National Transportation Safety Board

Office of Aviation Safety

Washington, DC 20594

DCA21FA085

OPERATIONAL FACTORS

Group Chair's Factual Report

October 24, 2022

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A. ACCIDENT

Location: Bloomfield, CO
Date: February 20, 2021
Time: 1309 Mountain Standard Time, MST[1]
2009Z Coordinated Universal Time
Airplane: B-777-222, N772UA, United 328

B. OPERATIONAL FACTORS GROUP

Warren Abrams[2]
Group Chairman
Operational Factors Division (AS-30)
National Transportation Safety Board

Todd Gentry
Air Safety Investigator
Accident Investigation & Prevention
Federal Aviation Administration

Jim LaRosa[3]
777 Captain
UAL- ALPA/CASC-Chairman

Brad Peterson[5]
778 Fleet Standards Manager
United Airlines Denver, CO

Sam Goodwill[4]
Senior Safety Pilot
Boeing Test and Evaluation
Boeing

C. SUMMARY

On February 20, 2021, about 1309 mountain standard time (MST), United Airlines flight 328, a Boeing 777-222, N772UA, experienced an engine fire and failure of the right engine, a Pratt & Whitney PW4077, while climbing through an altitude of about 12,500 feet mean sea level (msl) shortly after takeoff from Denver International Airport (DEN[6]), Denver, Colorado. The flight crew reported an engine fire to ATC[7], declared an emergency and started a left turn back to DEN. The crew performed the right engine fire checklist, discharged both fire bottles during the air turn back to DEN. The flight crew made an uneventful overweight single engine landing. After landing,

[1] All times are referenced to Mountain Standard Time, MST
[2] I was assigned as Ops Group Chairman on August 11, 2021
[3] Al Berlinberg was the ALPA Group Member but was replaced upon his retirement from United Airlines
[4] Sam Goodwill replaced Robert Aaron from the Boeing Company as Mr. Aaron was the original Boeing Rep assigned to the Ops Group.
[5] Brad Peterson replaced Robert Mackay; a United 777 Line Check Airman as Mr. Mackay was originally assigned to the Ops Group.
[6] The ICAO identifier for DEN is KDEN
[7] Air Traffic Control

airport rescue and firefighting (ARFF) crews met the airplane on the runway and observed smoke and flames emanating from the right engine. ARFF sprayed the engine with fire retardant foam for approximately 40 minutes and extinguished the fire and cool the engine. The airplane was towed to the gate and the passengers disembarked. There were no injuries to the 239 passengers and crew onboard, and the airplane sustained major damage. The regularly scheduled domestic passenger flight was operating under the provisions of Title 14 *Code of Federal Regulations (CFR*) Part 121 from DEN to Daniel K. Inouye International Airport (HNL[8]), Honolulu, Hawaii.

D. DETAILS OF THE INVESTIGATION

Upon notification, the NTSB launched the go-team lead by the investigator-in-charge and specialist in structures and powerplants. Specialist in metallurgy, flight crew operations, air traffic control, maintenance records, and flight recorders supported the investigation from other locations. The flight data recorder (FDR) and the cockpit voice recorder (CVR) were sent to the NTSB recorders Laboratory in Washington, DC, for download and analysis.

Parties to the investigation include The Boeing Company, Pratt & Whitney, the Federal Aviation Administration (FAA), United Airlines, the Air Line Pilots Association, and the International Brotherhood of Teamsters. Numerous local law enforcement and public safety agencies also assisted with the initial response and recovery.

The following groups have been formed to investigate this : structures, powerplants, metallurgy, maintenance records, flight crew operations, FDR, and CVR. Additional groups may be formed as the investigation progresses.

Operational Factors Group was formed on February 21, 2020. Several of the listed party members were assigned to the group, and others were assigned later during the investigation. Due to the time since the accident, several of the Group members were not available and have been replaced with new Group members.

On October 25, 2021, at 1400 the Ops Group conducted simulator evaluations of various scenarios at the United Airlines Training Center in Denver, CO. Scenarios included Normal Procedures as well as Non-Normal Procedures according to the United 777 Flight Manual. The running of the annunciated Engine Fire Checklist was combined with distractions that a 777-flight crew may encounter during a flight. Timing the crew running the FIRE ENG R checklist was accomplished on two separate occasions[9].

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[8] The ICAO identifier for HNL is PHNL

8 See Attachment 2 for the Simulator Evaluation

E. FACTUAL INFORMATION

1.0 History of Flight

The airplane departed at approximately 1304 from runway 25 at DEN. The captain was the pilot flying, and the first officer was the pilot monitoring. According to the FDR data and flight crew interviews, about 4 minutes after takeoff, the airplane was climbing through an altitude of about 12,500 feet msl with an airspeed of about 280 kts. Based on the preflight weather forecast, the flight crew indicated they advanced the power at the time to minimize time in expected turbulence during their climb up to their assigned altitude of flight level 230[10]. Approximately 5 to 7 seconds after the throttles were advanced a loud bang was recorded on the CVR. FDR data indicate the no. 2 engine made an uncommanded shutdown and the engine fire warning in the cockpit activated about 2 seconds later. The flight crew declared an emergency with ATC and stated their intention to return to DEN for an emergency landing. The flight crew began to complete multiple checklists, including the engine fire checklist. As required by the right engine fire checklist, the flight crew discharged both engine fire bottles, but the right engine fire warning did not extinguish until the airplane was on an extended downwind leg for landing.

The flight crew continued to prepare for the emergency landing by completing additional critical checklist and verifying airplane performance for landing. The FO[11], in his interview indicated that in discussion with the captain, they decided not to dump fuel for safety and time reasons. They also discussed the magnitude of the overweight landing, and it was not significant enough to outweigh other considerations. The captain, who was the pilot flying, (PF), accomplished the one-engine inoperative approach and landed on runway 26 at DEN, at 1328, and without further incident. Aircraft Rescue and Firefighting (ARFF) met the airplane as soon as it stopped on the runway and applied water and foaming agent to the right engine. The base or bottom of the engine experienced a flare up, which was quickly extinguished. Once cleared by ARFF, the airplane was towed off the runway where the passengers disembarked via air stairs and were bussed to the terminal.

2.0 Flight Crew Information

The flight crew consisted of a captain, who was the pilot flying (PF) and a first officer, who was the pilot monitoring (PM).

2.1 Captain

The captain, age 60, held an Airline Transport Pilot (ATP) certificate with a rating for airplane multiengine land, commercial privileges airplane single-engine land, and

[10] Any altitude above 18,000 feet is a flight level.
[11] Attachment 1, FO interview pg. 17/1-7.

included type ratings in the A-320[12], B-737[13], B-757,[14] B-767[15], B-777[16], CE-500[17] and EMB-110[18], EMB-120[19], with limitation of English Proficient; B-777 A-320 CIRC APCH. – VMC[20] ONLY, EMB-110 Second in Command Required.

At the time of the accident, he was San Francisco International Airport (SFO) San Francisco, California based.

2.1.1 The Captain's Pilot Certification Records

FAA Records of the captain indicated the following:

Private Pilot – Airplane Single-Engine Land certificate issued August 31, 1980.

Private Pilot – Airplane Single-Engine Land; Instrument Airplane certificate issued September 7, 1985.

Commercial Pilot – Airplane Single-Engine Land; Instrument Airplane certificate issued November 9, 1985.

Commercial Pilot – Airplane Single and Multiengine Land; Instrument Airplane certificate issued November 9, 1985[21].

Airline Transport Pilot – Airplane Multiengine Land, Commercial Privileges Airplane Single-Engine Land certificate issued January 8, 1987.

Airline Transport Pilot – Airplane Multiengine Land, CE-500; Commercial Privileges Airplane Single-Engine Land certificate issued August 21, 1987.

Notice of Disapproval – Airline Transport Pilot – Airplane Multiengine Land, EMB-120, was issued on May 3, 1988. Unsatisfactory items: Taxiing, Circling Approaches, Missed Approaches, Steep Turns, Approach to Stalls, and Judgement.

