and School of Public Health of Sun Yat-sen University and Shandong Zhaoguan Pharmaceutical Co., Ltd. (hereinafter referred to as "Shandong Zhaoguan").

The owners are 3 brothers, named as Brother A, Brother B, and Brother C respectively in this report.

The selling agents, consignors and their agents, include Jietong Overseas, Zhejiang Jietong, Ningbo Yuanhai International Logistics Co., Ltd. (hereinafter referred to as "Ningbo Yuanhai"), Guangzhou Ouhua International Freight Forwarders Co., Ltd. Ningbo Branch (hereinafter referred to as "Guangzhou Ouhua"), Zhejiang Jinyao International Freight Forwarders Co., Ltd. (hereinafter referred to as "Zhejiang Jinyao"), Shanghai Taichang Freight Forwarders Co., Ltd. (hereinafter referred to as "Shanghai Taichang"), Shanghai Fancheng International Freight Forwarders Co., Ltd. (hereinafter referred to as "Shanghai Fancheng").

The certificate institution was SRICI.

The ground service agents were PACTL and Shanghai International Airport Ground Service Co., Ltd. (hereinafter referred to as SIAS).

Refer to Figure 48 for the transport flow of the goods with the above air waybill.

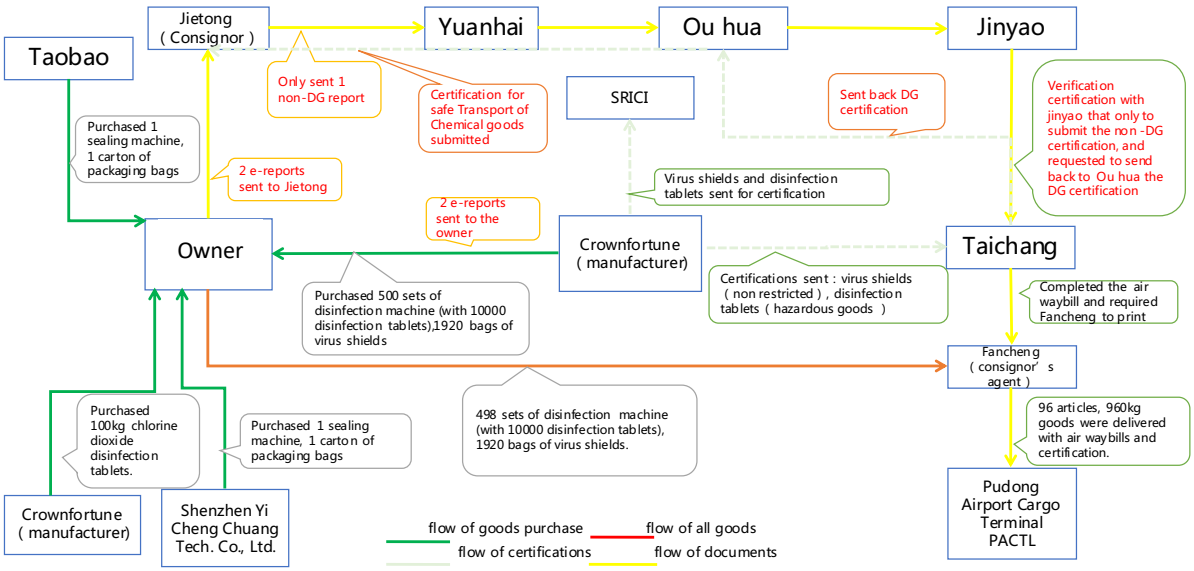


Figure 48 Flow Chart of Goods on the Air Waybill No.071-37696046

1.16.3.1 the Owners and the Purchase of Goods

The Owners of this air waybill are 3 brothers. Brother A is a permanent resident of Chile. On June 22, 2020, Brother B signed a purchase contract (hereinafter referred to as "the contract") with the Crownfortune for chlorine dioxide disinfection machine and virus shield (i.e., nano slow-release disinfection material (containing 1% chlorine dioxide adsorbed on nano material), hereinafter referred to as virus shield). Brother C was entrusted to pay a total of RMB 317,240 in four installments on June 23, and agreed that the goods should be sent to the consignee, Brother A, by express delivery. According to the contract, the owner, Brother A, purchased 500 sets disinfection machines (with chlorine dioxide disinfection tablets, 20 packages/set) and 1920 pieces of virus shields. On June 29, the Crownfortune delivered the goods through Deppon Express. The goods were disinfection machines and virus shields. There were 84 cartons of disinfection machines, of which 83 cartons were 6 sets per carton, and 1 carton containing 2 sets. There were 5 cartons of virus shields, of which 1 carton was virus shield packaging bag and 4 cartons were virus shields. The recipient's address is No.7 Wenbao 2nd Road, Shuige

Industrial Zone, Lishui City, Zhejiang Province, with a total of 89 pieces, 930 kg, and the express tracking number is 601982153.

On July 1, the Crownfortune delivered the goods by Sto Express. The goods were disinfectant powder (i.e., nano slow-release disinfection material (powder particles), hereinafter referred to as disinfectant powder), with a total of 10000 small packets in 1000 bags, 20g per packet. The package was the packing box of disinfection machine, 2 cartons in total. The purchaser, Brother C, bought packaging bags and sealing machines (2 boxes in total) on Taobao after receiving the goods.

In June, Brother A contacted Shandong Zhaoguan by telephone and WeChat, and purchased 100 kg (1 kg/bag, 100 bags in total) of chlorine dioxide disinfection tablets. The name displayed on package was "Zhaoguan Brand Chlorine Dioxide Disinfectant". The total payment was RMB 26,000 and was paid through Brother C. The Zhaoguan delivered the goods to No.7 Wenbao 2nd Road, Shuige Industrial Zone, Lishui City, Zhejiang Province through Tonghui Cargo Consignment Department of Linyi City in Shandong Province. In addition, Brother A purchased a chlorine dioxide test machine via WeChat and sent it to the above address.

1.16.3.2 the Actual goods and packaging

There are 96 pieces of goods with air waybill No.071-37696046, including 83 cartons of 498 sets disinfection machines and 1 chlorine dioxide detector, 7 cartons of mixed packaging of 10000 packets of disinfectant powder and 100 bags of chlorine dioxide disinfection tablets, 4 cartons of virus shields, 1 carton of packaging bags and 1 carton of sealing machine.

According to Brother A’s friend, who was in Chile at the time of the investigation), he worked in Brother C's enterprise (Zhejiang Lishui Youfu Knitting Co., Ltd., hereinafter referred to as "Youfu") in July when he, in accordance with the requirement of Brother A, repackaged 1000 bags of disinfectant powder (10000 packets) and 100 bags of chlorine dioxide disinfection

tablets into 7 cartons (the carton used for repackage was not standard carton but modified from clothing packing carton), and packed 1 chlorine dioxide detector in one of the disinfection machine carton. After that, via Huolala, a courier service provider, Brother C delivered 96 cartons of all the goods to Shanghai Fancheng Warehouse (No.1016, Shiwan 7 Road, Pudong New Area, Shanghai) to send to Brother A in Chile.

