Crash of Pinnacle Airlines Flight 3701
Bombardier CL-600-2B19, N8396A
Jefferson City, Missouri
October 14, 2004

ACCIDENT REPORT

NTSB/AAR-07/01
PB2007-910402

**National
Transportation
Safety Board**

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Aircraft Accident Report

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Notation 7695E
Adopted January 9, 2007

National Transportation Safety Board
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Washington, D.C. 20594

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Abstract: This report explains the accident involving a Bombardier CL-600-2B19, N8396A, which crashed into a residential area about 2.5 miles south of Jefferson City Memorial Airport, Jefferson City, Missouri. During the flight, both engines flamed out after a pilot-induced aerodynamic stall and were unable to be restarted. Safety issues discussed in this report focus on flight crew training in the areas of high altitude climbs, stall recognition and recovery, and double engine failures; flight crew professionalism; and the quality of some parameters recorded by flight data recorders on regional jet airplanes.

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Abbreviations

a.c.	alternating current
AC	advisory circular
AD	airworthiness directive
ADG	air-driven generator
AIRMET	airman's meteorological information
AIZ	Lee C. Fine Memorial Airport, Kaiser Lake Ozark, Missouri
ALPA	Air Line Pilots Association
AND	airplane nose down
ANU	airplane nose up
AOA	angle of attack
APU	auxiliary power unit
ARTCC	air route traffic control center
ASAP	Aviation Safety Action Program
ASOS	automated surface observing system
ATC	air traffic control
ATOS	Air Transportation Oversight System
ATS	air turbine starter
CFR	*Code of Federal Regulations*
cg	center of gravity
CRJ	Canadair regional jet
CRM	crew resource management
CVR	cockpit voice recorder
DTW	Detroit Metropolitan Wayne County Airport, Detroit, Michigan
EICAS	engine indicating and crew alerting system
FAA	Federal Aviation Administration
FCOM	flight crew operating manual

FDR	flight data recorder
FMS	flight management system
FOQA	flight operational quality assurance
fpm	feet per minute
FSDO	flight standards district office
GAO	Government Accountability Office
GE	General Electric
GPWS	ground proximity warning system
Hg	mercury
ICAO	International Civil Aviation Organization
ILS	instrument landing system
ISA	International Standard Atmosphere
JEF	Jefferson City Memorial Airport, Jefferson City, Missouri
KIAS	knots indicated airspeed
LBO	Floyd W. Jones Lebanon Airport, Lebanon, Missouri
LCV	load control valve
LIT	Little Rock National Airport, Little Rock, Arkansas
LOSA	Line Operations Safety Audit
METAR	meteorological aerodrome report
msl	mean sea level
MSP	Minneapolis-St. Paul International Airport, Minneapolis, Minnesota
N1	engine fan speed
N2	engine core speed
NWS	National Weather Service
POI	principal operations inspector
SB	service bulletin
SGF	Springfield-Branson Regional Airport, Springfield, Missouri
SMS	safety management system
S/N	serial number

SPS	stall protection system
TBN	Waynesville Regional Airport, Fort Leonard Wood, Missouri
VIH	Rolla National Airport, Rolla/Vichy, Missouri

Executive Summary

On October 14, 2004, about 2215:06 central daylight time, Pinnacle Airlines flight 3701 (doing business as Northwest Airlink), a Bombardier CL-600-2B19, N8396A, crashed into a residential area about 2.5 miles south of Jefferson City Memorial Airport, Jefferson City, Missouri. The airplane was on a repositioning flight from Little Rock National Airport, Little Rock, Arkansas, to Minneapolis-St. Paul International Airport, Minneapolis, Minnesota. During the flight, both engines flamed out after a pilot-induced aerodynamic stall and were unable to be restarted. The captain and the first officer were killed, and the airplane was destroyed. No one on the ground was injured. The flight was operating under the provisions of 14 *Code of Federal Regulations* Part 91 on an instrument flight rules flight plan. Visual meteorological conditions prevailed at the time of the accident.

The National Transportation Safety Board determines that the probable causes of this accident were (1) the pilots' unprofessional behavior, deviation from standard operating procedures, and poor airmanship, which resulted in an in-flight emergency from which they were unable to recover, in part because of the pilots' inadequate training; (2) the pilots' failure to prepare for an emergency landing in a timely manner, including communicating with air traffic controllers immediately after the emergency about the loss of both engines and the availability of landing sites; and (3) the pilots' improper management of the double engine failure checklist, which allowed the engine cores to stop rotating and resulted in the core lock engine condition. Contributing to this accident were (1) the core lock engine condition, which prevented at least one engine from being restarted, and (2) the airplane flight manuals that did not communicate to pilots the importance of maintaining a minimum airspeed to keep the engine cores rotating.

The safety issues discussed in this report focus on flight crew training in the areas of high altitude climbs, stall recognition and recovery, and double engine failures; flight crew professionalism; and the quality of some parameters recorded by flight data recorders on regional jet airplanes. Safety recommendations concerning these issues are addressed to the Federal Aviation Administration.

1. Factual Information

1.1 History of Flight

On October 14, 2004, about 2215:06 central daylight time,[1] Pinnacle Airlines flight 3701 (doing business as Northwest Airlink), a Bombardier CL-600-2B19,[2] N8396A, crashed into a residential area about 2.5 miles south of Jefferson City Memorial Airport (JEF), Jefferson City, Missouri. The airplane was on a repositioning flight[3] from Little Rock National Airport (LIT), Little Rock, Arkansas, to Minneapolis-St. Paul International Airport (MSP), Minneapolis, Minnesota. During the flight, both engines flamed out[4] after a pilot-induced aerodynamic stall and were unable to be restarted. The captain and the first officer were killed, and the airplane was destroyed. No one on the ground was injured. The flight was operating under the provisions of 14 *Code of Federal Regulations* (CFR) Part 91 on an instrument flight rules flight plan. Visual meteorological conditions prevailed at the time of the accident.

Flight 3701 departed LIT about 2121. The flight plan indicated that the company-planned cruise altitude was 33,000 feet. About 5 seconds after takeoff, when the airplane was at an altitude of about 450 feet mean sea level (msl)[5] (about 190 feet above ground level), the first of three separate pitch-up maneuvers during the ascent occurred when the flight crew moved the control column to 8° airplane nose up (ANU), causing the airplane's pitch angle to increase to 22° and resulting in a vertical load of 1.8 Gs.[6] The rate of climb during this pitch-up maneuver was 3,000 feet per minute (fpm). Immediately afterward, the flight data recorder (FDR) recorded stickshaker and stickpusher activations,[7] a full airplane-nose-down (AND) control column deflection, a decrease in pitch angle, and a drop in vertical load to 0.6 G.