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[12] Airbus SAS A-318 Series, A-319 Series, A-320 Series, A-321 Series and includes all models on TCDS A28NM. Source: FAA Order 8900.1 Figure 5-88, dated July 15, 2019.
[13] The Boeing Company, B-737-100, B-737-200, B737-300, B-737-400, B737-500, B737-600, B-737-700C, B-737-800, B737-900. Source: FAA Order 8900.1, Figure 5-88, dated July 15, 2019.
[14] The Boeing Company, 757-200 Series757-200PF Series 757-200CB Series 757-300 Series
[15] The Boeing Company, B767-200 Series, B767-300 Series, 767-300F Series, 767-400ER Series, 767-2C Series
[16] The Boeing Company, 777-200 Series, 777-300 Series, 777-300ER Series, 777-200LR Series, 777F Series
[17] Textron Aviation, CE-500, CE-560XL, CE-510, CE-510S, CE-525, CE-525S, CE-650, CE-680, CE-700, CE-750
[18] Empresa Brasileira de Areonuatica (Embraer), Brazil, S.A. EMB-110, EMB-110P1, EMB-110P2
[19] Empresa Brasileira de Areonuatica (Embraer), Brazil, S.A. EMB-120, EMB-120RT, EMB-120ER, EMB-120FC, EMB-120QC
[20] Visual meteorological conditions.
[21] Received Commercial, Single Engine Land and Multiengine Land Certificate on the same day.

Airline Transport Pilot – Airplane Multiengine Land, EMB-110 Second in Command Required, CE-500; Commercial Privileges Airplane Single-Engine Land certificate issued May 4, 1988.

Airline Transport Pilot – Airplane Multiengine Land, CE-500, EMB-110, EMB-120; Commercial Privileges Airplane Single-Engine Land; Limitations EMB-110 Second in Command Required; certificate issued July 26,1989.

Airline Transport Pilot – Airplane Multiengine Land, CE-500, EMB-110, EMB-120, B-757, B-767; Commercial Privileges Airplane Single-Engine Land; Limitations EMB-110 Second in Command Required certificate issued September 17, 1993.

Airline Transport Pilot – Airplane Multiengine Land, CE-500, EMB-110, EMB-120, B-757, B-767, B-737; Commercial Privileges Airplane Single-Engine Land; Limitations EMB-110 Second in Command Required certificate issued December 29, 1996.

Airline Transport Pilot – Airplane Multiengine Land, CE-500, EMB-110, EMB-120, B-757, B-767, B-737, A-320; Commercial Privileges Airplane Single-Engine Land; Limitations EMB-110 Second in Command Required, A-320 Circ Apch VMC Only certificate issued May 31, 2002.

Airline Transport Pilot – Airplane Multiengine Land, CE-500, EMB-110, EMB-120, B-757, B-767, B-737, A-320, B-777; Commercial Privileges Airplane Single-Engine Land; Limitations English Proficient: B-777, A-320 Circ. Apch. – VMC Only; EMB-110 Second in Command Required, Certificate issued January 12, 2020.

Ground Instructor, Advanced Ground Instructor certificate issued January 23, 1986

Flight Instructor, Airplane Single Engine Land; Limitation, Expires December 31, 1987, certificate issued December 9, 1985.

Flight Instructor, Airplane Single Engine Land, Instrument Airplane certificate issued February 3, 1986

Flight Instructor, Airplane Single and Multiengine Engine, Instrument Airplane, Limitation, Expires April 30, 1988, certificate issued April 4, 1986.

Flight Engineer, Turbojet Powered certificate issued January 16, 1990

Flight Instructor, Airplane Single and Multiengine Engine, Instrument Airplane, Limitation, Expires October 31, 2007, certificate issued October 13, 2005. Reissued on

September 13, 2007, August 12, 2009, August 11, 2011, August 21, 2013, July 29, 2015, August 12, 2017, and October 1, 2019

2.1.2 The Captain's Pilot Certificates held at Time of the Accident

AIRLINE TRANSPORT PILOT (issued January 12, 2020)
Airplane Multiengine Land
A-320, B-737, B-757, B-767, B-777, CE-500, EMB-110, EMB-120
Commercial Privileges – Airplane Single-Engine Land
Limitations: EMB-110 Second in Command Required, B-777, A-320 Circ Apch VMC Only. Certified Flight Instructor, Airplane Single and Multiengine; Instrument Airplane, last issued October 1, 2019, Flight Engineer, Turbojet Powered certificate issued January 16, 1990

MEDICAL CERTIFICATION FIRST-CLASS (Issued February 23, 2021)
Limitations: None.

2.1.3 The Captain's Flight Times

The following flight times were based on United Airlines provided NTSB form 6120.1 "Pilot/Operator Aircraft Accident/Incident Report" and were based on flight times gathered beginning in 1990 to the date of the accident. According to United Airlines the flight time dates started as the date of hire on May 7, 1990.

Total Flying Time:	28,062
Total PIC Time:	24,278
Total Flying Time Previous 24 hours:	4
Total Flying Time Previous 30 Days:	50
Total Flying Time the Previous 90 Days:	116
Total Flying Time the Previous 12 Months:	414
Total Flying time in the B-777 in the Previous 12 Months:	414

2.1.4 Captains Training

The captain was current and qualified in all required FAA training. This included Emergency Procedures as well as engine inoperative takeoff and landings. A list of the captains training modules that were successfully passed can be found in Attachment 8.

The captain's recent training history based on United Airlines records:

Date of Hire (United Airlines)	June 3, 1990
Date Upgraded to Captain on B-777	January 12, 2020
Date of Initial Type Rating at United on A-320	June 14, 2002
Date of Most Recent Proficiency Check	February 5, 2021
Date of Most Recent LOFT	February 6, 2021
Date of Most Recent Recurrent Ground Training	January 18, 2021
Date of Most Recent PIC Line Check	December 20, 2019

2.2 First Officer

The first officer, age 54, held an ATP certificate with a rating for airplane multiengine land and included type ratings in the A-320, B-757, B-767, B-777 and EMB-120 with limitation of ATP CIRC APCH. – VMC ONLY, A-320, B-777, B-757, B-767 CIRC. APCH. – VMC ONLY.

At the time of the accident, he was San Francisco International Airport (SFO) San Francisco, California based

2.2.1 The First Officers Certification of Records

FAA records of the first officer indicated the following:

Notice of Disapproval – Private Pilot, was issued on March 20, 1987. Unsatisfactory items: Pilot Operation, Preflight planning, and Cross-Country planning

Private Pilot – Airplane Single-Engine Land certificate issued March 29, 1987.

Private Pilot – Airplane Single-Engine Land; Instrument Airplane certificate issued October 22, 1987.

Commercial Pilot – Airplane Single and Multiengine Land; Instrument Airplane; certificate issued December 19, 1987.

Airline Transport Pilot- Airplane Multiengine Land; EMB-120, Commercial Privileges Airplane Single-Engine Land; certificate issued February 13, 1998.

Airline Transport Pilot- Airplane Multiengine Land; EMB-120, B-757, B767, Commercial Privileges Airplane Single-Engine Land; Limitations: ATP Circ. Apch. – VMC Only; B-757, B-767 Circ. Apch. – VMC Only certificate issued June 17, 2001.

Airline Transport Pilot- Airplane Multiengine Land; EMB-120, B-757, B767, A-320, Commercial Pilot Privileges Airplane Single-Engine Land; Limitations: ATP Circ. Apch. – VMC Only; B-757, B-767 Circ. Apch. – VMC Only, A-320 SIC[22] Privileges only and Circ Apch. VMC only certificate issued April 5, 2006.

Airline Transport Pilot- Airplane Multiengine Land; EMB-120, B-757, B767, A-320, Commercial Pilot Privileges Airplane Single-Engine Land; Limitations: English Proficient; B-757, B-767 A-320 Circ. Apch. – VMC only certificate issued March 12, 2013.

Airline Transport Pilot- Airplane Multiengine Land; EMB-120, B-757, B767, B-777, A-320, Commercial Pilot Privileges Airplane Single-Engine Land; Limitations: English Proficient; B-777, B-757, B-767 A-320 Circ. Apch. – VMC only certificate issued December 23, 2013.

Ground Instructor, Advance Ground, Instrument Ground certificate issued December 5, 1990

Notice of Disapproval, Flight Instructor was issued on February 24, 1988. Areas to be reexamined were Oral: Effective Preflight and Postflight Instruction of Turns around a point, 8's on Pylon's, and rectangular courses. The entire flight portion. First failure.

Flight Instructor, Airplane Single Engine; certificate was issued on March 2, 1988.

Notice of Disapproval, Instrument Instructor PA-28-140, Entire Flight Test (First Failure) was issued on August 10, 1988.

Flight Instructor Airplane Single Engine Land, Instrument Airplane; certificate was issued on July 20, 1989.

Flight Instructor, Airplane Single and Multiengine Land, Instrument Airplane; certificate issued on March 13, 1990. Certificate reissued March 23, 1992, January 23, 1993, January 18, 1995, and January 6, 1997

2.2.2 The First Officer's Pilot Certificates Held at Time of the Incident

AIRLINE TRANSPORT PILOT (issued December 23, 2013)
Airplane Multiengine Land
A-320, B-757, B767, B-777, EMB-120
Commercial Privileges – Airplane Single-Engine Land

[22] Second in Command.