1.16.3.3 Delivery of Goods

In order to transport the above goods to Chile, Brother C entrusted Zhejiang Jietong to handle customs declaration and air transportation. Zhejiang Jietong entrusted Ningbo Yuanhai, Ningbo Yuanhai entrusted Guangzhou Ouhua, Guangzhou Ouhua entrusted Zhejiang Jinyao, and Zhejiang Jinyao entrusted Shanghai Taichang to make the booking and deliver the goods. After Shanghai Taichang completed the booking, it entrusted Shanghai Fancheng to handle the relevant consignment matters. Shanghai Fancheng delivered the goods to PACTL, where the examination of the goods transportation documents was completed. The goods entered the warehouse of PACTL after security inspection. Shanghai Fancheng completed the packing board assembly of goods in the warehouse agent assembly area of PACTL. After checking and weighing, the airport ground service accepted and transported the goods to the apron and loaded to the aircraft.

1.16.3.4 Certification of Goods

As the goods contain chemicals, Zhejiang Jietong informed Brother C that a certification was required. Brother C asked Crownfortune for the certification. On July 6, 2020, Crownfortune entrusted the certification to SRICI and sent two samples: one sample (Figure 49) named "nano slow-release disinfection material (containing 1% chlorine dioxide adsorbed on nano material)", the manufacturer was "School of Public Health, Sun Yat-sen University, Guangdong Province"; the other sample (Figure 50) named "nano slow-release disinfection material (powder

particles)", and the manufacturer was " School of Public Health, Sun Yat-sen University, Guangdong Province ". SRICI issued two certifications for the above two samples. "Certification for Safe Transport of Chemical Goods (No.2020072245)" (Appendix 7) recognized that the nano slow-release disinfection material (containing 1% chlorine dioxide adsorbed on the nano material) was "unrestricted goods". Certification for Safe Transport of Chemical Goods (No.2020072246)" (Appendix 8) recognized that the nano slow-release disinfection material (powder particles) was "dangerous goods", and the hazards identification was: "oxidizer (main), corrosive (sub)".

Figure 49 Virus shield

Figure 50 Disinfectant powder

1.16.3.5 Declaration of Goods

In the process of consignment, the goods name provided by the owner to the operator of Zhejiang Jietong who in charge of booking and information transmission (hereinafter referred

to as "Jietong Operator") is "Intelligent Sprayer, Chlorine Dioxide Virus Shield, Chlorine Dioxide Disinfectant, Packaging Bag and Sealing Machine". Jietong Operator knew that there were two certifications corresponding to the chemical products contained in the consignment, and the certification conclusions were "unrestricted goods" and "dangerous goods". After communicating with the employee of Brother C's factory, Jietong Operator decided to use the Sample name stated in the Certification for Safe Transport of Chemical Goods with the certification conclusion of "unrestricted goods" to carry out the follow-up entrusted business, only declaring the goods name as "Nano slow-release disinfection material (including 1% chlorine dioxide adsorbed on nano-material)", concealed the virus shield, disinfection powder and chlorine dioxide disinfection tablets, etc. which actually delivered.

1.16.3.6 Acceptance of Goods

Shanghai Fancheng completed the delivery of goods of air waybill No.071-37696046 at the airport cargo terminal on behalf of the consignor. The goods receiving staff of PACTL, in accordance with the Operation Manual of the department, examined the goods via Tianyuntong System, an internal air transport management system. The goods receiving staff, via Tianyuntong System, conducted preliminary check, including checking the name of goods, requirement of air carriers, number of pieces, weights and destination airports and so on. The goods of this air waybill were declared as common cargo with Certification for Safe Transport of Chemical Goods with the conclusion of "unrestricted goods". No abnormality was found during the pre-check process. The goods entered the site for security inspection after the pre-check completed. The goods were put into storage after security inspection. The staff of Shanghai Fancheng completed the board assembly on site. Then, the goods were weighed and checked by PACTL and finalized the acceptance.

According to the Operation Manual, for the acceptance of declared hazardous goods, the receiving staff is required to carry out on-site inspection and complete the Inspection Form for Acceptance and Transport of Dangerous Goods; For lithium battery goods such as electric

vehicles and scooters, the receiving staff shall perform unpacking inspection.

In accordance with Regulation on the Transport of Dangerous Goods by Air (CCAR-276), the PACTL has established a specification to prevent hidden or concealed dangerous goods. Chapter 8 “International Outbound Air waybill Operation” of the Operation Manual of the department states “Hidden or concealing the name of dangerous goods, shall be judged according to the relevant description in the chapter of hidden dangerous goods in the latest edition of Technical Instructions for the Safe Transport of Dangerous Goods by Air (ICAO Doc 9824), or requiring the owner or agent to demonstrate a non-dangerous statement to prove that there is no suspected hidden dangerous goods attached. If it is verified as non-dangerous, it is required to indicate' Not restricted' in the name column of the air waybill. For goods suspected to be hazardous goods, an authoritative hazardous certification is required.".

1.16.4 Security Inspection of Goods No.071-37696046

The security inspection on goods of air waybill No.071-37696046 was conducted via The X-ray machine, model CMEX-160190, S/N 111004013. The latest periodic check of the machine was occurred on May 9, 2020, valid to November 8, 2020. According to the test report of periodic check, the machine met all standards required.

At 20:27:30 on July 20, the X-ray machine operator reviewed the Declaration Form of Air Cargo Security Inspection and the Certification for Safe Transport of Chemical Goods.

At 20:34:10, the goods declared as nano slow-release disinfection material entered the security inspection channel.

At 20:34:21, the goods declared as nano slow-release disinfection material entered the X-ray machine for inspection.

At 20: 34: 52, the X-ray machine generated the goods image on the screen (Figure 51). The operator stopped the machine and used the operation function key (highlight key) to check the

images (Figure 52). The operator discovered particles of suspected chemical products. the operator instructed the unpacking operator to check the transport documents of chemical products.

Figure 51 Cargo X-ray Machine Image

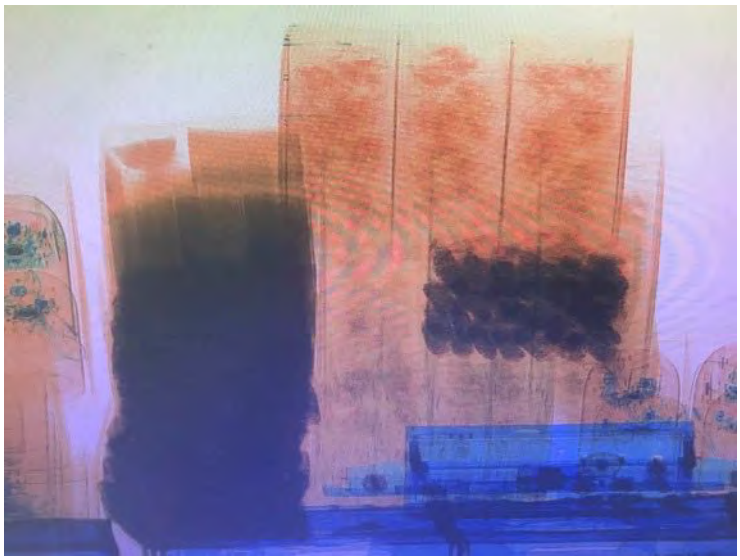


Figure 52 Highlighted Cargo Image

At 20:36:45, the pallet was shoveled away from the X-ray machine after the inspection.