About 2125:55, when the airplane was at an altitude of about 14,000 feet, the flight crew engaged the autopilot. The air traffic control (ATC) transcript and FDR data showed

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[1] All times in this report are central daylight time based on a 24-hour clock.

[2] The accident airplane was a Canadair regional jet (CRJ) -200 model, which is one of three models in the CL-600-2B19 series. (The other two models are the CRJ-100 and CRJ-440.) Bombardier acquired Canadair in December 1986.

[3] A repositioning flight relocates an airplane to the airport where the airplane's next flight is scheduled. Repositioning flights do not carry revenue passengers or cargo but can carry nonrevenue passengers.

[4] A flameout is an interruption of a turbine engine's combustion process that results in an uncommanded engine shutdown.

[5] All altitudes and elevations in this report are msl unless otherwise noted.

[6] G is a unit of measurement that is equivalent to the acceleration caused by the earth's gravity (32.174 feet/second^2).

[7] The stickshaker produces vibrations in the control columns to warn pilots of an impending stall. If the angle of attack (AOA) continues to increase, the stickpusher moves the control columns forward (nose down) automatically to prevent an aerodynamic stall, which can occur afterward.

that the flight crewmembers changed seats in the cockpit during this time,[8] but the ATC transcript did not indicate the reason for the seat change. About 2127:15, when the airplane was at an altitude of about 15,000 feet, the flight crew disengaged the autopilot.

About 2127:17, when the airplane was in level flight at an altitude of 15,000 feet, the second pitch-up maneuver began when the flight crew moved the control column to 3.8º ANU, causing the airplane's pitch angle to increase to 17º and resulting in a vertical load of 2.3 Gs. The rate of climb during this pitch-up maneuver reached 10,000 fpm briefly. Between about 2128:40 and about 2128:43, the flight crew made a left rudder input of 4.2º, a right rudder input of 6.0º, and a left rudder input of 0.4º, resulting in lateral loads of -0.16 G, 0.34 G, and -0.18 G, respectively. About 17 seconds later, the flight crew made a right rudder input of 7.7º. About 2132:40, when the airplane was in level flight at an altitude of 24,600 feet, the third pitch-up maneuver began when the flight crew moved the control column to 4º ANU, which increased the airplane's pitch angle to more than 10º and resulted in a vertical load of 1.87 Gs.[9] The rate of climb during this pitch-up maneuver reached 9,000 fpm briefly.

The ATC transcript showed that the captain requested a climb to 41,000 feet, which is the Canadair regional jet (CRJ) maximum operating altitude,[10] about 2135:36[11] and received clearance to climb to that altitude about 2136:13.[12] The cockpit voice recorder (CVR) recording began about 2144:44 with the captain and the first officer discussing the climb to 41,000 feet. About 2148:44, the first officer stated, "man we can do it. Forty one it." About 2151:51, the first officer stated, "there's four one oh my man." About 2152:04, the CVR recorded the first officer laughing as he stated, "this is … great." FDR data showed that, about 2152:08, the airplane was in level flight at 41,000 feet. FDR data also showed that the airplane climbed from 37,000 to 41,000 feet at an airspeed that decreased from 203 knots/0.63 Mach[13] at the start of the climb to 163 knots/0.57 Mach as the airplane leveled off.[14] The FDR data further showed that the autopilot vertical speed

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[8] The cockpit voice recorder (CVR) did not preserve any information or sounds associated with the seat change because the CVR had the capability to record only the final 30 minutes of the flight. For information about the seat change, see section 1.16.2.

[9] According to the ATC transcript, the controllers made no transmissions to the pilots that required them to perform the three pitch-up maneuvers during the ascent. For more information about the three pitch-up maneuvers, see section 1.16.1.1.

[10] The maximum operating altitude of the CRJ-200 is the maximum density altitude at which the airplane is certified to operate. For the CRJ-200, the maximum operating altitude of 41,000 feet represents the maximum capability of the airplane; the actual altitude capability will primarily depend on airspeed, weight, and ambient temperature.

[11] The airplane was at an altitude of about 32,000 feet at the time.

[12] During postaccident interviews, Pinnacle Airlines pilots stated that some pilots had expressed curiosity about operating the airplane at 41,000 feet and that an informal "[flight level] 410 club" existed at the airline. Managers at Pinnacle Airlines, including the chief pilot, the CRJ program manager, and the vice president of safety and regulatory compliance, were not aware of the club's existence.

[13] Mach is a number that expresses the ratio of the speed of an object to the speed of sound in the surrounding medium. The Safety Board calculated Mach number using the computed airspeed and total air temperature recorded on the FDR.

[14] All airspeeds cited in this report are knots indicated airspeed unless noted otherwise.

mode was engaged during the climb with a commanded vertical speed of 500 fpm and that the airplane's angle of attack (AOA) at 41,000 feet was initially 5.7º.

About 2152:22, the CVR recorded the captain asking the first officer whether he wanted something to drink and then the first officer responding that he wanted a soda. CVR evidence indicated that the captain left his seat shortly afterward to get the drink.

About 2153:28, the CVR recorded the captain stating, "look how high we are." About 2153:42, a controller at the Kansas City Air Route Traffic Control Center (ARTCC) asked the pilots whether they were flying a CRJ-200. The captain confirmed this information, and the controller stated, "I've never seen you guys up at forty one there." About 2153:51, the captain replied, "we don't have any passengers on board so we decided to have a little fun and come on up here." About 2153:59, the captain added, "this is actually our service ceiling."[15]

About 2154:07, the captain told the first officer, "we're losing here. We're gonna be … coming down in a second here." About 3 seconds later, the captain stated, "this thing ain't gonna … hold altitude. Is it?" The first officer responded, "it can't man. We … (cruised/greased) up here but it won't stay." About 2154:19, the captain stated, "yeah that's funny we got up here it won't stay up here."

About 2154:32, the captain contacted the controller and stated, "it looks like we're not even going to be able to stay up here … look for maybe … three nine oh or three seven."[16] About 2154:36, the FDR recorded the activation of the stickshaker.[17] FDR data showed that, at that point, the airplane's airspeed had decreased to 150 knots, and its AOA was about 7.5º.

The FDR recorded activations of the stickshaker and the stickpusher[18] three times between 2154:45 and 2154:54.[19] FDR data showed that, after the second activation of the stickshaker and stickpusher, the No. 1 (left) and No. 2 (right) engines' N_1 (fan speed) and fuel flow indications began decreasing. FDR data also showed that, at the time of the second stickpusher activation, the airplane's AOA had increased to 12º and that, after the stickpusher activated for the third time, the pitch angle decreased from 7º to -20º.