2.2.3 The First Officer's Flight Times

The following flight times were based on United Airlines provided NTSB form 6120.1 "Pilot/Operator Aircraft Accident/Incident Report" and were based on flight times gathered beginning in 1999 to present. According to United Airlines the flight time dates start as the date of hire on January 11, 1999.

Total Flying Time:	18,612
Total PIC Time:	2,400
Total SIC Time:	1 6,212
Total SIC Time in B-777:	4,190
Total Flying Time Previous 24 Hours:	8
Total Flying Time Previous 30 Days:	56
Total Flying Time Previous 90 Days:	108
Total Flying Time Previous 12 Months:	355
Total Flying Time in the B-777 the Previous 12 Months:	355

2.2.4 The First Officer's Training and Proficiency Checks Completed

The first officer was current and qualified in all required FAA training. This included Emergency Procedures as well as engine inoperative takeoff and landings. A list of the first officer's training modules that were successfully passed can be found in Attachment 9.

The FO's recent training history based on United Airlines records:

Date of Hire (United Airlines)	January 22, 1999
Date of Initial Type Rating onB-777	January 19, 2015
Date of Most Recent Proficiency Check	November 27, 2020
Date of Most Recent LOFT	November 28, 2020
Date of Most Recent Ground Training (Initial)	June 22, 2018

3.0 Aircraft Information

The accident airplane was a Boeing 777-222. The airplane was manufactured in 1994, registered to and operated by United Airlines. The airplane held a transport category airworthiness certificate dated September 29, 1995. The airplane was powered by two Pratt & Whitney PW4077 engines, and each were rated at 77,000 pounds of takeoff thrust. The airplane was configured with 2 pilot seats, 2 cockpit observer seats, 12 flight attendant seats, and 364 passenger seats.

Photo 1: Stock Photo of Accident Airplane. (Source: Jetphotos.com)

4.0 Meteorological Information

Airport weather observations for DEN were obtained from the National Weather Service.

Airport weather information found in the METAR[23] originated from an Automated Surface Observing System (ASOS). The following METARs were issued for DEN for the time period surrounding the accident:

[1253 MST] METAR KDEN 201953Z 18005KT 10SM FEW085 SCT130 SCT200 13/M09 A2970 FEW200 11/M07 A2979 RMK AO2 SLP040 T013311094 =

Decoded: *Routine weather observation for KDEN at 1253 local, wind from 180 at 05 knots, visibility 10 statute miles or more, a few clouds at 8,500 ft agl, scattered at 13,000ft. scattered at 20,000 ft, temperature 13° Celsius (C), dew point temperature of -9° C, altimeter 29.70 inches of mercury (inHg). Remarks; automated station with a precipitation discriminator, sea-level pressure 1004.0-hectopascals (hPa), temperature 13.3° C, dew point temperature -9.4° C.*

[1353 MST] METAR KDEN 202053Z 36019KT 10SM BKN100 BKN200 11/M04 A2967 RMK AO2 SLP031 T01111039 56036=

Decoded: Routine weather observation for KDEN at 2053Z, wind from 360° at 19 knots, visibility 10 miles or more, ceiling broken at 10,000 ft agl, broken at 20,000 ft,

[23] Meteorological Aerodrome Report.

temperature 11° C, dew point temperature of -4° C, altimeter 29.67 inHg. Remarks; automated station with a precipitation discriminator, sea-level pressure 1003.1-hPa, temperature 11.1° C, dew point temperature -3.9° C, 3-hour pressure tendency fallen 3.6-hPa.

5.0 Weight and Balance

According to the information provided by United Airlines, the following weight and balance calculations were used by the crew for the operation of the aircraft. Aircraft Limitations are listed in bold type. All weights below are in pounds (lbs.)

WEIGHT & BALANCE / PERFORMANCE	
Basic Operating Weight (ZFW)	364,296
Zero Fuel Weight	364,296
Maximum Zero Fuel Weight	**415,915**
Fuel Weight	112,370
Ramp Weight	537,126
Maximum Ramp Weight	**555,000**
Taxi Fuel Burn	1,100
Actual Takeoff Weight	527,185
Maximum Takeoff Weight	**540,185**
Estimated Landing Weight	520,685[24]
Maximum Landing Weight	**445,000**
CG	29.2% MAC
CG Limits	FWD CG Limit: 15.1% MAC, AFT CG Limit: 44.0% MAC
Landing Flaps	20
V_{REF}	136

6.0 Company Overview[25]

United Airlines first began in 1929 and was called United Aircraft Transport and Transportation Company, or UATC. UATC came together and formed United Airlines. Today, United Airlines it's a subsidiary of UAL Corporation with corporate offices in Chicago. United's largest hub was Chicago's O'Hare International Airport. United also has hubs in Washington Dulles International Airport, Denver International Airport, San Francisco International Airport, Los Angeles International Airport, Newark International Airport, Miami International Airport and Houston Intercontinental Airport.

[24] The estimated landing weight was based on a takeoff weight of 527,185 and landing 24 minutes later in DEN with a fuel consumption of 6,500 pounds of fuel used.

[25] Britannica.com

7.0 Relevant Systems

7.1 Electronic Checklist (ECL)

In the United Airlines B-777 Flight Manual (FM), Introduction section, 0.20.3 describes the operation of the ECL:

Operation with the electronic normal checklist is the same as the printed normal checklist except that there is no need to read aloud or visually confirm items that are complete (green).

Closed-loop (sensed) checklist items change from white to green when the action is taken. The PM checks off any open-loop (not sensed) item and verifies that all closed-loop items are green. See the Systems chapter, Flight Instruments, Displays, for a complete description of the ECL system.

The ECL presents a Non-Normal Menu, the primary purpose of which is to access Unannunciated Checklists and/or the condition statements for EICAS alert messages that are without rectangle icons.

7.2 Fire Protection

The United Airlines B-777 Flight Manual, Chapter 6.80, section 10, pg. 6.80.10.1, Fire Protection stated the following:

The B-777's has fire detection and extinguishing systems for both engines, the auxiliary power unit, cargo compartments, and lavatory smoke. The engines also have an overheat detection systems. The engine and APU fire and overheat detection systems are powered by the battery bus. Fire extinguishing systems are powered by the hot battery bus.

7.2.1 Engine Fire Protection

The United Airlines 777 Flight Manual, Rev 5-20, Chapter 6.80, Section 10 describes the Engine Fire Protection as follows:

Engine fire protection consists of these systems:

- *Engine fire and overheat detection*
- *Engine fire extinguishing*

7.2.2 Engine Fire and Overheat Detection

The United Airlines B-777 Flight Manual, Chapter 6.80, section 10, pg. 6.80.10.1, Engine Fire and Overheat Detection, stated the following:

There are two detector loops in each engine nacelle. Each detector loop provides both fire and overheat detection. Normally, both loops must detect a fire or overheat condition to cause an engine fire warning or overheat caution. If a fault is detected in one loop, the system automatically switches to single loop operation. If the operating loop senses a fire or overheat, the system provides the appropriate fire warning or overheat caution.

If there are faults in both detector loops in an engine nacelle, no fire or overheat detection is provided. The EICAS advisory message DET FIRE ENG (L or R) is displayed if the engine fire detection system fails.

7.2.3 Engine Fire Warning

The United Airlines B-777 Flight Manual, Rev 5-20, Chapter 6.80, Section 10.2 described the Engine Fire Warning as follows:

Indications of an engine fire are:

- *Fire bell sounds.*
- *Master WARNING lights illuminate.*
- *EICAS warning message FIRE ENG (L or R) displays.*
- *Engine fire switch (LEFT or RIGHT) fire warning light illuminates.*
- *Engine fire switch unlocks.*
- *Engine FUEL CONTROL (L or R) switch fire warning light illuminates.*

7.2.4 Engine Fire Extinguishing

The United Airlines B-777 Flight Manual, Rev 5-20, Chapter 6.80, Section 10.2 described the Engine Fire Warning extinguisher bottles as follows:

There are two fire extinguisher bottles. Either or both bottles can be discharged into either engine.

When the engine fire switch is pulled out, rotating the fire switch in either direction discharges a single extinguisher bottle into the associated engine. Rotating the engine fire switch in the other direction discharges the remaining extinguisher bottle into the same engine.