At 20:41:00, the unpacking operator verified the shipping mark on the outer packaging of the goods[11] against the transport documents. The unpacking operator confirmed that the name of the goods conformed with the transportation documents, took photos and loaded them to Tianyuntong System.

After the verification of the shipping marks, images and transportation documents, the X-ray machine operator released the goods.

At 21:08:19, the whole batch of goods passed the security inspection after double checked

[11] Shipping mark: air cargo transportation mark.

transport documents. (This batch of goods were large in amount and was released after all inspections completed).

1.16.5 Storage of Goods of Air Waybill No.071-37696046 at PACTL

The goods of Air Waybill No.071-37696046 were loaded and transported to PACTL on July 20, 2020, and then stored in the warehouse of PACTL after the acceptance and security inspection at about 21:23. At about 20:35 on July 21, the board assembly started and finished at about 21:30. The assembled goods were weighed at 22:04 at the airport cargo terminal, and the goods were accepted at 22:45 and transported to the airside of PACTL.

1.16.6 Loading of Goods of Air Waybill No.071-37696046 on the Aircraft

On July 22, flight ET3739 carried a total of 28 pallets of cargo and 540 kg bulk cargo. Among the 28 pallets of goods, 22 pallets were loaded in the main deck cargo compartment and 6 pallets were loaded in the lower lobe. Goods of air waybill No. 071-37696046 was loaded on pallet PMC3324ET.

On July 22, 2020, the cargo of this flight was transferred from PACTL to the vicinity of parking positionNo.306 for loading. At about 13:25, the airport ground service began loading. The loading finished and the cargo door was closed at about 15:00. During the whole loading process, the loading staff did not observe any abnormal situation.

1.16.7 Reconstruction of Pallet PMC3324ET

After reviewing the good assembly video records and cargo photos of pallet PMC3324ET, the investigation team collecting articles like the packing cartons of the same batch and quantity, with the cooperation of the personnel responsible for loading the pallet PMC3324ET, accomplished the reconstruction of the pallet loaded at a ratio of 1:1. The replica was loaded on the accident aircraft where the pallet PMC3324ET had been placed. (Figure 53 and 54).

Figure 53 Pallet Reconstruction

Figure 54 Replica Loaded Position

1.16.8 Unlawful Interference Investigation

The International Airport Branch of Shanghai Public Security Bureau re-examined the video footage related to the goods of the five key pallets involved in the flight, including 24 air waybills, 697 pieces of goods. Video footage of the delivery of the first piece of goods on July 12 to the occurrence of the accident were re-examined, no abnormality was found in goods delivery lane, sorting and assembly area and weighing lane.

The International Airport Branch of Shanghai Public Security Bureau conducted background re-check and re-comparison on the personnel who entered the cargo transport restricted area of Terminal 1 of PACTL from July 12 (the time when the first air waybill of cargo of the accident flight entered the cargo terminal) to the time of the occurrence. A total of 1,139 people and 14,486 person-times were re-checked, and no suspicious people were detected.

From January 1 to July 22, 2020, Pudong Airport did not receive any unlawful interference information (including telephone threats) against aircraft.

1.17 Additional information

1.17.1 Similar Case of spontaneous combustion of chlorine dioxide disinfectant.

At 21: 07 on August 25, 2019, Qingchuan County Medical Center of Sichuan Province of China caught fire due to spontaneous combustion of a box of bottled chlorine dioxide disinfection tablets placed in the disinfection drug storage.

2. Analysis

2.1 Aircraft Fire

The investigation team firstly determined the initial fire area and the origin point of the fire. Secondly, the team recognized that the chlorine dioxide disinfection tablets caused the fire. Through postfire remnants survey, examination of the goods from the origin of the fire, the possibility of arson, lithium batteries fire or electrical component failures was ruled out.

2.1.1 Area and Origin of the Fire

2.1.1.1 Initial Fire Area

a) The flight crew opened the rigid cargo barrier door and entered the main deck cargo compartment from the supernumerary area when fire warning was triggered. After opening the door, the smoke in the main deck cargo compartment was observed. The flight crew returned waiting for further instruction.

b) According to site survey, the entire main deck cargo compartment sustained extensive fire damage. The supernumerary area and the cockpit suffered high temperature smoke only. The aft area and the upper section of the right sidewall suffered fire damage. (Figure 55-59).

Figure 55 Main Deck Cargo Compartment (Forward and Aft Area)

Figure 56 Cockpit

Figure 57 Supernumerary Area

Figure 58 Lower Lobe Cargo Compartment

Figure 59 Bulk Cargo Compartment

c) There were multiple burn-through areas in the crown centerline of the fuselage skin, among which the largest area was located between STA1790 to STA2129 (Figure 60).

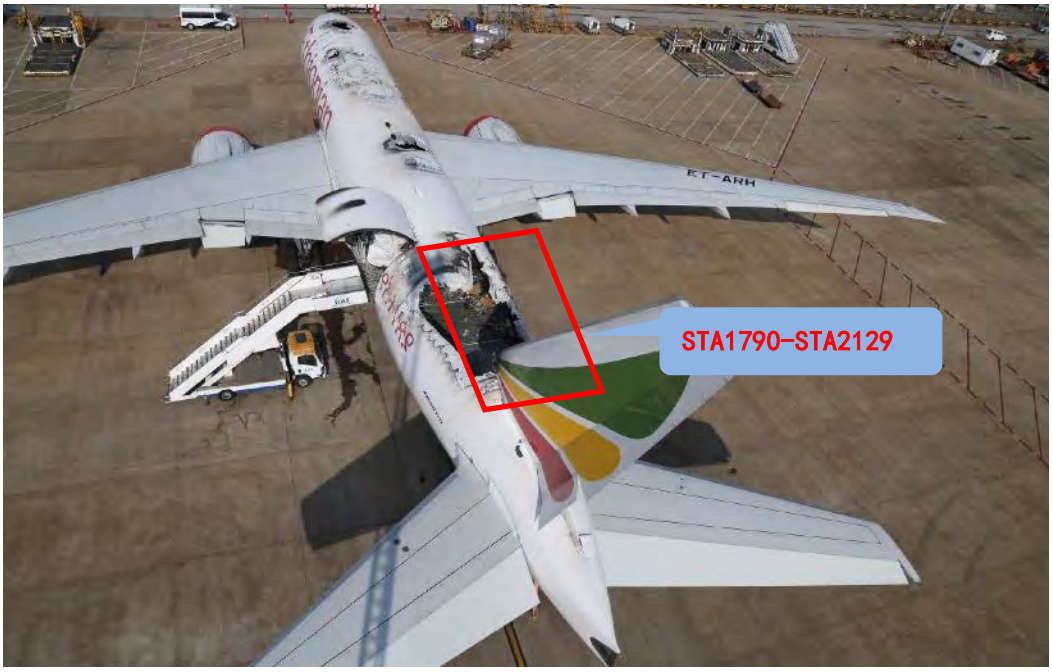


Figure 60 the Largest Burn-through Area of Aircraft Skin

d) The CCTV footage of parking position No. 307 showed that the heat discoloration firstly happened to the skin of the aft area of main deck cargo compartment, while the rest part of the compartment skin did not discolor at that time (Figure 61).