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[15] The service ceiling is the altitude at which the best rate of climb airspeed will produce a 100-fpm climb. The service ceiling varies depending on airspeed, weight, and ambient temperature. The accident airplane was not at maximum weight and was capable of climbing at a rate greater than 100 fpm while at an altitude of 41,000 feet if the airspeed had been maintained at Mach 0.7.

[16] The ATC transcript showed that, after this request, the controller began coordinating the descent.

[17] For the Mach number at this time, the CRJ-200 stickshaker AOA is about 7.8º at the time of shaker activation. The stickshaker activates at an airspeed of about 150 knots.

[18] For the Mach number at this time, the CRJ-200 stickpusher AOA is about 10.5º at the time of pusher activation. The stickpusher activates at an airspeed of about 142 knots.

[19] For more information about the stickshaker and stickpusher activations, see section 1.16.1.2.

About 2154:57, the FDR recorded the fifth activation of the stickshaker and the fourth activation of the stickpusher. Even with the stickpusher's activation, the motion of the airplane continued to increase its AOA to the maximum measurable value of 27º.[20] The pitch angle increased to 29º, and the airplane entered an aerodynamic stall. Afterward, a left rolling motion began, which eventually reached 82º left wing down, the airplane's pitch angle decreased to -32º, and both engines flamed out. About 2155:06, the captain stated to the controller, "declaring emergency. Stand by." FDR data showed that, during the next 14 seconds, the flight crew made several control column, control wheel, and rudder inputs and recovered the airplane from the upset at an altitude of 34,000 feet. During the recovery, the CVR recorded a sound similar to decreasing engine rpm, and FDR data showed that the No. 1 and No. 2 engines' N_1 indications continued to decrease and that the engines' fuel flow indications were at zero.[21]

About 2155:14, the controller told the pilots to descend and maintain an altitude of 24,000 feet; about 5 seconds later, the captain acknowledged the assigned altitude. About 2155:20, the FDR stopped recording because normal a.c. power to the airplane was lost. (The CVR had a different source of power and continued to record.) The last reliable N_2 (core speed) recorded by the FDR before it stopped operating was 46 percent for the No. 1 engine and 51 percent for the No. 2 engine.

About 2155:23, one pilot stated to the other, "we don't have any engines," and, about 10 seconds later, the captain stated, "double engine failure." About 2156:42, the flight crew began performing the double engine failure checklist,[22] which required pilots to maintain 240 knots until they were ready to initiate the double engine failure procedure.[23] The checklist indicated that, if the airplane were at or below 21,000 feet and above 13,000 feet, pilots should relight the engines using the windmill restart procedure,[24] which required an airspeed of at least 300 knots. The procedure indicated that an altitude loss of 5,000 feet could be expected when accelerating from 240 to 300 knots.

The FDR resumed operation about 2159:16.[25] FDR data showed that the auxiliary power unit (APU) was supplying electrical power to the airplane, both engines' N_1 indications continued to decrease, and both engines' N_2 indications were at zero. FDR data also showed that the airplane's altitude was 29,200 feet and that its airspeed was 178 knots.

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[20] The 27º AOA value is the physical limit of the sensor that measures this parameter. AOAs that are physically higher were recorded as this limit.

[21] FDR data and the CVR recording indicated that the engines were operating normally before the upset.

[22] For information about this checklist, see section 1.17.2.2.

[23] This requirement was a checklist memory item.

[24] A windmill restart is an emergency in-flight procedure in which the effect of ram airflow passing through the engine provides rotational energy to turn the engine's core.

[25] At that time, the cabin altitude warning signal was being recorded by the FDR. The FDR did not record the cabin altitude warning signal any time before the loss of engine power or the beginning of the gap in FDR data. The CVR recorded the first activation of the cabin pressure warning about 2157:04. For information about the cabin pressurization system and oxygen mask use during the flight, see sections 1.6.2 and 1.18.1, respectively.

About 2200:38, the captain told the first officer to increase the airspeed to above 300 knots, and the first officer acknowledged this instruction. FDR data showed that the airplane pitched down to -4.4º and accelerated to an airspeed of 200 knots but that, during the next 25 seconds, the airplane pitched up to 0º while its airspeed remained at 200 knots. About 1 minute later, the captain again told the first officer to increase the airspeed to 300 knots. FDR data showed that the airplane pitched down to -7.5º and accelerated to an airspeed of 236 knots (the maximum airspeed achieved during the windmill restart attempt) but that, during the next 22 seconds, the airspeed decreased to 200 knots.[26]

About 2201:51, the captain stated, "we're not getting any N two at all. So we're gonna have … to go to … thirteen thousand feet. We're going to use the APU bleed air [restart] procedure."[27] Shortly afterward, the captain resumed the double engine failure checklist, which indicated that pilots were to maintain between 170 and 190 knots until they were ready to initiate the APU bleed air restart procedure.

About 2203:09, the controller asked the flight crew about the nature of the emergency. The captain responded, "we had an engine failure up there … so we're gonna descend down now to start our other engine." About 2203:30, the captain stated, "we're descending down to thirteen thousand to start this other engine," and the controller replied, "understand controlled flight on a single engine right now." FDR data showed that, during the next several minutes, four APU-assisted engine restarts were attempted, but the N_2 speed for both engines remained at zero throughout the restarts. About 2206:40, the controller asked the flight crewmembers whether they wanted to land; the captain replied, "just stand by right now we're gonna start this other engine and see … if everything's okay." About 2206:54, the controller informed the flight crew that JEF was up ahead, and the captain acknowledged this information.

About 2208:17, the CVR recorded the captain stating, "switch." About 2209:02, the captain instructed the first officer to tell the controller that they needed "to get direct to [an] airport neither engine's started right now." The first officer informed the controller for the first time of the double engine failure,[28] and the controller then asked the pilots if they wanted to go direct to JEF. The captain stated, "any airport and closest airport," and the first officer told the controller, "closest … airport. We're descending fifteen hundred feet per minute we have … nine thousand five hundred feet left."

Between about 2210:21 and about 2211:20, the controller provided information about the winds, the approach frequency, and the localizer frequency for an instrument landing system (ILS) landing to runway 30 at JEF. About 2212:24, the first officer asked the controller where to look for the airport,[29] and the controller provided position, distance, and heading information. About 1 minute later, the controller provided additional location information for JEF. About 2213:37, the captain asked the first officer whether

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[26] For more information about these and other events during the airplane's descent, see section 1.16.1.3.

[27] Bleed air refers to pressurized air that is provided by the engines or the APU.

[28] At this time, the first officer was recorded transmitting from the right seat, which was his proper position in the cockpit.