If an extinguisher bottle is discharged or has low pressure:

- *ENG BTL (1 or 2) DISCH light illuminates.*
- *EICAS advisory message BOTTLE (1 or 2) DISCH ENG displays.*

7.2.5 Engine Fire Extinguishing Diagram

The following two diagrams showing a diagram of the B-777 Fire Extinguishing system and the Discharge Nozzle location.[26]

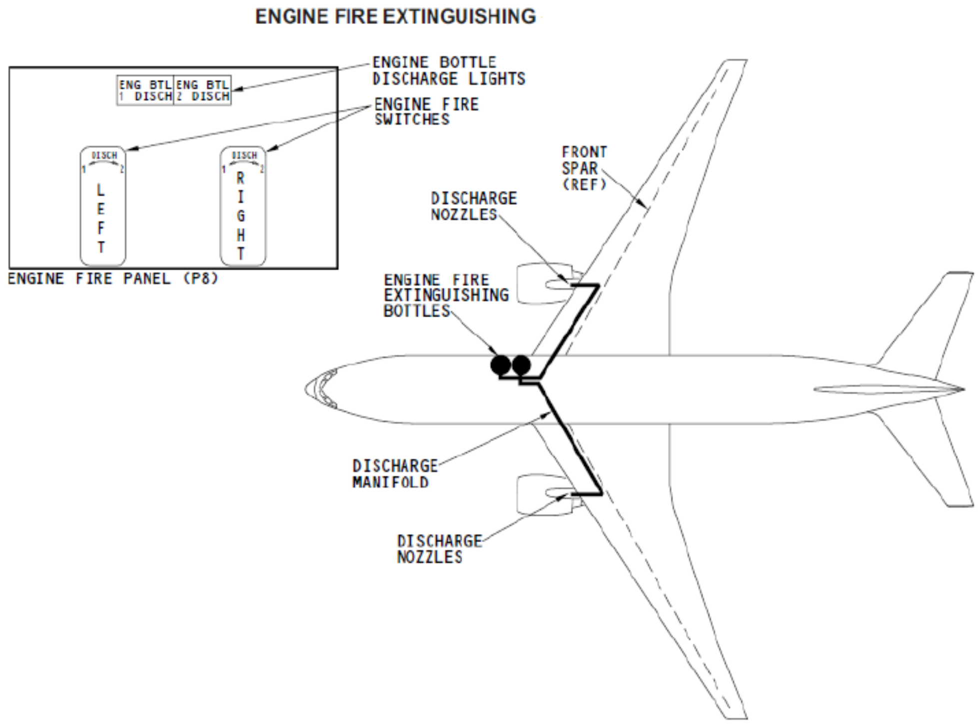


Diagram 1: Diagram of Engine Fire Extinguishing System

7.2.6 Discharge Nozzle Location

The Discharge Nozzles were located inside of the engine nacelle and cowling of the engine.

[26] Discharge Nozzle location are displayed with the approval of Boeing: Copyright © Boeing. Reprinted with permission of The Boeing Company

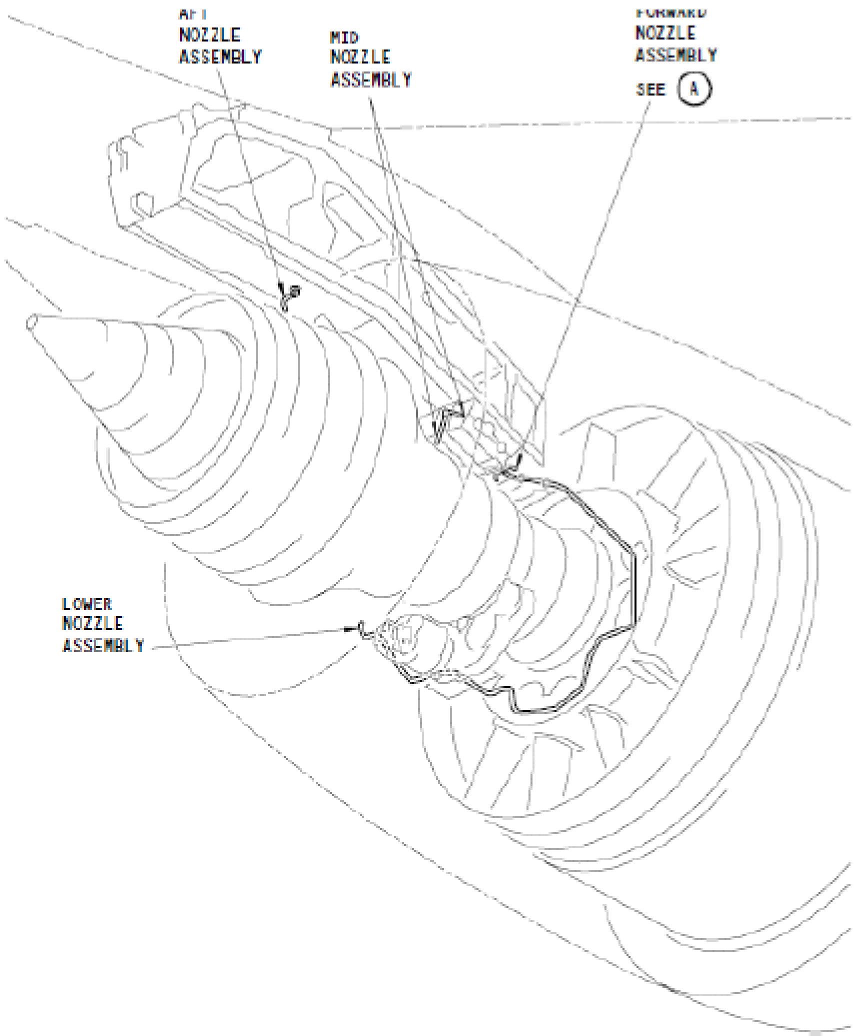


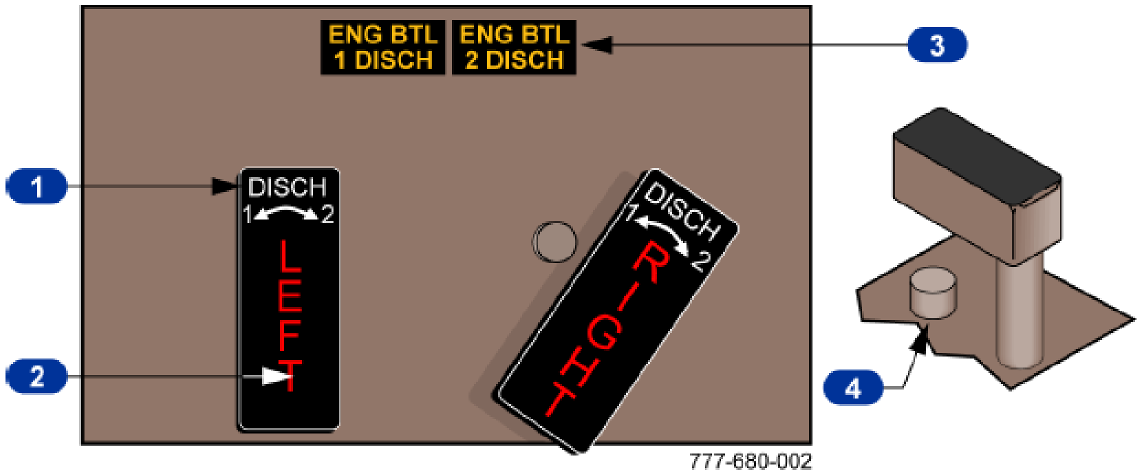
Diagram 2: Location of fire extinguishing discharge nozzles

7.2.7 Engine Fire Protection Control and Indicators

The United Airlines B-777 Flight Manual, Rev 5-20, Chapter 6.80, Section 20, Fire Protection Controls, and Indicators showed the Engine Fire Panel located on the Control Stand, just below the throttle quadrant.

See Photo 2 below and Attachment 2; 777 Simulator and Cockpit Observations for a further explanation of the Engine Fire protection System.

Photo 2: United Airlines B-777A, model simulator showing Right Engine Fire (Source: Attachment 2: 777 Simulator and Cockpit Observations)



1 Engine Fire Switch Mechanically locked in normal position. Unlocks automatically during a fire warning or manually by a button under each switch. Also unlocks when the FUEL CONTROL switch is moved to CUTOFF while the battery switch is on. Pulling the switch:

- Arms fire extinguishers.
- Closes engine and spar fuel valves.
- Closes engine bleed air valves.
- Trips generator fields and breakers.
- Shuts off hydraulic fluid to the engine-driven hydraulic pump.
- Depressurizes engine-driven hydraulic pump.
- Removes power from the reverser isolation valve.

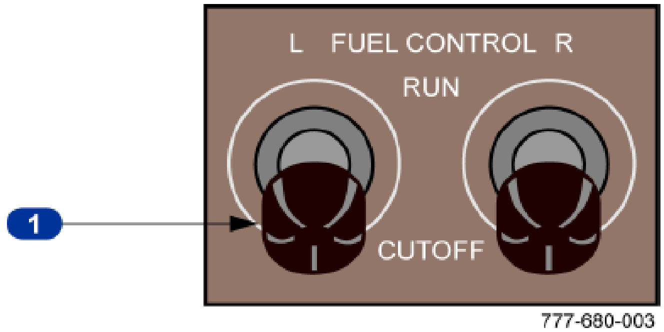
Rotating extended switch (left or right) discharges fire bottle number 1 or 2 into respective engine.