Figure 61 Screenshot of CCTV Footage of Parking Position No. 307

e) The test report (NO.ER15081) submitted by MEGGITT, the manufacturer of the Cargo Smoke Detector Controller (CSDC), indicated that there were 15 failed detectors recorded in the controller. These detectors were evenly distributed in the aft area of the main deck cargo compartment between STA1778.5 and STA2122, located from aft area of section 46 to section 47.

According to the law of combustion, when the thermal load of the fire is evenly distributed, the most severely burnt-out area can be determined as the initial fire area, excluding factors such as external ventilation. The material used for the skin and the structure of different sections of the accident aircraft fuselage were consistent. Cargo in the main deck cargo compartment were stacked evenly, and the influence of ventilation in the main deck cargo compartment was inapparent during the early stage of fire growth. The remnants presented that the aft area of main deck cargo compartment, The skin and the structure of the main deck cargo compartment sustained the most severe damage. The skin of this area discolored firstly. combining the aforesaid analysis with the CSDC data, the investigation team concludes that the initial fire area was located between STA1790 and STA2129 in the main deck cargo compartment.

2.1.1.2 The Origin of the Fire

a) the aircraft fuselage skin and the structure between STA1937 and STA1958 in the initial area of fire sustained the most severe fire damage, and the right side of which was more severe than that of the left side. The left remaining skin of fuselage between STA1937 and STA1958 was higher than the right side, with the height of 2.5m on the left and 1.58m on the right from the main deck cargo compartment floor (Figure 62).

Figure 62 Fuselage Damage Between STA1937 and STA1958

b) The upper part of the aft pressure bulkhead and aft crown of the main deck cargo compartment were completely burnt-out, while the lower part of which remained, indicating the fire damage was more severe on the right side (Figure 63). Goods on the left side of PR position in the main deck cargo compartment were only superficially damaged by the fire and partly collapsed to the right side, while goods on the right side was seriously burnt and collapsed onto the PR pallet, indicating the fire damage was more severe on the right side (Figure 64).

Figure 63 The Aft Pressure Bulkhead and Aft Main Deck Compartment Damage

Figure 64 Remaining Onboard Goods at PR Position

c) the skin and the structure at PR position in the main deck cargo compartment sustained the most serious fire damage with the lowest residual skin in height. The heat discoloration trace on the skin of this area was distributed along the lowest fuselage body waterline among all the fire damages. The composite linings in this area were mostly burnt-out, and the remaining stringers and frames sustained partial burnt which

showed a V-shape, the burning severity gradually diminished toward the front and the rear from this point (Figure 65-67).

Figure 65 Fire Damage and Heat Discoloration Trace at PR Position (Outer view)

Figure 66 Remained Skin and Frames at PR Position (Interior View)

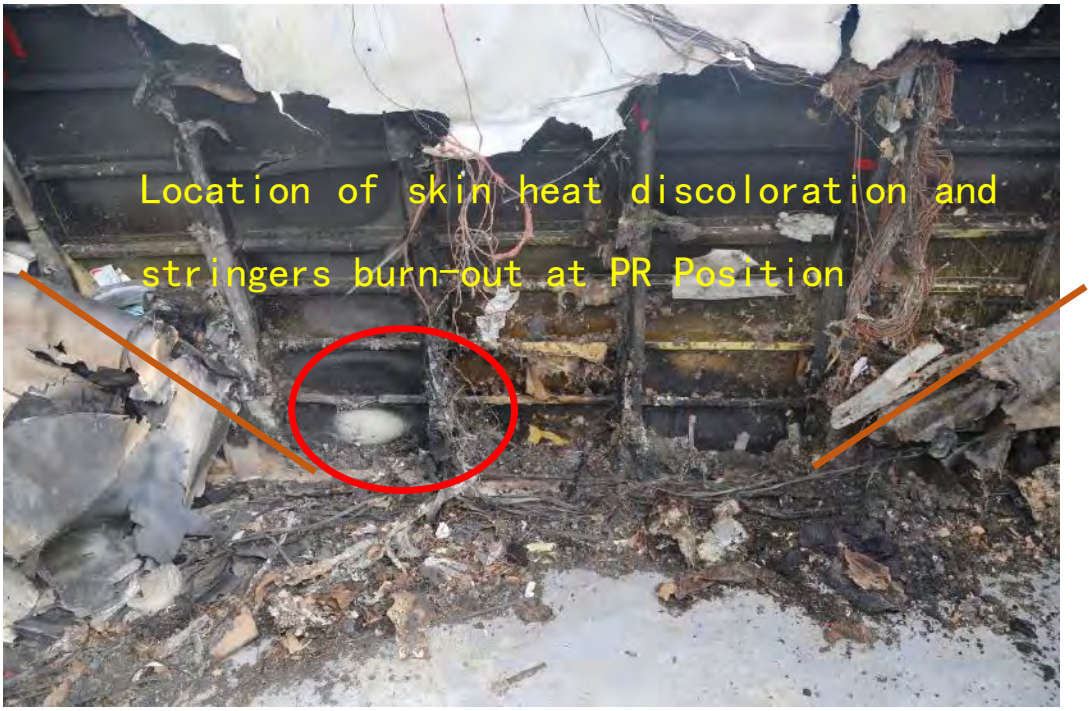


Figure 67 Details of Fire Damage at PR Position (Interior View)

d) The aluminum-made APU main feeder cables, which were located at the top of the fuselage between station STA1916 and STA2048 in the main deck cargo compartment, was broken by the fire and partially missing.

e) The investigation team identified and marked the frames, pallets and the main deck floor in the fire-damaged area on the outer skin of the fuselage. According to this identification and the CCTV footage of the parking position No.307, area on the right side of the fuselage in which the skin presented the first heat discoloration, was located between station STA1916 and STA2048, the PR position in the main deck cargo compartment (Figure 68 and 69).

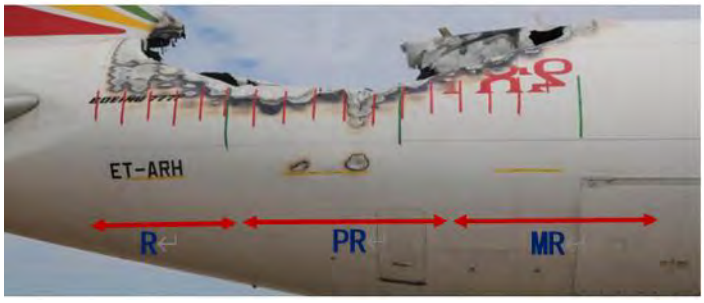


Figure 68 Marked Frames, Pallets and Floor Positions

Figure 69 Comparison between the CCTV Footage of Parking Position No.307 (right) and the Post fire Aircraft (left)

f) According to the test report of smoke detectors (NO.ER15081) submitted by MEGGITT, the manufacturer (Appendix 9), 13 of the 15 failed detectors were located on the right side of the main deck cargo compartment, that was accounting for 87%. Furthermore, the first fault record was produced by the failed detector on the right side.