[29] The airplane had descended out of clouds at an altitude of about 5,000 feet.

the airplane was aligned with the runway, and the first officer notified the controller that he did not see the runway. The controller provided further directional information, and the first officer told the controller that he thought he had the approach end of the runway in sight. The controller received no further transmissions from the flight crew.

About 2214:02, the first officer told the captain that he had the runway in sight. The captain questioned the first officer about the location of the runway and then stated, about 2214:17, "we're not gonna make this." About 2214:38, the captain stated, "is there a road? We're not gonna make this runway." Radar data showed that the airplane then turned left and headed toward a straight and lit section of highway. About 2214:46, the captain stated, "let's keep the gear up … I don't want to go into houses here." About 2214:53, the final radar return was received when the airplane was about 0.58 nautical mile southeast of the crash site and at an altitude of 930 feet.

About 2214:54, 2214:58, and 2215:00, the CVR recorded the enhanced ground proximity warning system (GPWS) alerts "too low gear," "too low terrain," and "pull up," respectively. About 2215:03, the CVR recorded the captain stating, "we're gonna hit houses," and, about 2 seconds later, the enhanced GPWS alert "pull up." About 2215:06, the CVR recorded a sound similar to an impact and stopped recording about 1 second afterward.

1.2 Injuries to Persons

Table 1. Injury chart.

Injuries	Flight Crew	Cabin Crew	Passengers	Other	Total
Fatal	2	0	0	0	2
Serious	0	0	0	0	0
Minor	0	0	0	0	0
None	0	0	0	0	0
Total	2	0	0	0	2

1.3 Damage to Airplane

The airplane was destroyed by impact forces and a postcrash fire.

1.4 Other Damage

Trees were damaged during the accident sequence. Also, a garage and items in the backyards of six houses were damaged by the impact of the airplane, a property line fence was damaged when the No. 1 engine separated from the airframe after impact, and nearby houses received heat damage from the postcrash fire.

1.5 Personnel Information

1.5.1 The Captain

The captain, age 31, held an airline transport pilot certificate and a Federal Aviation Administration (FAA) first-class medical certificate dated July 22, 2004, with a limitation that required him to wear corrective lenses while exercising the privileges of this certificate. The captain received a type rating on the CL-65 in August 2004. (The CL-600-2B19 airplane is included in the CL-65 type rating.)

The captain was hired by Pinnacle Airlines in February 2003. According to the captain's application for employment, he graduated in May 1995 from Embry-Riddle Aeronautical University in Florida with a bachelor of science degree in aeronautical science. The application indicated that the captain worked as a flight instructor for Embry-Riddle Aeronautical University from August 1996 to October 1999, a first officer on the British Aerospace Jetstream at Trans States Airlines from January 1999 to May 2000, and a captain on the Beech 1900 at Gulfstream International Airlines from June 2000 to September 2002.[30] The captain's résumé indicated that he had received FAA high altitude physiological training.

Pinnacle Airlines employment and flight records indicated that the captain had accumulated 6,900 hours of total flying time, including 5,055 hours as a pilot-in-command, 973 hours on the CL-65, and 150 hours as a CL-65 pilot-in-command. He had flown 667, 154, and 75 hours in the 12 months, 90 days, and 30 days, respectively, before the accident. The captain's last recurrent ground training occurred on December 8, 2003; his last recurrent proficiency check was on August 10, 2004; and his last pilot-in-command line check occurred on August 26, 2004. FAA records indicated no accident or incident history or enforcement action, and a search of records at the National Driver Register found no history of driver's license revocation or suspension.

According to his wife, the captain was in good health and exercised regularly. He did not smoke and used alcohol only occasionally. He did not take prescription or nonprescription medicine (other than daily vitamins and ibuprofen when needed). He had not been sick in the days before the accident. He would generally wake at 0745 and go to sleep no later than 2300 when on reserve and not flying. A company first officer (who knew the captain since they were at Gulfstream International Airlines) stated that no

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[30] In August 2000, the captain received a type rating on the Beech 1900.

significant changes had occurred in the captain's life during the year preceding the accident.

The captain went to a movie with his wife on the evening before the accident. On the day of the accident, he went to a park with his family, went shopping, and went out for lunch. The captain was on standby status at Detroit Metropolitan Wayne County Airport (DTW), Detroit, Michigan, on the day of the accident. Crew scheduling notified him about 1700 that he was to "deadhead" (that is, travel on a company flight as a nonrevenue passenger) on flight 5809 from DTW to LIT, reposition the accident airplane from LIT to MSP, and remain in Minneapolis overnight. Flight 5809 departed DTW about 1919 and arrived at LIT about 2036. Two Northwest Airlines[31] customer service agents, who spoke briefly with the captain after he deplaned, reported that he "looked fine," "did not appear tired," and "appeared to be in a good mood." The captain's wife did not think that he had flown with the accident first officer before the accident flight.

The captain's wife stated that he had experienced only one previous emergency during his flying career, which occurred while he was with Gulfstream International Airlines. She stated that the landing gear did not extend and that the flight crew had to use the emergency extension procedures. She also stated that the captain had received a letter of commendation from the president of Gulfstream International Airlines, which recognized the captain's actions during a landing in challenging crosswind conditions.

1.5.1.1 Pilot and Simulator Instructor Interviews Regarding the Captain

Most pilots who had flown with the captain had favorable comments about his flying abilities. These pilots stated that the captain operated the airplane in a standard manner, demonstrated good crew resource management (CRM) skills, and was "easy to get along with." Also, a first officer (who had known the captain since they were at Gulfstream International Airlines) stated that the captain was "the best stick and rudder pilot he had ever flown with." Another first officer stated that the captain set a tone in the cockpit that made the first officer feel comfortable bringing concerns to the captain's attention.

A first officer who flew with the captain from October 7 to 8, 2004, stated that the flights were conducted in a standard manner with no deviations from the flight crew operating manual (FCOM). Another first officer (who had also known the captain since they were at Gulfstream International Airlines) stated that the captain did not seem to be a risk taker. All of the pilots who were interviewed after the accident stated that the captain had never discussed flying at 41,000 feet.

The simulator instructor who conducted part of the captain's upgrade training stated that, during training, the captain did not always perform checklists according to company procedures and did not always use the correct checklists.[32] For example, the instructor stated that the captain would, at times, misstate the status of a checklist item,

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[31] At LIT, Northwest Airlines provided ground support for Pinnacle Airlines.