2 Engine Fire Warning Light Illuminates when a fire is detected or when the FIRE/OVHT TEST switch is pushed.

3 ENG BTL DISCH Lights Indicate low pressure in respective extinguishers.

4 ENG (and APU) Fire Override Switch Unlocks respective fire switch.

Diagram: Left and Right Engine Fire Control Switches.



1 Fire Warning Lights Illuminate red when an engine fire is detected or when the FIRE/OVHT TEST switch is pushed. Also, moving the associated FUEL CONTROL switch to CUTOFF unlocks the fire switch.

Diagram: Fuel Control Cutoff Switches, Left and Right, Source; United Flight Manual, Chapter 6.8


Photo 3. Picture of accident airplane, right engine (Source YouTube)

7.3 Fire and Overheat Detection System Fault Test

The United Airlines Flight Manual, 6.80.10.8, Fire Protection has the following description of the engine fire and overheat detection system:

The fire and overheat detection system has automatic and manual fault testing.

7.4 Fire and Overheat Automatic Fault Test

Fire and overheat detection system testing is automatic. The engine and APU systems continuously monitor the fire/overheat detector loops for faults. The cargo and wheel well systems continuously monitor for any system faults.

If a fault is detected, the system automatically reconfigures for single-loop operation. Complete system failures are indicated by an EICAS advisory message for the failed system:

- *DET FIRE ENG (L or R)*
- *DET FIRE APU*
- *DET FIRE CARGO (FWD or AFT)*

7.5 Manual Fault Test

The fire and overheat detection systems can be tested manually by pushing and holding the FIRE/OVHT TEST switch.
Indications for a manual fire and overheat detection system test are:

- *Fire bell sounds.*
- *Nose wheel well APU fire warning horn sounds (on the ground).*
- *EICAS warning message FIRE TEST IN PROG displays.*
- *The following lights illuminate:*
  - *Master WARNING lights*
  - *LEFT and RIGHT engine fire warning lights*
  - *APU fire warning light*
  - *Nose wheel well APU fire warning light*
  - *FWD and AFT CARGO FIRE warning lights*
  - *L and R FUEL CONTROL switch fire warning lights*

When the test is complete, the EICAS warning message FIRE TEST PASS or FIRE TEST FAIL replaces the FIRE TEST IN PROG message; the switch can be released. The appropriate system EICAS messages display with the FIRE TEST FAIL message:

- *DET FIRE ENG (L or R)*
- *DET FIRE APU*
- *DET FIRE CARGO (FWD or AFT)*
- *DET FIRE WHEEL WELL*
- *DET OVERHEAT ENG (L or R)*

All test messages clear when the test switch is released. If the switch is released with the FIRE TEST IN PROG message displayed, the test ends without completing

7.6 Thrust Asymmetry Compensation (TAC)

Section 6.90.10.12 of the United Airlines B-777 Flight Manual under Flight Controls, provided a description of the TAC and its features and functionally. It states:

The TAC system significantly reduces uncommanded flight path changes associated with engine failure. TAC continually monitors engine data to determine each engine's thrust level. If the thrust on one engine differs by 10% or more from the other, TAC automatically adds rudder to minimize yaw. Before liftoff TAC does not fully compensate for the failed engine so the engine failure can be recognized through roll/yaw cues. After liftoff TAC attempts to fully compensate for the failed engine. Compared to an aircraft without TAC, these roll/yaw cues are greatly reduced. The amount of rudder used is proportional to the engine thrust difference. Rudder movement is back-driven through the rudder pedals and displayed on the rudder trim indicator. Following engine failure, the pilot can trim the aircraft using additional rudder trim, control wheel input, aileron trim, or autopilot engagement.

*TAC is available **except**:*

- *When airspeed is below 70 knots on the ground, **or***
- *When reverse thrust is applied*

TAC automatically disengages if engine thrust data is lost. TAC may also disengage following severe engine damage or surge if it is unable to determine an accurate thrust level. TAC may still cause some rudder deflection in the appropriate direction just before automatically disengaging.

TAC can be manually overridden by rudder pedal inputs. TAC is available only in the normal flight control mode. To manually disarm TAC, push the THRUST ASYM COMP switch on the overhead panel. If TAC is automatically or manually disconnected, the EICAS advisory message THRUST ASYM COMP displays.

7.6.1 Engine Inoperative ILS Approach

The United Airlines B-777 Flight Manual, section 2.70.25 described an engine inoperative landing and the methods and policies that should be utilized. Factual Report sections 7.6.1 and 7.6.2 both use the same reference pages.

A flaps-20 approach is preferred anytime an engine is shut down or operating at reduced thrust. A flaps-30 approach is available when stopping distance is critical or other considerations make a flaps-30 approach necessary. Check performance limit weight to ensure go-around capability. If go-around becomes necessary from a flaps-30 engine inoperative approach, use flaps 20.

Intercept the localizer with flaps 5 at flaps 5 maneuvering speed. When the glideslope is at 1-1/2 dots, extend the flaps to 20, set target speed, lower the landing gear, and call for the Landing Checklist. Fly the approach at flaps-20 target speed.

An autoland may be accomplished if the quality of the approach is satisfactory. Additional engine-out logic is incorporated during runway alignment to ensure the downwind wing is not low at touchdown. If the crosswind is from the side opposite the failed engine, a failed engine high (upwind wing low) attitude is maintained during the approach. An additional sideslip is induced proportional to the engine-out crab and the crosswind sideslip (up to 5°) and is additive to the sideslip.

7.6.2 Engine Inoperative

The flight profile for an engine inoperative landing is the same as for a normal landing. Asymmetrical reverse thrust may be used with an engine inoperative. Use normal reversing procedures and techniques. TAC does not operate while using reverse thrust or below 70 KIAS. If directional control becomes marginal during deceleration, return the reverse lever to the idle detent. Single-engine taxi to the gate is permissible at Captain's discretion.

7.6.3 Tow-In Checklist

The United Airlines B-777 Flight Manual, Supplementary Procedures, section 4.90.11 provided the following Tow-In communication checklist:

Communications
Tow-in without headset communication is prohibited. During tow-in, the Captain monitors the interphone and the First Officer monitors ATC and Ramp, unless circumstances dictate otherwise. Oral challenges and responses must be made in a clear, concise manner, using the statements given below.

[F] APU. . . . . Start, if available
If the APU will be used for electrical power during tow-in, ensure the APU is supplying power before shutting down engines.

[C] Parking brake . . . . Set
Set the parking brake, observe PARKING BRAKE SET EICAS message displays, and verify brake pressure is normal.

[F] Passenger announcement . . . . Accomplish
Advise passengers to remain seated until the seatbelt signs are turned off.

[C] Fuel control switches . . . . Cutoff
If the APU or APU GEN is inoperative, leave the left engine running to supply electrical and pneumatic power.

After tow-in is completed:

[C, F] Parking normal procedures . . . . Accomplish

7.6.4 Quick Reference Checklist

The United Airlines Quick Reference Checklist (QRC) was described in the Flight Manual, Introduction section, 0.30.5[27]

QRCs are carried on the flight deck and contain some non-normal checklists from the Flight Manual used to stabilize the aircraft during a non-normal situation. Additionally, the QRC ensures critical steps are accomplished in a timely and consistent manner. The Flight Manual takes precedence over the QRC for any conflicts between the Flight Manual and QRC. Highlights are:

- *Immediate action items are enclosed in a double box.*
- *The Evacuation checklist is enclosed in a Red Box to make it easier to find.*

7.6.5 Evacuation Checklist

The 777 Evacuation Checklist was found on the United Airlines QRC that was in the cockpit. It was also found on the back cover of the Quick Reference Handbook.

[27] See Attachment 3 for a copy of the Quick Reference Checklist

EVACUATION

ATC	Advise [F]
Parking brake	Verify set [F]
OUTFLOW VALVE switches (both)	MAN [F]
OUTFLOW VALVE MANUAL switches (both)	Full OPEN [F]
FUEL CONTROL switches (both)	CUTOFF [F]
Engine fire switches	Pull [F]
APU fire switch	Override and pull [F]

If an engine or APU fire warning occurs:

Illuminated fire switch(es)	Rotate to the stop and hold for 1 second [F]

Evacuation	Announce, "Release your seatbelts and get out" [C]
EVAC COMMAND switch (as installed)	ON [C]

■ ■ ■ ■

FAA Approved - 2009

Caption 1: Evacuation Checklist

8.0 Relevant Procedures

8.1 Checklist

Normal Checklist

In the United Airlines Flight Manual, (FM) , chapter 0, section 20, pg. 0.20.1, the Normal Checklist is described as follows.