To sum up, goods in the main deck cargo compartment that sustained the greatest burning loss and majority collapse were loaded at PR position, where also presented the lowest remaining frames and skin in height after the fire. The fire damage of the aft pressure bulkhead and the missing section of the APU main feeder cables suggested the fire started from PR position. Considering the location at which the first heat discoloration appeared and the earliest failure detector installed, it can be determined

that the fire started from PR position, located on the right side of the main deck cargo compartment between station STA1916 and STA2048 (Figure 70).

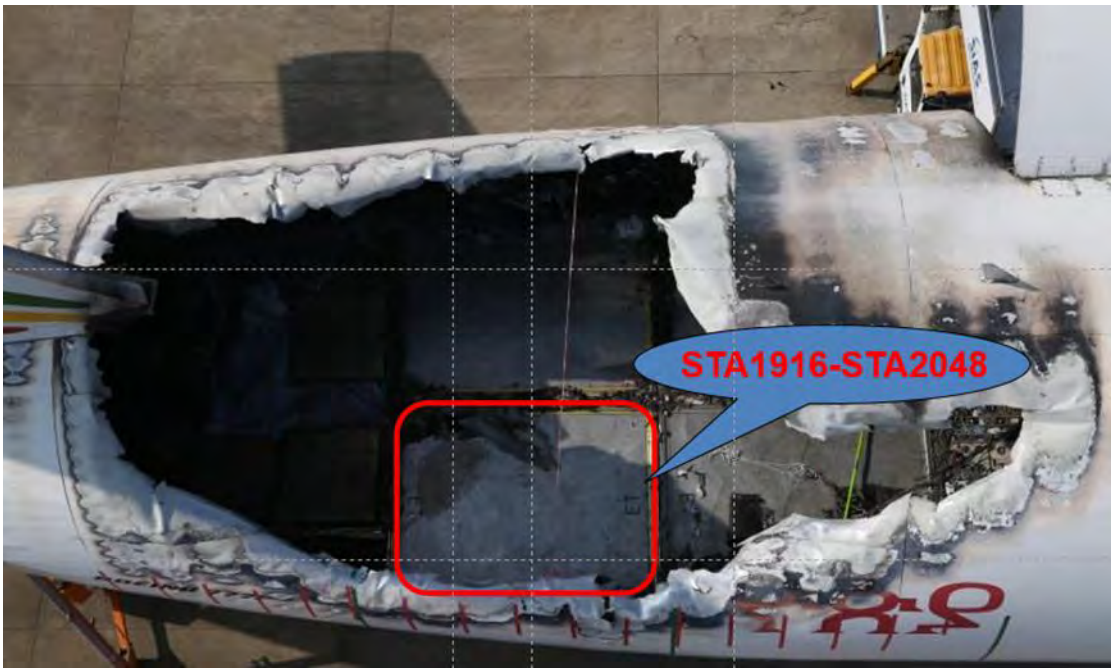


Figure 70 Bird View of PR Position

2.1.2 Cause of the Fire

2.1.2.1 Sabotage and Kindling Entrainment Aspects

According to the flight crew statements and the security information provided by Pudong International Airport, neither the flight crew nor the airport had received any threat of unlawful interference. The airport CCTV footage indicated that only personnel providing routine pre-departure ground service approached the aircraft during the period from the aircraft arrived at parking position No.306 to the fire on July 22, and the airport was guarded during the period.

According to Public Security Branch at Pudong International Airport, there was no abnormality in the cargo handling, and the background screening was conducted on personnel of restricted area of cargo terminal related to this flight, and nothing suspicious was detected.

Strict access control is implemented in the cargo warehouse area. Personnel and articles entering the warehouse area must go through the security check, and kindlings are stringently banned. By screening the CCTV recordings, all personnel and articles entering the warehouse area passed the security check without any exceptions.

The investigation team excluded the unlawful interference factors, since no evidence of arson or kindling entrainment in the process of cargo loading was found.

2.1.2.2 Electrical Fire Aspects

CCTV footage indicated, the main deck cargo door was properly opened at 15:30:36, and two lights installed on the side wall panel to the right of LR position were giving illumination. At 15:35:54, the APU air inlet door started to close. According to the mobile phone video taken by ground personnel, three lights installed on the top of the main deck cargo compartment were on when the main deck cargo door was fully opened. Based on the above, it can be implied that the main deck cargo door, the illumination system in the main deck cargo compartment and the APU air inlet door were still powered during this period.

Electrical cables and wirings were laid in the interlayer between the aircraft skin and the linings. Identified wirings which passing over the origin of the fire included the main feeder cables of the APU, wirings of the lights and outlets on the side wall panels, and signal leads, etc. Upon site survey, the main feeder cables of the APU were broken by the fire and partially missing in the corresponding position located between station STA1916 and STA2048 in the main deck cargo compartment. The remaining APU cables and other wirings were collected and sent to Tianjin Fire Evidence Identification Center of Fire Bureau of Ministry of Emergency Management for appraisal, and all the fractures were identified as fire melted trace.

The survey of the postfire aircraft found that both the forward and aft outflow valves were in open position when the fire occurred, which made the air in the interlayer space of the fuselage connected with the atmosphere outside the aircraft. From the moment of fire warning in the cockpit till the heavy smoke pouring out of the opened main deck compartment door, CCTV footage indicated no smoke outward flowing from either of the two valves. In addition, the flight crew stated, there was no warnings or fault messages except the fire warning in the main deck cargo compartment. Therefore, there was no evidence showing the fire firstly started in the interlayer space of the fuselage. The investigation team ruled out that fire caused by aircraft electrical failures.

2.1.2.3 Lithium Battery Aspects

There were 4 air waybills marked containing lithium battery, the goods of which were loaded at Positions R, PR, AR and 32P. Among them, positions R and PR were within the initial fire area. The goods of position AR located at the forward section of the main deck cargo compartment. Goods of position 32P located in the cargo compartment. Goods on position R were a carton of 50 mesh nebulizers. Each mesh nebulizer contained a lithium-ion cell of model 14500(voltage 3.7V). On position PR，there were 15 Hisense POS products. Each Hisense POS product was embedded with a button lithium-ion cell (voltage 3V). Goods of positions AR and 32P were distant from the initial fire area, not possible as the origin of the fire.

The site survey found 50 mesh nebulizers on position R, 15 Hisense POS products on position PR, in consistence with the product name, quantity and position declared on the air waybill. Each product was examined, the mesh nebulizer was mostly intact, only part of their plastic packaging was molten. 2 out of 15 Hisense POS products were damaged seriously. After the disassembly, it was found that the metallic enclosure discoloured due to heat, and the discoloration is more serious on the outside surface than the inner side. The circuit board was comparatively intact. The damage was deemed caused by fire from the outside (Figure 71, Figure 72).

Figure 71 Damage to Mesh Nebulizer and Hisense POS product

Figure 72 Hisense POS Product disassembled

In addition, a chlorine dioxide gas detector was found on position PR, the product name was not on the air waybill. The examination showed that the embedded power plant was lithium battery. There was no damage to the detector. The site survey did not discover any more lithium battery or embedded lithium battery equipment or device (Figure 73)

Figure73 Chlorine Dioxide Gas Detector found on Position PR

In conclusion, it is excluded the possibility that the lithium battery caused the fire.