[32] The simulator instructor stated that he debriefed the captain about these deficiencies.

read a checklist item but not accomplish it, or take action on an airplane system that was not the one noted in the checklist. The instructor also stated that the captain would, at times, see the appropriate checklist displayed in an engine indicating and crew alerting system (EICAS) message[33] but would still call for the wrong checklist. In addition, the instructor stated that the captain flew the airplane "just fine" but that his biggest weaknesses were his critical decision-making and judgment. In contrast, the captain's simulator partner thought that all checklists during their training had been performed according to company procedures and stated that, during the debriefing sessions, the instructor did not make any negative comments about the captain's decision-making.

Another simulator instructor who conducted part of the captain's upgrade training stated that he had no recollections of the captain rushing checklists and that the captain's judgment was "above average." A check airman who conducted part of the captain's upgrade operating experience stated that the captain displayed the profile that he looked for in upgrading captains: proficiency, judgment, initiative, leadership, deliberate and thoughtful actions, and no rushing.

1.5.2 The First Officer

The first officer, age 23, held a commercial pilot certificate with airplane single- and multiengine land and instrument airplane ratings. The first officer also held an FAA first-class medical certificate dated January 14, 2004, with a limitation that required him to wear corrective lenses while exercising the privileges of this certificate.

The first officer was hired by Pinnacle Airlines in April 2004. According to the first officer's application for employment, the first officer attended Broward Community College in Florida from May 2001 to December 2003 and received an associate of science degree in professional pilot technology. In October 2002, the first officer began training at Gulfstream Academy of Aeronautics and subsequently became a first officer on the Beech 1900 for Gulfstream International Airlines.[34]

Pinnacle Airlines employment and flight records indicated that the first officer had accumulated 761 hours of total flying time, including 222 hours as a CL-65 second-in-command. He had flown 380, 192, and 60 hours in the 12 months, 90 days, and 30 days, respectively, before the accident. The first officer's initial proficiency check occurred on June 27, 2004. FAA records indicated no accident or incident history or

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[33] Pinnacle Airlines' checklists were typically used with EICAS messages. Pilots were to call for the checklist noted in an EICAS message and then use that checklist to guide them through a sequence of actions.

[34] The first officer's personnel file contained letters of recommendation from Gulfstream International Airlines pilots. For example, in an August 10, 2003, letter, a captain who had trained and flown with the first officer wrote that he displayed "capable skills in maneuvering the aircraft smoothly and safely" and that he exhibited "excellent situational awareness and decision-making ability." The letter further stated that the first officer showed strict adherence to company procedures, emphasized CRM, and had strong communication skills.

enforcement action, and a search of records at the National Driver Register found no history of driver's license revocation or suspension.

According to his father, the first officer was in good health and exercised regularly. The first officer was a nonsmoker and used alcohol only occasionally. He was not taking any prescription or nonprescription medications. The first officer was described as someone who had a positive attitude, was motivated, and was happy to be with Pinnacle Airlines.

The first officer was on reserve duty beginning on October 11, 2004. He flew a trip from October 11 to 12 and was on reserve duty on October 13. As with the captain, the first officer was notified during the afternoon of October 14 of the repositioning flight, and he departed DTW about 1919 as a deadheading crewmember and arrived at LIT about 2036. A Northwest Airlines customer service agent, who spoke briefly with the first officer after he deplaned, reported that he "appeared to be in a good mood" and "did not seem tired." According to his father, the first officer had not previously flown with the accident captain.

1.5.2.1 Pilot and Simulator Instructor Interviews Regarding the First Officer

During postaccident interviews, captains who had flown with the first officer described him as a confident pilot who was good with checklists and as someone who would ask questions if he did not understand something. The captain who flew with the first officer on the trip from October 11 to 12, 2004, described him as an "average" first officer. This captain did not note any problems with checklists during the trip. All of the pilots interviewed stated that the first officer had not expressed curiosity about flying at 41,000 feet.

A simulator instructor who trained the first officer stated that he was a good pilot with a positive attitude. The instructor also stated that he was not concerned about the first officer's abilities and that he would have made a fine captain. The simulator check airman who conducted the first officer's simulator checkride stated that he did a good job on the checkride and that he made only minor mistakes that were not uncommon for first officers to make.

1.6 Airplane Information

The accident airplane, a Bombardier CL-600-2B19, serial number (S/N) 7396, was delivered new to Pinnacle Airlines on May 18, 2000. At the time of the accident, the airplane had accumulated 10,168 total flight hours and 9,613 total flight cycles.[35]

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[35] An aircraft cycle is one complete takeoff and landing sequence.

On the day of the accident, another flight crew was scheduled to fly the accident airplane from LIT to MSP. The flight crew rejected the takeoff after receiving an EICAS message that read "R 14TH DUCT." The airplane returned to the gate,[36] and a maintenance contractor was called to examine the problem. The maintenance contractor could not find the source of the problem, so two Pinnacle Airlines mechanics were dispatched from Memphis, Tennessee, to LIT to resolve the problem. The mechanics found that the No. 2 engine pylon 14th stage bleed air duct sensing loop had some chafing damage where it passed through a rib in the pylon. The loop was replaced, and the No. 2 engine was tested for about 30 minutes. The airplane was then released for service.

The airplane's actual takeoff weight was 39,336 pounds, which was less than the maximum takeoff weight of 53,000 pounds. The takeoff center of gravity (cg) was 21.6 percent mean aerodynamic chord, which was within the cg limits of 9.0 to 35.0 percent.

1.6.1 Powerplants

The airplane was equipped with two General Electric (GE) CF34-3B1 turbofan engines. The No. 1 (left) engine, S/N 872746, was installed on the airplane on April 6, 2004, and had accumulated 8,856 total flight hours and 8,480 total flight cycles since new. The No. 2 (right) engine, S/N 873514, was installed new on the airplane on October 23, 2003, and had accumulated 2,304 total flight hours and 1,971 total cycles since new.

The No. 1 engine's fuel control had been replaced on January 3, 2002. The No. 1 engine had been removed from another company airplane on October 30, 2003 (when the engine had accumulated 7,594 flight hours and 7,422 flight cycles); afterward, Pinnacle Airlines maintenance personnel replaced the stage 9 compressor blades, the scavenge oil lube pump, and the fan inlet sensor and installed the engine on the accident airplane. The No. 2 engine's fan inlet sensor and fuel control unit had been removed from an engine on another company airplane and were installed on the accident airplane's No. 2 engine. No other major engine components had been changed on either engine since the time of manufacture.