Normal checklists contain the minimum items needed to operate the aircraft safely. The items on a normal checklist are first accomplished in a procedure (typically when accomplishing a flow) then confirmed through a challenge and response process. Do not accomplish normal checklists from memory. Normal checklists include:

- *Items essential to safety of flight that are not monitored by an alerting system*

- *Items essential to safety of flight that are monitored by an alerting system but, if not done, would likely result in a catastrophic event if the alerting system fails*
- *Items needed to meet regulatory requirements*
- *Items needed to maintain fleet commonality*
- *Items that enhance safety of flight and are not monitored by an alerting system (e.g., autobrakes)*
- *Items that could result in injury to personnel or damage to equipment if not accomplished.*

8.2 Types of Normal Checklist

The United Airlines Flight Manual, Introduction. Non-Normal Operations, pg. 0.30.2 describes two types of Normal Checklist.

Immediate Action Checklists with items that must be accomplished immediately and, if delayed, would put the crewmembers, passengers, or aircraft in immediate jeopardy. These memory items are enclosed in a double box.

Read and Do Checklists accomplished by read and do in a timely manner, referencing the appropriate non-normal checklist. If the checklist is on the QRC, its initial steps are read and accomplished from the QRC; follow-on non-normal steps are accomplished by referring to the ECL or FM.

8.3 Non-Normal Checklist Operations, Introduction

In the United Airlines B-777 Flight Manual, Chapter 0, Section 30, the description, and non-normal checklist philosophy was presented.

> WARNING: *In determining the safest course of action, troubleshooting may cause further loss of system function or system failure (i.e., taking steps beyond published non-normal checklist steps). Consider troubleshooting only when completion of the published non-normal checklist results in an unacceptable outcome.*

Fly the Aircraft, Silence the Warning, and Confirm the Emergency are critical steps in any non-normal situation, and must be performed in conjunction with the non-normal procedures.

A Quick Reference Checklist (QRC) provides pilots a tool to recover and stabilize the aircraft from a non-normal situation while minimizing errors and ensuring timeliness in accomplishing the checklist(s).

Non-normal checklists start with steps to correct the situation. If needed, information for planning the rest of the flight is included. When special items are needed to configure the aircraft for landing, the items are included in the checklist under Deferred Items.

No critical system control (e.g., thrust lever, fuel control switch, fire handle/switch, A/T arm switch, and generator control/disconnect switch) will be moved during a non-normal procedure without the concurrence of both pilots.

The non-normal procedures in this manual represent the best available information. Pilots shall follow these procedures as long as they fit the situation. If at any time they are not adequate or do not apply, consider all available options. The Captain must then determine the best course of action.

The non-normals cannot cover all emergency situations. In an emergency situation that requires immediate decision and action, FARs[28] allow the Captain to take any action that he considers necessary under the circumstances. In such a case, he may deviate from prescribed operations, procedures and methods, weather minimums, and the non-normal procedures to the extent required in the interest of safety.

While every attempt is made to supply needed non-normal checklists, it is not possible to develop checklists for all conceivable situations. In some smoke, fire, or fumes situations, pilots may need to move between the Smoke, Fire or Fumes checklist and the Smoke or Fumes Removal checklist. In some multiple failure situations, pilots may need to combine the elements of more than one checklist. In all situations, the Captain must assess the situation and use good judgment to determine the safest course of action.

The Captain is responsible for ensuring that all checklists are completed.

8.4 Engine Anomalies

The United Airlines B-777 Flight Manual, 0.30.3, Introduction, Non-Normal Operations provided the following about engine anomalies:

Checklists directing an engine shutdown must be evaluated by the captain to determine whether an actual shutdown or operation at reduced thrust is the safest course of action.

8.5 FIRE ENG L (R)

The United Airlines B-777 Flight Manual, Non-Normals, Fire Protection, 2.80.7 provided the following checklist for an engine fire, left or right:

[28] Federal Aviation Regulation

[ ] FIRE ENG L (R)

Condition: Fire is detected in the engine.

1 A/T ARM switch
(affected side). Confirm . . . . OFF

2 Thrust lever
(affected side). Confirm. . . . . Idle

3 FUEL CONTROL switch
(affected side). . . . . Confirm . . . . CUTOFF

4 Engine fire switch
(affected side). Confirm. . . . . Pull

5 **If the FIRE ENG message stays displayed:**

Engine fire switch . . . . Rotate to the stop and hold for 1 second

If after 30 seconds, the FIRE ENG message stays displayed:

Engine fire switch (affected side). Rotate to the other stop and hold for 1 second

6 Choose one:

◆ **On the ground:**

■■■■

◆ **In flight:**

▶▶**Go to step 7**

7 Driftdown checklist . . . . Consider

8 APU selector (if APU available) . . . . START, then ON

9 Transponder mode selector . . . . TA ONLY

10 ***Plan to land at the nearest suitable airport.***

▼ **Continued on next page** ▼

▼ **FIRE ENG L (R) continued** ▼

Note: *A flaps-20 approach is preferred anytime an engine is shut down or operating at reduced thrust. A flaps-30 approach is available when stopping distance is critical or other considerations make a flaps-30 approach necessary.*

Check landing distance (Non-Normal Configuration table, Performance chapter).

If planning flaps-30 approach, check performance limit weight (Performance Limit Weights table, Performance chapter). If actual weight exceeds landing performance limit weight, conduct a flaps-20 approach.

Check the ACARS Landing Data message for an engine failure procedure.

For a flaps-20 approach and landing, REF speed is 20 REF. Select the GND PROX FLAP OVRD switch to OVRD. Use flaps 5 for go-around.

For a flaps-30 approach and landing, REF speed is 30 REF. Use flaps 20 for go-around.

11 Do ***not*** accomplish the AUTOTHROTTLE checklist.

12 Checklist complete except Deferred Items

▼ ▼ ▼ ▼ ***DEFERRED ITEMS*** ▼ ▼ ▼ ▼

Descent Checklist

- ■ Recall and notes . . . . Checked
- ■ Landing distance and autobrakes . . . . Checked, ___set
- ■ Reference speed . . . . Flaps___, (REF)___, set [PM], set [PF]
- ■ FMC, radios . . . . Set
- ■ Arrival briefing . . . . Complete
- ■ Ground proximity flap override switch . . . . As required

Landing Checklist

- ■ Speed brake . . . . Armed
- ■ Gear . . . . Down
- ■ Flaps . . . . ___

■ ■ ■ ■

8.6 Land at Nearest Suitable Airport,

The United Airlines Flight Operations Manual (FOM), Section2.30.1, dated March 26, 2021, has the following requirements for landing at the nearest suitable airport.

PLAN TO LAND AT THE NEAREST SUITABLE AIRPORT

Some emergency or non-normal procedures direct the pilots to plan to land at the nearest suitable airport. Diversion to this airport is considered by United to be the diversion alternative that, in the Captain's best judgment and considering all applicable factors, results in the highest level of safety. A suitable airport is an airport with facilities and conditions that will not expose the passengers and crew to greater risk than continuing to a more distant airport. Factors to consider include abut are not limited to:

- *Nature of the emergency/non-normal*
- *Time/Distance/Fuel to airport*
- *Runway/Length/Width/Condition*
- *Enroute and terminal weather*
- *Aircraft performance*
- *Approaches, navaids, and chart availability*
- *Enroute terrain and obstructions*
- *Emergency ARFF/Medical facilities*
- *Pilot airport familiarity*
- *Geo-political factors*

Although the Captain's/crew's judgment (along with recommendations from Dispatch) is paramount in deciding the appropriate course of action, this guidance does not authorize flying beyond an airport at which the highest level of safety can be attained (including continuing to the original destination). Factors beyond safety considerations (e.g., Company economics, availability of maintenance/station personnel, passenger accommodations, connecting flights) are secondary considerations and should not impact the decision to land at the nearest suitable airport when an emergency/non-normal procedure or regulations direct such action.

If diversion to an undesignated or emergency airport is required, the Captain must exercise his emergency authority. Additionally, airports designated as emergency airports are typically only issued a single approach chart which may cause problems depending on the current wind or NAVAID[29] status.

[29] Navigational Aid

None of the guidance provided above precludes the definition of Adequate Airport in the Glossary as they apply to ETOPS[30]*.*

8.7 Engine Start

Engine Start General

In the United Airlines B-777 Flight Manual, Normals, section 50, pg. 3.50.1, provided the following engine starting and Autostart guidance:

The engine start sequence begins when the Captain calls for the first engine to be started.
When communicating with pushback personnel, refer to the left engine as "number 1" and the right engine as "number 2."