The investigation team concludes that sabotage, brought in kindling during loading, airborne electronic equipment malfunction and lithium battery have been ruled out as the cause of the fire.

2.1.2.4 Goods at Position PR

There were 85 air waybills of goods (75 were air cargo, 10 were mail). According to the air waybills, the goods at position PR contain: rapid diagnostic test paper, Rapid test buffer, Novel coronavirus (2019-nCoV) IgM/IgG Antibody test kit, Hisense POS product, chlorine dioxide air disinfection machine, sealing machine, nano slow-release disinfection material, packaging bag, non-medical brand-free MZ-02 mask, scented tea, game handle and live broadcast lamp. During the site survey, granular substance packed in green aluminum foil bags, powdery substances packed in silvery aluminum foil bags and white tablets (small round tablets, 12.9mm in diameter, 6mm in thickness) packed in transparent plastic bags and silver aluminum foil bags were found at PR position.

According to the note on the air waybill, the goods in PR position contain 11 pieces of nano slow-release disinfection material, which were 4 pieces in 1920 bags, 3 pieces in 10000 bags and 4 pieces in 100 kg respectively. According to the owner's interview and purchase records, there were 1920 bags of nano virus shield (granular substance packed in green aluminum foil bag), 10000 bags of chlorine dioxide disinfectant (powdery substance packed in silvery aluminum foil bag) and 100 kg of chlorine dioxide disinfection tablets (white tablets, 1kg/bag, 100 bags in total). The owner declared and delivered the above three kinds of goods with the name of nano slow-release disinfection material.

The granular substance packed in green aluminum foil bag was nano virus shield (Sample 3 in Table 3). According to the Certification for Safe Transport of Chemical Goods (NO2020072245) submitted by the owner at the time of delivery, the conclusion was that the goods are unrestricted and non-flammable.

The powdery substance packed in silvery aluminum foil bag was chlorine dioxide disinfectant (Sample 4 in Table 3). Appraised by the SRICI, this article was corrosive dangerous goods, and it was packaged in aluminum foil bags, 20 grams in each bag. This article was packaged separately, leak proof. The spontaneous combustion condition was insufficient. Therefore, the possibility of spontaneous combustion of Article 4 was ruled out.

Sample 1 and Sample 2 (in Table 3) were chlorine dioxide disinfection tablets (Figure 74). According to site survey, there were 23 intact plastic bags (each weighing about 1kg), 10 broken plastic bags and 1 aluminum foil bag, all of which have no marks on them. Sample 2 was sent to the SRICI for qualitative test. The composition of the Sample sent for test was quite similar to that of disinfection products commercially available which can release chlorine dioxide, and the chlorine dioxide was produced when the Sample reacted with water. Samples 1 and 2, together with chlorine dioxide effervescent tablets purchased in the market, were sent to Tianjin Fire Evidence Identification Center of Fire Bureau of Ministry of Emergency Management for

appraisal and analysis. The conclusions are as follows: The Samples sent for inspection have a certain spontaneous combustion risk when they are damped at normal temperature, and the self-heating power of Sample 1 is much higher than that of commercial products, so the spontaneous combustion risk is extremely high. In case of unfavorable heat dissipation, it is possible to accumulate heat in a short time to reach the spontaneous combustion temperature.

Figure 74 Chlorine Dioxide Disinfection Tablets

According to Article 8.3 of " Solid composition releasing chorine dioxide " (GB/T27802-2011), the chlorine dioxide solid releasing agent should be stored in a cool, dry and ventilated place to prevent damp, heat or sunlight exposure. Based on meteorological data and appraisal report, chlorine dioxide disinfection tablets at position PR were likely to be exposed to high temperature and moisture.

According to the video footage and firefighters' statement, a small amount of white smoke came out once the aircraft main deck cargo door was opened, and turned into black smoke after about 4 minutes, which is in line with the characteristics of spontaneous combustion (Figure 75).

Figure 75 Screenshot of CCTV Footage from Parking Position No.305

The investigation team concludes that, the chlorine dioxide disinfection tablets found at PR position have spontaneous combustion risk under the conditions of high temperature and moisture. According to the simulation, under similar meteorological conditions, the temperature inside the stack was much higher than the ambient temperature, and condensation occurred inside the film, unfavorable for heat dissipation, which provided sufficient condition for spontaneous combustion. It can be concluded that the fire was caused by the spontaneous combustion of chlorine dioxide disinfection tablets.

2.1.3 Fire Growth

At 15:30:13, the CCTV footage showed, after the fire truck arrived at parking position No.306, the load master, following the captain's instruction, opened the main deck cargo door via the door control panel installed near 1L door, which could have caused a large amount of air pouring into the main deck cargo compartment and aggravated the growth of the fire.

2.2 Freight Flow

2.2.1 Consignment Process of Air Waybill No.071-37696046

The goods of air waybill No.071-37696046 were loaded at position PR with declared names "packaging bags, sealing machine, disinfection machine and nano slow-release disinfection material (including 1% chlorine dioxide adsorbed on nano material)".

Besides packaging bags, sealing machine, disinfection machines and nano slow-release disinfection material (containing 1% chlorine dioxide adsorbed on nano material), the goods in this shipment actually contained disinfection powder and chlorine dioxide disinfection tablets. Disinfection powder and chlorine dioxide disinfection tablets were certified as dangerous goods. The owner and the agents did not declare disinfection powder and chlorine dioxide disinfection tablets.

It was determined as a concealing of the name of goods and consigning dangerous goods with the name of non-dangerous goods.

2.2.2 Security Inspection of Acceptance and Transport with Air Waybill No.071-37696046

The PACTL completed the examination of cargo transport documents. The goods entered the warehouse of PACTL after security inspection. The investigation team reviewed the X-ray machine images of the goods (Figure 76). The images showed that there were two areas with granular physical morphology, of which granular shape was obvious in the light color area, and in the dark color area, supported by image highlight function key, showed evident granular shape at the edge. It conformed the granule described in " Appearance & Odor" in the Certification for Safe Transport of Chemical Goods for nano slow- release disinfection material. According to Article

147 of CAAC Security Inspection Operation Manual, it is not within the category of the goods required to be unpacked check mandatorily.