1.6.2 Systems

The airplane was equipped with a Honeywell (formerly Garrett Airesearch) GTCP 36-150RJ APU. The APU can provide electrical and pneumatic power to the airplane's systems when the main engines are not powering those systems. The maximum altitude permitted for the use of bleed air with this APU is 15,000 feet, although design documents showed that the APU was capable of providing pneumatic power at 21,000 feet. For the CRJ-200, the APU can be started when the airplane is at an altitude that is less than 30,000 feet. A load control valve (LCV) was mounted on the APU

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[36] Afterward, the crew and passengers were put on another airplane so that the flight to MSP could resume.

pneumatic supply outlet. When the LCV opens, it allows pneumatic power from the APU to become available to each engine's 10th stage bleed air valves[37] and then to the air turbine starters (ATS), which turn energy from pneumatic air into mechanical torque for rotation of the engine cores. Figure 1 shows components in the airplane's pneumatic supply and start systems, including the APU, LCV, 10th stage bleed air valves, and ATS.

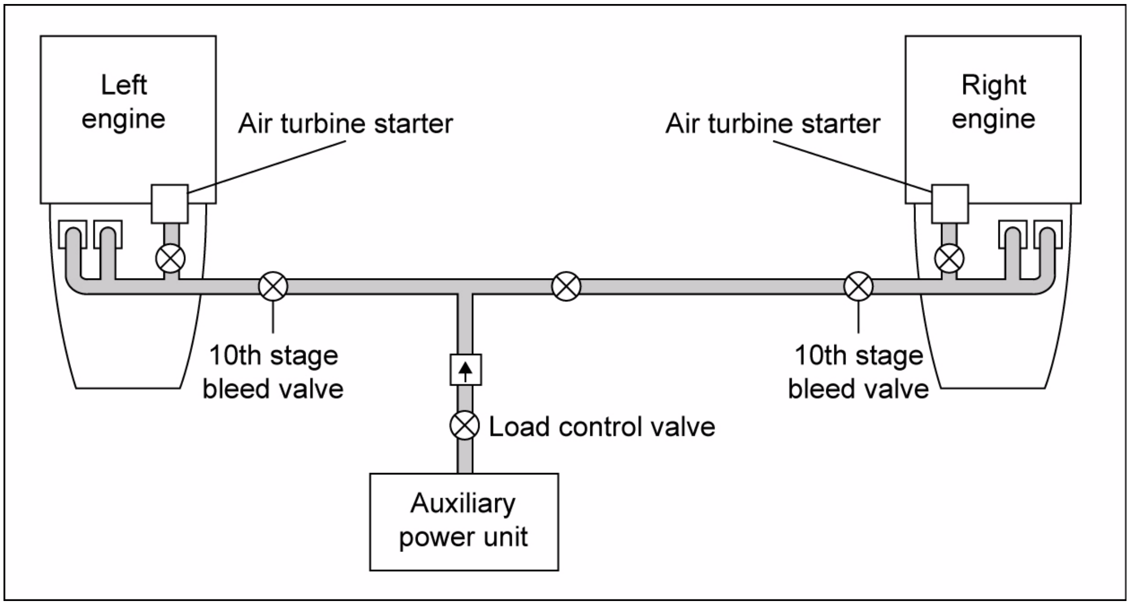

Figure 1. Components in the CRJ Pneumatic Supply and Start Systems

The pneumatic system also supplied air to the cabin pressurization system, which was digitally controlled to maintain a maximum cabin altitude of 8,000 feet (± 100 feet). The system was designed to provide a cabin altitude/cabin pressure warning[38] at a cabin altitude of 10,000 feet and to deploy cabin oxygen masks at a cabin altitude of 14,000 feet.

The airplane was equipped with a stall protection system (SPS), which provides the flight crew with warnings of an impending stall condition.[39] The stickshaker is one component of the system.[40] After stickshaker activation, the SPS protects against aerodynamic stalls via a stickpusher.

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[37] FDR data showed that the LCV opened at an altitude of 13,000 feet. The LCV remained open during each of the four APU-assisted engine restart attempts and then closed afterward. Bombardier maintenance training manuals indicated that opening the LCV at altitudes above 15,000 feet would result in a cockpit warning. The accident CVR recorded a cockpit warning associated with the LCV opening. FDR data from the accident flight showed that the LCV opened when the airplane was at 15,400 feet and then closed a few seconds later.

[38] When this warning occurs, "CABIN ALT" is displayed on the EICAS, and "cabin pressure" is announced in the cockpit.

[39] SPS activation criteria depend on the airplane's AOA, as measured by vanes mounted on the forward fuselage.

[40] In addition to the stickshaker, stall warnings are indicated by activation of the engine autoignition, autopilot disconnect, aural warning, and red "STALL PUSH" lights on the glareshield.

1.6.3 Maintenance Records

The Pinnacle Airlines maintenance program requires a service check every 3 days and a routine check every 100 hours. The last service check performed on the accident airplane was on October 13, 2004, and the last routine check was performed on October 7, 2004; no discrepancies were noted during either check.

The Pinnacle Airlines maintenance program also requires an A check every 500 hours; this check consists primarily of system inspections, lubrications, and adjustments. The last A check was accomplished on August 18, 2004. Also, the maintenance program includes C checks, which involve detailed visual inspections of flight controls, powerplants, and structures. Until the time that an airplane accumulates 8,000 total flight hours, the C check is performed at phased intervals to prevent the airplane from being out of service for an extended period of time. Once the airplane accumulates 8,000 flight hours, it must be out of service for an extended period of time to perform the full C check.[41] The accident airplane's full C check was performed in September 2003.

Finally, Pinnacle Airlines uses a calendar inspection program for "maintenance significant items" and "structural significant items." These inspections occur every 12, 24, 36, 48, 60, 72, and 96 months. The last inspections that were performed on the accident airplane were the 24- and 48-month inspections, which occurred concurrently during February and March 2004.

The airplane's daily aircraft maintenance logs between April 2001 and October 2004 showed no discrepancies related to the circumstances of this accident. Also, the airplane's discrepancy list for the 30 days before the accident showed no evidence of any major repairs to the airplane.

1.7 Meteorological Information

JEF has an automated surface observing system (ASOS), which is maintained by the National Weather Service (NWS). The ASOS records continuous information on wind speed and direction, cloud cover, temperature, precipitation, and visibility.[42] The ASOS transmits an official meteorological aerodrome report (known as a METAR) each hour. The 2153 METAR indicated the following: wind from 290º at 6 knots, visibility unrestricted at 10 miles, ceiling overcast at 4,400 feet, temperature 10º C, dew point 5º C, and altimeter 29.63 inches of mercury (Hg). The 2253 METAR indicated the following: wind from 270º at 5 knots, visibility unrestricted at 10 miles, sky clear below 12,000 feet, temperature 8º C, dew point 5º C, and altimeter 29.63 inches of Hg.

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[41] After the first full C check at 8,000 hours, all subsequent full C checks are performed every 4,000 hours.

[42] Cloud cover is expressed in feet above ground level. Visibility is expressed in statute miles.