Use autostart unless otherwise directed by Maintenance. Monitor the autostart attempts but do not intervene; an ECL directs the appropriate action following the last unsuccessful start attempt.

If the autostart sequence fails, complete the subsequent ECL, then contact Maintenance for further action.

8.7.1 Engine Start Procedure

The United Airlines B-777 Flight Manual, Normals' section 50, pg. 3.50.1 had the following engine start procedure.

ENGINE START PROCEDURE

After clearance to start engine(s) is received:

■ [C] Engine start . . . . Announce
  Announce which engine(s) to start.

■ [F] EICAS . . . . Recall/cancel
  - Recall EICAS and resolve any messages or indications that might require pilot or maintenance action.
  - Clear EICAS messages with the CANC/RCL switch after resolving all messages.

[30] Extended-range Twin-engine Operational Performance Standards.

■ [F] Secondary engine indications . . . . Verify displayed

Note: *Observe oil pressure increase. Autostart does not monitor oil pressure or oil temperature. Abort start if no oil pressure is observed after initial EGT rise. Monitor engine instruments for normal indications as the engines accelerate and stabilize at idle.*

■ [F] START/IGNITION selector(s) . . . . START

■ [F] FUEL CONTROL switch(es) . . . . RUN

■ [F] Engine indications . . . . Monitor

Observe the following indications:

- N2 rotation
- N1 rotation
- Fuel flow
- EGT indication
- Oil pressure increase. During cold weather starts, initial oil pressure may be slow to rise and higher than normal.

8.8 Dual Verification of Critical Controls

The United Airlines, B-777 Flight Manual, Non-Normal Operations, pg. 0.30.7 described how to run a Non-Normal checklist and their hierarchy of items to accomplish first. United Airlines used the word "Confirm" to describe dual verification when moving a switch and/or throttle.

Confirm Included in checklist items when both pilots must verbally agree before action is taken. During an inflight non-normal situation, verbal confirmation is required for:

- *Engine thrust lever*
- *Fuel control switch*
- *Engine or APU fire switch, or a cargo fire alarm switch*
- *A/T arm switch (for some fleets)*
- *Generator drive disconnect switch*

8.9 Engine Failure in Flight

The United Airlines FOM, Engine Emergencies, 2.10.6, provided the following guidance on engine failure in flight:

If an engine failure or shutdown occurs on a two-engine aircraft, diversion is required to the nearest suitable airport, in point of time, where a safe landing can be made (FAR

121.565). The Captain must notify ATC and Dispatch as soon as possible, provide reason for the engine shutdown, and keep them informed regarding the progress of the flight.

8.10 Elec Gen Drive L/R

The United Airlines Flight Manual, section 2.60.3 displays the checklist to be used for an Electrical Generator Drive failure:

[ ] ELEC GEN DRIVE L (R)

Condition: A generator drive fault occurs.

Note: *With this single failure, the aircraft remains fully capable of prolonged, safe operations.*

1 ⚠ Action is irreversible.

DRIVE DISC switch
(affected side) . . . . Confirm . . . . Push and hold for 1 second

2 APU selector
(if APU available) . . . . START, then ON

3 Do *not* accomplish the ELEC GEN OFF checklist.

8.11 Electrical Back Up Generators, BUG

The FO, in his interview said he saw PMG[31] briefly display on the EICAS at the time of the engine failure and fire. The United Airlines Flight Manual, section 6.60.10.8 described the Backup Generators, BUG[32]'s and the PMGs, as follows:

Backup power is provided by one variable speed, variable frequency generator mounted on each engine. A frequency converter converts the generator frequency to a constant 400 Hz. Only one backup generator can power the converter at a time. Each backup generator contains two permanent magnet generators (PMGs) that supply power to the flight control DC electrical system. If both IDGs and the APU generator are inoperative, a backup generator powers essential aircraft equipment. To reduce electrical loading on the backup generator, the following systems are inoperative:

- *TCAS*
- *SATCOM*
- *Right HF radio and associated datalink*
- *Center tank override/jettison pumps (center tank fuel is unusable and cannot be jettisoned)*
- *Position and other exterior lights (except nose gear landing lights)*
- *All non-essential cabin equipment (galleys, entertainment systems, etc.)*
- *Passenger cabin lighting (except night, galley, and cross-aisle lights)*

[31] Permanent Magnet Generator
[32] Back Up Generator

- *Cabin temperature control (remains operative, but in degraded mode)*

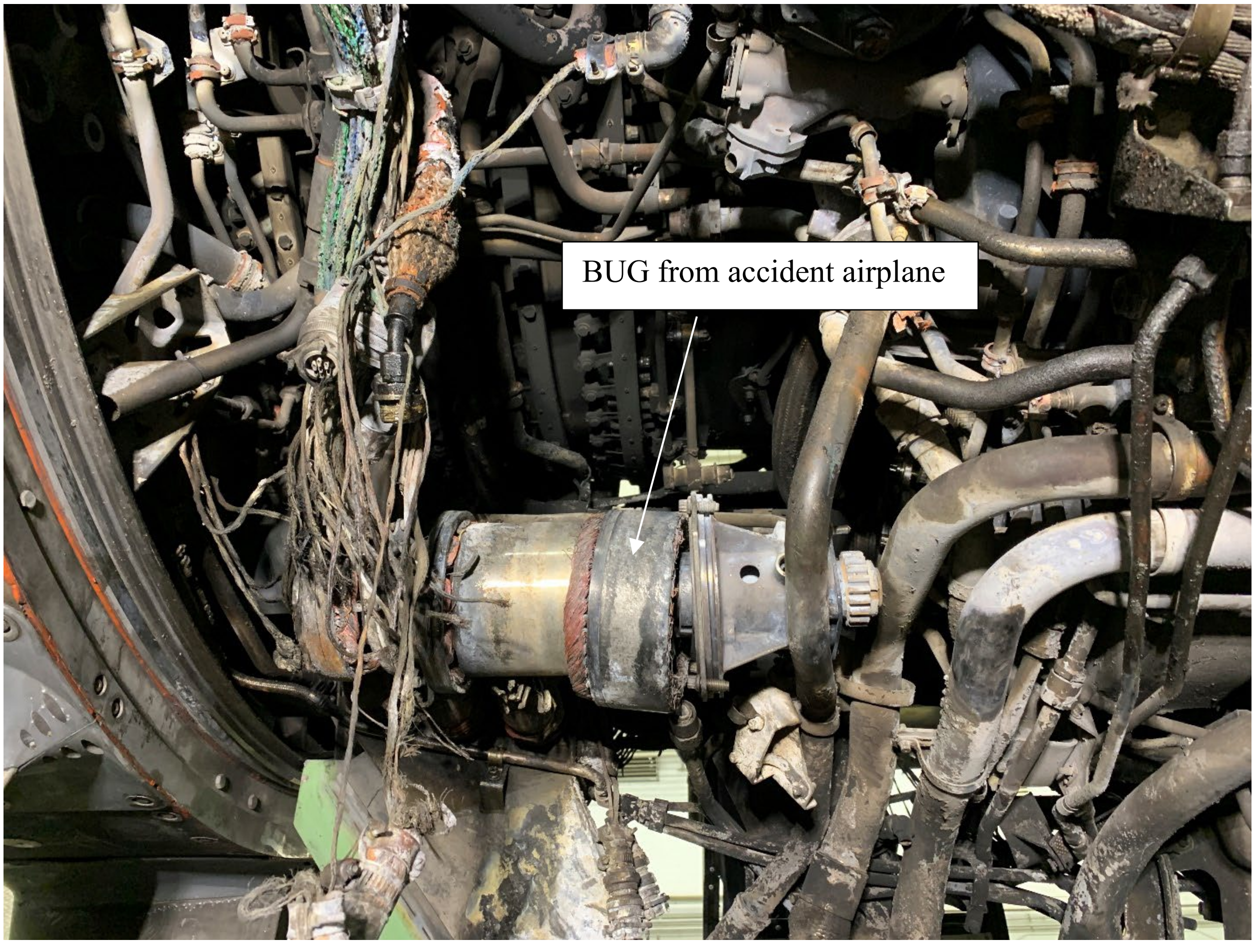


Photo 4, Back Up Generator, from the accident airplane. Source: NTSB photo

8.12 Bleed Air Loss Body R Configuration

[ ] BLEED LOSS BODY R

Condition: Bleed air from the right body duct is not available.