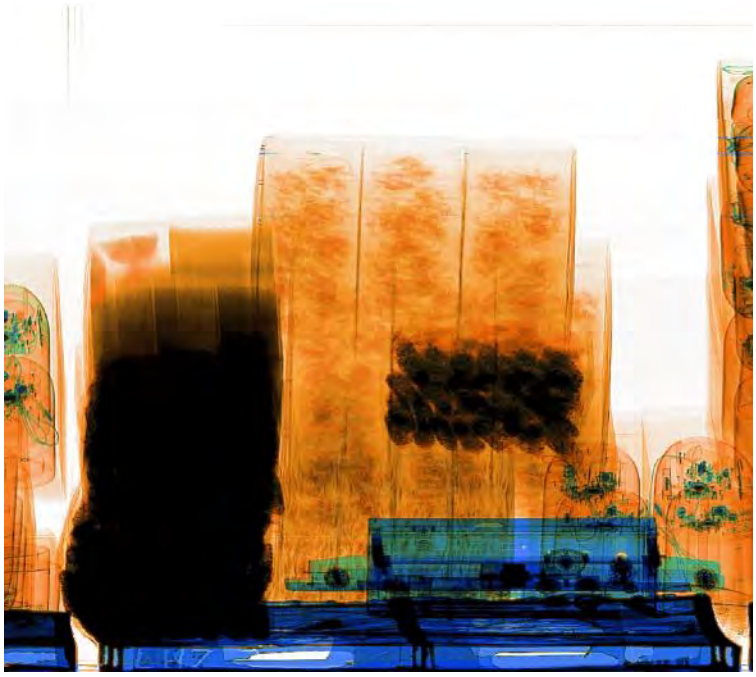


Figure 76 Security Inspection Image

2.3 Personnel Performance

2.3.1 Flight Crew Performance

2.3.1.1 Initial Operation After Fire Warning

While the flight crew was making pre-flight preparations in the cockpit, a red warning message "FIRE CARGO MAIN DECK" was indicated on EICAS with an aural warning. The flight crew reset the warning and executed the electronic quick checklist "FIRE CARGO MAIN DECK".

The captain assigned the load master to the main cargo deck to check smoke/fire, the load master entered the main deck cargo compartment through the rigid cargo barrier without wearing any personal protective equipment.

2.3.1.2 Opening of the Main Cargo Compartment Door

At 15:30:36, after the firefighting vehicle arrived at Parking Position No.306, under the instruction of the captain，the load master opened the main cargo compartment door through the cargo compartment door operation panel located near the Left 1(1L) door.

According to the airport CCTV footage, when the main cargo compartment door was being opened, there were four crews on board and one crew was near the main cargo compartment door off the plane.

The investigation team determines that the crew failed to follow *Warning! "Inform ground personnel NOT to open any cargo door until all supernumeraries and crew have exited the airplane and firefighting equipment is nearby",* article 8.26 in QRH of Ethiopian Airlines.

2.3.1.3 Deplane of the Crew

The crew had recognized that there was fire warning in the main deck cargo compartment, accompanied with smoke. According to the Chapter 3, SECTION3.1 of Ethiopian Airlines Flight Operation Manual, *"Crew Duties and Responsibilities in – Emergency",* that the smoke and fire in the main deck cargo compartment was deemed as an emergency, the flight crew should have identified the situation and initiated the evacuation, but the crew failed to do so.

The emergency procedure requires to shut down APU by pulling out APU fire warning switch before the flight crew leaves the aircraft. The investigation team found that the flight crew failed to execute evacuation procedure, fuel and electric power supply were failed to cut out, the APU was still running after all crews deplaned the aircraft until it

shut down automatically, and posed potential risks to the aircraft.

2.3.2 Controller Performance

2.3.2.1 Controller of Air Traffic Control Tower

Upon receiving the fire warning reported by the flight crew, the Pudong ATC tower controller immediately reported to the airport AOC, the airport apron control, the Approach Control and ATC duty manager, and handed over the aircraft to the airport apron control on 121.65MHZ according to 5.2.8 of Emergency Plan of Eastern Air Traffic Management Bureau. Meanwhile, the ATC tower controller suspended the ground operation north of Taxiway T4, as well as the handover of aircraft between the ATC Tower and the airport apron control. Before the open fire, the ATC tower controller observed the appearance of flight ETH3739 through telescope, which was uneventful.

After observing the open flame of the aircraft, the ATC controller immediately suspended the operation of runway 17R, instructed two aircrafts on final abort approach, and informed the Shanghai Terminal Control to deploy the follow-up traffic to the runway 16L. Then the airport AOC called the Tower that firefighting force needed to cross the runway. Considering the smoke could impact the landing pilots' visual contact of the landing runway, the ATC tower controller decided to continue to suspend the operation of runway 17R. and used runway 16L for landing, and runway 16R for takeoff. At 16:35, the airport AOC informed the ATC tower that it could not be able to operate flights due to the downgrade of firefighting level, and all runways needed to stop the service for about one hour; The ATC tower informed the airport AOC to immediately issue a NOTAM, at the same time, the ATC tower stopped the running of all runways in Pudong Airport, and notified neighboring ATC units.

2.3.2.2 The Airport Apron Controller

At 15:16:18, the flight crew made the first transmission with the airport apron control: "*Please sir, we need fire truck immediately, we have fire warning on our cargo compartment*." and "*For the time, please, we need only fire truck*…." The airport apron controller immediately reported to the duty manager at the airport AOC that the aircraft at the parking position No.306 required for a fire truck,*" Only firefighting required."* The airport AOC sought for confirmation by asking *"Only one firefighting vehicle?"*, the airport apron controller confirmed "*Correct, correct*".

At 15:19:32, the crew contacted the apron control, urged the fire truck to arrive and expressed EMERGENCY. The apron controller replied that the fire truck was on the way and confirmed the emergency.

At 15:20:47, the apron controller called the airport AOC, inquired about the position of the fire truck, and reported "*the crew reported it could be urgent.*"

At 15:21:32, the flight crew declared MAYDAY and reported to the apron control "*fire on board*". The apron controller reported to the airport AOC that the aircraft had declared MAYDAY and urged the fire truck. The airport AOC replied that the fire truck would be arriving within 5 minutes. The apron controller only reported to the airport AOC that the aircraft declaring MAYDAY, failed to relay the information of *FIRE ON BOARD*. The incomplete transmission would have an impact on the activation of emergency plan. Then, the apron control informed the flight crew that the passenger stair would be arriving immediately and the fire truck in 5 minutes.

The investigation team believes that the airport apron control failed to accurately relay the crucial information of EMERGENCY and FIRE ON BOARD, which weakened the emergency degree in the process of information relaying.

2.3.3 Airport Security Inspection Personnel

Security Check and Guarding Department was responsible for the safety check conducted on the goods and mails carried by the accident aircraft. All personnel and equipment were properly qualified and certificated.

The security inspection personnel on duty performed the security check under the procedure by reviewing the declaration form, judging the screenshot of the cargo, verifying the transportation documents. The cargo X-ray machine showed granular substance, which was in accordance with the physical characteristics described by the Certification for Safe Transport of Chemical Goods. After verifying the mark, the image and transportation documents, CAAC Security Inspection Operation Manual, the X-ray machine operator released the goods.

According to the Civil Aviation Security Inspection Manual and Civil Aviation Cargo Transportation Guard Rules ", the security check personnel shall verify the name on the cargo following the air security check declaration form, carrying out technical interpretation and review the image of the goods. Un-pack examination shall be performed when any of the following encountered:

-The name declared is inconsistence with the X-ray image;

-The image is obscured and the object cannot be passed by the X-ray;

-Suspicious of concealing the name of goods and consigning dangerous goods, prohibited articles and controlled objects;

-According to image interpretation, it is deemed as suspectable goods of which the safety cannot be assured.