The closest upper air sounding[43] along the route of flight was from Springfield, Missouri, which was about 50 miles west-southwest of the upset location and about 90 miles south of the accident site. The 1900 sounding showed that the approximate base of the clouds was at an altitude of 4,135 feet, the freezing level was at an altitude of 4,699 feet, the top of the clouds was at an altitude of about 7,000 feet, and another cloud layer was at an altitude of about 18,000 feet. The atmosphere was classified as stable. The maximum wind was from 345º at 60 knots at an altitude of 29,000 feet. The wind was from 315º at 48 knots at an altitude of 41,000 feet.

The NWS issued Airman's Meteorological Information (AIRMET)[44] Tango for turbulence, which was valid from 2045 on October 14 to 0300 on October 15, 2004, along the route of flight and over the location of the upset. The AIRMET indicated that occasional light to moderate turbulence could be encountered between 20,000 and 39,000 feet.

1.8 Aids to Navigation

No problems with any navigational aids were reported.

1.9 Communications

The airplane was handled by air traffic controllers at LIT, the Memphis ARTCC, and the Kansas City ARTCC. No communications problems were reported.

1.10 Airport Information

JEF is located 2 miles northeast of Jefferson City at an elevation of 549 feet. The airport has two runways, 9/27 and 12/30. The flight crew was attempting to land on runway 30, which had an ILS available. The airport's ATC tower was closed at the time of the accident.

1.10.1 Air Traffic Control

ATC radar data were primarily obtained from the Kansas City ARTCC long range radar site located in Crocker, Missouri.[45] Additional radar data were provided by the LIT ATC tower, the Memphis ARTCC, and the Airport Surveillance Radar-9 radar site located in Columbia, Missouri.

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[43] An upper air sounding shows the wind profile and the expected clear air turbulence, cloud layers, and icing potential.

[44] An AIRMET is an in-flight advisory that notifies en route pilots of the possibility of encountering hazardous flying conditions that may not have been forecast at the time of a preflight briefing.

[45] At this radar site, air route surveillance radar data are obtained once every 12 seconds.

The Kansas City ARTCC comprises several sectors (altitudes/areas of responsibility), and the sectors are denoted by numbers. The sector 30 radar controller at the ARTCC handled the accident flight when it was at an altitude of 24,000 feet and above, and the sector 53 radar controller at the ARTCC handled the airplane when it was below an altitude of 24,000 feet. The National Transportation Safety Board conducted postaccident interviews with these controllers.

The sector 30 radar controller first became aware of the accident flight when he accepted a handoff from the sector 29 radar controller.[46] The flight was at an altitude of 41,000 feet at the time. The sector 30 radar controller stated that he asked the flight crew to confirm that the type of airplane was actually a CRJ because the flight level seemed "odd" for that airplane model. The radar controller stated that the flight crew confirmed that the airplane was a CRJ and that, 1 minute later, the flight crew requested a lower altitude. The radar controller stated that he was coordinating the descent with the sector 29 controller when he heard one of the pilots saying something similar to "emergency" in a stressed voice. The sector 30 radar controller stated that he immediately handled the airplane as if it were experiencing an emergency, notified his supervisor of the situation, and instructed the sector 29 controller to turn away another airplane from the accident airplane.

The sector 30 radar controller stated that the flight crew did not provide him with much information about the in-flight situation, so he assumed that the flight crew did not want to deal with additional ATC transmissions during this time. The airplane's data block had lost altitude information, so the controller began switching between the main and backup radar systems to monitor altitude and rate of descent. The controller stated that he did not receive an altitude readout until the airplane reached 33,000 feet.

The sector 30 radar controller stated that the flight crew requested a descent to 13,000 feet. The controller stated that he first coordinated with underlying radar sectors to permit the airplane to descend below 24,000 feet and that he then issued the clearance to 13,000 feet. The controller stated that he then instructed the flight crew to contact the sector 53 radar controller. The sector 30 radar controller assisted the sector 53 radar controller by referring to the JEF approach charts for information about the ILS frequency and the airport beacon.

The sector 53 radar controller first became aware of the accident flight when she overheard the sector 30 controller notifying their supervisor of an emergency airplane. She then began monitoring the airplane from her position. The sector 53 radar controller stated that, once the pilots were on the sector 53 frequency and reported that the airplane was descending to 13,000 feet, she advised them of the airports that were available for a landing. After the flight crew requested a lower altitude for the engine restart, the controller assigned an altitude of 11,000 feet. Shortly afterward, the airplane descended through 10,500 feet, and the flight crew notified the controller of a double engine failure.

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[46] The sector 29 controller was also responsible for the accident flight when it was at an altitude of 24,000 feet and above.

The sector 53 radar controller stated that she immediately called Mizzou approach control to advise that the airplane had lost power and would be descending to land at JEF.

The sector 53 radar controller stated that she directed the flight to JEF and provided the minimum instrument altitude for the area and the localizer frequency for the runway 30 ILS approach. The controller stated that the pilots asked her where the airport beacon was located, and she provided them with a description of the beacon in relation to the runway. The controller stated that she received no further voice transmissions from the flight crew and that the last radar contact with the airplane was at an altitude of about 900 feet. The controller stated that, after losing radar contact, she tried to contact the airplane several times but received no response.

In addition, ATC transcripts showed that, after the loss of radar contact with the airplane (the final radar return was received about 0.58 nautical mile southeast of the crash site and at an altitude of 930 feet), the Mizzou approach controllers reported the location of a probable accident to the police and fire services in Jefferson City.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

The airplane was equipped with a Fairchild model A100S solid-state CVR, S/N 02804. The CVR did not sustain any heat or structural damage, and the audio information was extracted normally and without difficulty.

The CVR recording contained four channels of audio data.[47] The first channel recorded excellent audio quality information from the observer's seat audio panel.[48] The second channel recorded excellent audio quality information from the copilot's station. The third channel recorded good audio quality information from the pilot's station. The fourth channel contained fair audio quality information from the cockpit area microphone. A transcript was prepared of the entire 30-minute 23-second digital recording (see appendix B).

The first, second, and third channels all contained audio information from the airplane's aural warning system, including the synthesized voice of the crew alerting system. The fourth channel also recorded aural warnings but did so via a cockpit speaker.

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[47] The Safety Board rates the audio quality of CVR recordings according to a five-category scale: excellent, good, fair, poor, and unusable. Appendix B describes each of these categories.

[48] Federal regulations state that the first channel is to record audio information from the third flight crewmember station. Because a third flight crewmember was not required for the CRJ-200, the source for the information recorded by the first channel could be determined by the operator. The first channel did not record any intercom or radio communications.