1 C2 AIR DEMAND pump selector . . . . OFF

2 ***CAUTION:* *Do not change the APU bleed, engine bleed, or bleed isolation switch positions. Airplane damage can occur.***

3 Do ***not*** accomplish the HYD PRESS DEM C2 checklist.

9.0 Training Information

9.1 Crew Resource Management and Threat and Error Management

Sections 9.0 – 9.8 of this factual report were all contained in the United Airlines Flight Operations Manual, Operating Information, Chapter 3, Section 20, Operating Information, CRM/TEM which stated:

Crew Resource Management (CRM) enhances a critical set of observable interpersonal human behaviors that go beyond technical stick and rudder skills. CRM augments technical expertise to create a more productive and safer crew environment. CRM focus communicate and manage resources.

Threat and Error Management (TEM) refers to the process of managing operational threats and human errors. Threat management reduces the potential for pilot error, while error management mitigates the negative consequences of errors. These combined techniques are known as Threat and Error Management, or TEM. TEM promotes vigilance versus complacency by implementing an active, continuous process of identifying and preparing for threats and identifying and repairing errors at their earliest opportunity. Failing the effectively manage either threats or errors will negatively influence a crew's ability to maintain a safe operation.

*The fundamental purpose of CRM/TEM is to focus on the effective utilization of available resources as a countermeasure to operational threats and human errors. CRM and TEM are independent yet, interdependent. CRM emphasizes **how** crews communicate and manage resources. TEM emphasizes **what** crewmembers manage and communicate about: operational threats and human errors. For CRM/TEM to be effective, crewmembers must be proficient in both CRM and TEM skills.*

Maintaining safe operations is achieved by successfully employing both CRM/TEM and technical skills. Failing to effectively manage either threats or errors will negatively influence the ability to maintain safe operations.

*The goal of the CRM/TEM program remains singularly focused: **maximize flight safety by minimizing incidents and accidents caused by human factors.***

9.2 Communications and Monitoring Strategies

9.2.1 Verbalize, Verify and Monitor (VVM)

VVM is an effective TEM strategy to counter threats and errors encountered during flight operations. Crewmembers who verbalize plans and ideas, verify them with others, and monitor for the expected result are better threat and error managers, enhancing safe operations.

9.3 Threats

Operational threats and human errors are inevitable within the aviation environment. Line Operational Safety Audit (LOSA) data shows that on average, pilots encounter three operational threats per flight. Threats are operational events or concerns that:

- *Occur outside the influence of the crewmember*
- *Increase operational complexity*
- *Require crewmember attention to maintain safety margins.*

Threats can be either anticipated or unanticipated. For example, anticipated threats could include terrain, adverse weather, deferred maintenance items, or airport conditions. Examples of unanticipated threats are system malfunctions, medical emergencies, or an unpredicted windshear encounter.

9.3.1 Threat Management

Effective threat management reduces the potential for crewmember error. The first step in effective threat management is to ***identify threats****, both anticipated and unanticipated. The earlier a threat is identified, the more quickly and effectively it can be managed, minimizing the impact on safe operations. Effective threat management strategies include proper preparation by:*

- *Adhering to standard operating procedures*
- *Applying applicable CRM/TEM skills*
- *Persistently briefing applicable threat(s) to safe operations*

Stated simply: ***Identify And Prepare***

Errors may occur when a threat is not identified or identified but not effectively managed.

9.4 Errors

An error is an unintentional deviation from desired performance. Errors are things we do incorrectly, or things we neglect to do. These are referred to as acts of commission or omission, respectively. While error is inevitable in human activity, the numbers and severity of these can be mitigated through training, vigilance, teamwork, communication and monitoring strategies (3.20), and CRM/TEM skills (3.20). In short, while error may be inevitable, many controls are available to reduce them. Still, pilot error is an ever-present threat each individual crew member poses to safe operations.

9.4.1 Error Management[33]

Effective error management utilizes tools and techniques to proactively and/or eliminate the negative consequences of errors. Proper threat management prevents many errors from taking place. However, errors also occur in the absence of threats. Therefore, good error management begins with error

[33] Topics 9.4.1 and 9.5 are both titles Error Management but this was taken for the United FOM pages 3.20.2 and 3.20.3

identification. VVM are essential tools for trapping errors. The earlier an error is identified, the sooner it can be repaired and alleviate potential for an Undesired Aircraft State (UAS). The complete return to safe operations does not end there. A dialogue facilitated through use of the Debrief Card will enable a true understanding of error and mismanaged threats; providing opportunity to improve.

9.4.2 Intentional Non-Compliance Impact on TEM Performance

Intentional non-compliance (INC) is a decision to operate outside established standard operating procedures and/or governing regulations. Acts of INC are related to subsequent pilot errors and mismanaged threats relative to safe operations. According to Line Operations Safety Audit (LOSA) industry data, intentionally non-compliant flight crews are far more likely to commit errors. LOSA refers to errors caused by INC as intentional non-compliance errors.

When INC becomes habitual in the absence of consequences, Normalization of Deviation is established as an alternative to compliance. This creates opportunity for exponential errors, and a growing systemic threat to safe operations. The best defense against intentional non-compliance is holding oneself and each o accountable to the established standard operating policies and procedures.

9.5 Error Management

*Effective error management mitigates the negative consequences of human errors. The first step in error management is to **identify errors**. The earlier an error is identified, the more quickly it can be repaired, thus returning the flight to a safe operation. The strategies for error management are the implementation of applicable CRM/TEM skills. These may include:*

- ***Monitor/Cross-**Check by maintaining awareness of the aircraft status and the crewmember's action.*
- ***Workload Management** by ensuring task are properly prioritized and managed.*
- ***Automation Management** by ensuring proper automation levels are selected.*

*Stated Simply: **Identify and Repair.***

9.6 Undesired Aircraft State

Undesired Aircraft State (UAS) is a position, attitude, condition, or configuration of an aircraft that reduces safety margins. It is a safety-compromising state that results from ineffective error management. Identifying an UAS is the first step to returning the flight to safe operations. The earlier an UAS is identified the earlier recovery can occur. Pilots must take immediate action that may include a combination of CRM/TEM and technical skills. These may include:

- ***Monitor/Cross-Check** to actively verify aircraft position and configuration.*
- ***Automation Management** to ensure proper automations levels are selected.*
- ***Technical Skills** (stick and rudder) to fly the aircraft.*

*Stated simply: **Identify and Recover***
An aircraft operation in an undesired state and not promptly recovered may lead to an incident or accident.

9.7 CRM/TEM Skills

A safe operation is maintained by combining technical skills with managing threats and errors through the effective implementation of CRM and TEM skills. These observable and assessable human behaviors include both CRM and TEM skills that when combined enhance flight safety by giving crewmembers tools to manage operational threats and human errors. The CRM/TEM skills are:

***Situational Awareness** Correctly assess the current and anticipated environment; identify and anticipate threats and errors.*
***Leadership Effectiveness** Exercise responsibilities in a manner that promotes teamwork, professionalism, and mentoring.*
***Planning and Decision Making** Incorporate relevant information, develop operational strategies, and chooses the best course of action consistent with safe, reliable, and efficient operations.*
***Communication** Exchange information, ideas, and/or instructions in a timely manner.*
***Monitor/Cross-check** Actively verify aircraft systems, aircraft position/configuration, and crewmember actions; resolve inconsistency and uncertainty.*
***Workload Management** Effectively manage tasks to optimize overall performance.*
***Automation Management** Select appropriate level of automation for the situation and verify automation status.*

9.8 CRM/TEM Model

CRM/TEM may be visualized using the CRM/TEM model below. Safe operations are depicted at the top of the model and represent the desired operating environment. As a crew encounters operational threats or human error, there is a potential to move away from the safe operations area. If the trend continues, the result may be an incident or accident. Effective application of CRM/TEM skills creates a path away from an incident/accident and will turn a divergent trend back toward safe operations.

CRM/TRM Model

F. LIST OF ATTACHMENTS

Attachment 1 - Flight Crew Interview and Transcripts
Attachment 2 - 777 Simulator and Cockpit Observation
Attachment 3 - United 777 Quick Reference Checklist
Attachment 4 - Flight Dispatch Release
Attachment 5 - United 777 Flight Manual {Excerpts}
Attachment 6 - ACARS[34] Communications
Attachment 7 - Flight Plan
Attachment 8 - Captains Trainings Records
Attachment 9 - First Officers Training Records

Submitted by:

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Warren Abrams
Air Safety Investigator

[34] Aircraft Communication Addressing and Reporting System ACARS (pronounced AY-CARS) is a digital data link system for the transmission of messages between aircraft and ground stations, which has been in use since 1978. At first it relied exclusively on VHF channels but more recently, alternative means of data transmission have been added which have greatly enhanced its geographical coverage. There has also been a rapid trend towards the integration of aircraft systems with the ACARS link. Both have led to rapid growth in its use as an operational communications tool. Source: Skybray.aero

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