The investigation team reviewed the X-ray image of the suspected bill. The images showed that there were two areas with granular physical morphology, of which granular shape was obvious in the light color area, and in the dark color area, supported by image highlight function key, showed evident granular shape at the edge. It conformed with the granule described in " Appearance & Odor" in the Certification for Safe Transport of Chemical Goods. The cargo security inspection of the Airport met the requirement of CAAC Security Inspection Operation Manual.

2.3.4 Airport Firefighter

After receiving AOC's instructions, the Airport firefighting senior command post dispatched one fire truck from No.3 Fire station to the parking position No.306 to check the fire. According to CCTV footage and the build-in GPS trajectory recording of the fire truck, 35 seconds after receiving the task, three fire trucks drove out and rushed to the parking position No.306 along the service lane. On the way, the on-training fire truck F302 joined the three trucks and rushed to the parking position No.306.

After the firefighting force was in place, required the passenger stair moving to the main deck cargo compartment for fire reconnaissance. Without the consent of the firefighting forces, the main deck cargo compartment door was opened by the crew, and a small amount of smoke drifted out. After that, the smoke gradually increased and the open fire appeared. The firefighting force deploy agent immediately to extinguish the fire.

2.4 Organizational and Management Information

2.4.1 Boeing Manual

The main deck cargo compartment of the Boeing 777 freighter was designed as class E cargo compartment, which had an independent smoke/fire detection system without any fire extinguishing equipment, as a consequence, timely fire response and rescue operations were needed in much greater urgency when the aircraft caught fire on ground. According to the checklist in Boeing 777 FCOM, the flight crew were instructed to inform ground personnel not to open any cargo door until all supernumeraries and crew have exited the airplane and firefighting equipment is nearby. But there were no further instructions or procedures for protective settings of the aircraft system before the evacuation of the crew.

3. Conclusions

3.1 Findings

(1) The flight crew, ATC controllers, firefighting and security inspection personnel were properly qualified in the event.

(2) The load master opened the rigid cargo barrier door and entered the cargo compartment under Captian's instruction.

(3) The main cargo compartment door opened with 4 flight crews on board.

(4) Neither the FDR nor the CVR recorded the accident data, as the engines were not started, while the QAR recorded the startup information of the APU.

(5) All goods contain lithium battery in the vicinity of position PR have been found, and no fire ignition evidence was found. The lithium battery was ruled out as the cause of the fire.

(6) Electrical components failure was ruled out as the cause of the fire.

(7) There was no evidence of arson, kindling entrainment, and sabotage was ruled out as the cause of the fire.

(8) There were 4 kinds of articles containing chlorine dioxide found during site survey, including transparent plastic bags (1 kind), aluminum foil bags (3 kinds).

(9) There was no other item present in position PR that could have caused or contributed to the incident.

(10) The consignor only offered the Certification for Safe Transport of Chemical Goods (SRICI No. 2020072245). Samper name was "nano slow-release disinfection material (containing 1% chlorine dioxide adsorbed on nano material)", the conclusion was "unrestricted goods".

(11) The disinfectant is dangerous goods. The consignor failed to declare the goods name and hazardous goods, and concealed the information that there were hazardous goods in the goods.

(12) The chlorine dioxide disinfection tablets packed in aluminum foil bag had a spontaneous combustion temperature at 150℃.

(13) The cargo security inspection was in compliance with CAAC Security Inspection Operation Manual.

(14) Goods on Pallet PR were packed with plastic film. During the storage in the airport, the goods can be affected by high temperature and moisture of the environment.

(15) During the accident, the temperature and moisture of Pudong Airport is relatively high, which may have caused the goods in the package to be at a higher ambient temperature and the possibility to be damp.

(16) The initial fire area was located between STA1790 and STA2129 in the main deck cargo compartment.

(17) The origin of the fire was located between station STA1916 and STA2048.

(18) The cause of the fire was determined as the spontaneous combustion of the undeclared Chlorine Dioxide.

(19) There was smoke when the main deck cargo door was opened fire started at 4 minutes later.

(20) Shanghai Municipal Firefighting Department engaged in these firefighting efforts.

(21) The accident did not incur catastrophic result such as fuel tank explosion, the aircraft destruction, and fatal injuries.

(22) During the process of information transmission, the apron control failed to relay the status of emergency and the fire information to the Airport AOC accurately and completely.

3.2 Probable Cause

The investigation team determines that the initial fire area was in the main deck cargo compartment located between STA1790 and STA2129.The origin of the fire was located between station STA1916 and STA2048 (PR position), on the right side of the main deck cargo compartment. The chlorine dioxide disinfection tablets loaded in the cargo compartment spontaneous combustion in high temperature and moisture environment, and caused the fire.

4. Safety Recommendations

4.1 ICAO

As the global epidemic has not ended and the market demand for disinfection products containing chlorine dioxide is huge, it is suggested to make further research, refine the air transportation conditions of disinfection products with different contents of chlorine dioxide, and revise relevant items into the technical instructions for the safe transport of dangerous goods by air, so as to better and safer air transportation.

4.2 Pudong Airport

Enhance the application of standard terminology regarding the relay of information, to ensure an accurate and smooth relaying of emergency information.

4.3 Ethiopian Airlines

Enhance the emergency response capability of the crew to ensure that all procedures in the Flight Crew Operation Manual (FCOM) and company operation manual can be completed correctly.

4.4 BOEING Company

Highlight the sign of "In the Event of Smoke or Cargo Fire, Do Not Open" on the B777 freighter rigid cargo barrier in a prominent manner and consider clarifying it in the crew operation and training manuals.

4.5 CAAC

Avoid or reduce the risk of dangerous goods boarding the aircraft in violation of laws or regulations, by improving and refining existing regulations and standards related to the air transport of dangerous goods and by adopting new technology in security inspection.

APPENDICES

Appendix 1: Analysis and Appraisal Report on Evidence Identification of Ethiopian Airlines Ground Fire at Pudong Airport issued by Tianjin Fire Evidence Identification Center of Fire Bureau of Ministry of Emergency Management

Appendix 2: APPRAISAL REPORT No: 20201412 issued by Tianjin Fire Evidence Identification Center of Fire Bureau of Ministry of Emergency Management

Appendix 3: APPRAISAL REPORT No: 20201743 issued by Tianjin Fire Evidence Identification Center of Fire Bureau of Ministry of Emergency Management

Appendix 4: Analysis Report No. SHA20090108-01 issued by Ingeer (ICAS) Testing Technology Service (Shanghai) Co., Ltd (SRICI)

Appendix 5: Qualitative Test Results of "Suspected Chlorine Dioxide Disinfection Tablets" issued by Testing Co., Ltd. of Shanghai Research Institute of Chemical Industry(SRICI)

Appendix 6: Material Evidences Analysis and Identification Report on the Accident of Ethiopian Airlines B777F Aircraft issued by Tianjin Fire Evidence Identification Center of Fire Bureau of Ministry of Emergency Management

Appendix 7: Certification for Safe Transport of Chemical Goods No. NO.2020072245 issued by Testing Co., Ltd. of Shanghai Research Institute of Chemical Industry

Appendix 8: Certification for Safe Transport of Chemical Goods No. NO.2020072246 issued by Testing Co., Ltd. of Shanghai Research Institute of Chemical Industry