1.11.2 Flight Data Recorder

The accident airplane was equipped with an L3 Communications Fairchild model F-1000 FDR, S/N 01094. The FDR recorded flight information in a digital format using solid-state memory as the recording medium.

The FDR was sent to the Safety Board's laboratory for readout and evaluation. The FDR was in good condition, and the data were extracted normally. About 51 hours of data were recorded on the FDR, including about 55 minutes of data from the accident flight. During the flight, power was lost to the FDR, which resulted in a data dropout of about 3 minutes 56 seconds (2155:20 to 2159:16). Data recorded immediately before the dropout, from 2155:16 to 2155:19, and immediately after the FDR was back on line, from 2159:16 to 2159:21, had some parameters that appeared to be valid but others that appeared to be invalid.

The accident airplane's FDR was not in compliance with the requirements in 14 CFR 121.344, Appendix M. Specifically, the source of the vertical acceleration parameter was not updated at a rate that met the required recording intervals. Also, the pitch attitude parameter was recorded at a higher sample rate than the source was updated. On May 16, 2003, the Safety Board issued Safety Recommendation A-03-15 to the FAA because of problems with the quality of FDR data recorded by several regional jet airplanes, including the CRJ. Section 1.18.3.3 provides information about this safety recommendation.

1.12 Wreckage and Impact Information

The main airplane wreckage was located at an elevation of 740 feet. Several tree strikes were identified along the airplane's flightpath before the main wreckage location. The direction of the tree strikes was on a magnetic heading of about 304º. The first signs of tree strikes were found on a tree that was located about 474 feet from the main wreckage location; the top branches of the tree were severed very slightly. The first tree that showed signs of a major impact was located about 425 feet from the main wreckage location. The tree's limbs were severed at a height of 43 feet above ground level, and small fragments of the airplane wreckage were found near this tree.

About 14 feet of the outboard left wing, including the winglet, was located about 187 feet before the main wreckage location. This wing section showed two large indentations in the leading edge; two large tree limbs with the same diameter as the indentations were located within 12 feet of the wing section. The tree that was struck was located 190 feet before the left wing section.

About 92 feet before the main wreckage location, a large tree was slightly damaged on one side. A large group of trees about 18 feet to the right of that tree also showed slight damage. The airplane traveled through the 18-foot gap between the trees. The left wing impacted the ground at the same location as a small tree that was sheared at a height of about 12 feet above ground level. A large ground scar measuring about 87 feet in length and having a shape similar to the top of the airplane's nose was located 30 feet before the main wreckage location. The ground scar contained material from the top of the forward cabin.

Measurements of tree strikes along the flightpath showed that the airplane was descending at a pitch attitude of about -2.5º. The airplane struck the first trees in a 40º left-wing-down attitude. The airplane impacted the ground nose first in a close-to-inverted attitude. All of the airplane wreckage was accounted for at the accident site. The airplane's wreckage extended along a 1,234-foot path, beginning with the initial impact point (the first major tree strike), continuing through six residential backyards, and ending past a residential street.

1.12.1 Powerplants

Examination of the engines at the accident site found that neither engine exhibited classic rotational damage[49] or ingestion evidence. The engines were disassembled and inspected at GE's manufacturing facility in Lynn, Massachusetts. The engine core rotors were rotated, and neither core was found seized. Teardown inspections found no mechanical failures or evidence of seizure in either engine.[50] A materials investigation of the high pressure turbine seal hardware found no abnormal rotational marks.

1.12.2 Systems

Inspection and testing of the airplane's pneumatic supply and start systems found nothing that would have prevented them from providing torque to either engine.

The APU was found in its installed position with light soot on its top surfaces. The APU was subsequently examined at Honeywell's facility in Phoenix, Arizona. A borescope inspection noted no internal physical damage. After the replacement of an impact-damaged part, the APU operated and exceeded the performance requirements for a newly overhauled unit.

The LCV was found with light soot and no observable damage. During postaccident testing, the LCV hesitated initially before opening fully the first time, and, with each subsequent opening, the LCV opened more freely than the previous time. (The first test was performed with opening commands that were intentionally applied slower than normal,[51] and the subsequent tests were performed at the conditions under which the

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[49] Classic rotational damage includes reverse bending of rotating airfoils and circumferential scraping signatures along fan blade paths.

[50] The inspection disclosed thermal damage to the turbine blades in the No. 2 engine that would have impeded the engine from producing thrust but would not have prevented the core from rotating. (The inspection found no preimpact damage to the No. 1 engine.)

[51] Other possible reasons for the initial hesitation included the impact forces that caused the surrounding structure (including the APU mount and housing where the LCV was positioned) to buckle and the dirt and debris that was found inside the APU and the LCV.

LCV was designed to operate.) The testing showed that the LCV was capable of allowing pneumatic power from the APU to enter the 10th stage bleed air valves and then the ATS.

Flight control cable continuity could not be established because of the impact damage to the forward portion of the airplane, but CVR and FDR evidence indicated that the flight controls operated normally during the flight.

1.13 Medical and Pathological Information

Tissue specimens from the captain and the first officer tested negative for ethanol and a wide range of drugs, including major drugs of abuse.

1.14 Fire

The airplane wreckage showed no evidence of an in-flight fire. Major portions of the wreckage showed postcrash fire damage.

1.15 Survival Aspects

According to the Boone/Calloway County Medical Examiner's office, the cause of death for the captain and the first officer was blunt force trauma.

1.16 Tests and Research

1.16.1 Aircraft Performance Study

The Safety Board performed an aircraft performance study for this accident. FDR, CVR, weather, and ATC radar and communications data were used to develop the time history of the accident airplane's motion. These data were time correlated. The study results for the airplane's performance during the climb to 41,000 feet, aerodynamic stall and upset event, and descent and glide are presented in sections 1.16.1.1 through 1.16.1.3, respectively.

1.16.1.1 Climb to 41,000 Feet

FDR data showed that the airplane's initial takeoff rotation occurred about 2121:45 and that, 3immediately after liftoff, the pitch angle of the airplane was about 6º. Four seconds later, when the airplane was at an altitude of about 450 feet, the first of three pitch-up maneuvers during the ascent occurred when the flight crew moved the control column to 8º ANU,[52] causing the airplane's pitch angle to increase to 22º and resulting in a vertical load of 1.8 Gs. Immediately afterward, the FDR recorded stickshaker and stickpusher activations, a full AND control column deflection, a decrease in pitch angle, and a drop in vertical load to 0.6 G. After the stickpusher deactivation, the airplane continued to climb at a pitch angle between 10º and 14º ANU.

About 2127:17, when the airplane was in level flight at an altitude of 15,000 feet and with the autopilot in vertical speed mode, the second pitch-up maneuver during the ascent began. FDR data showed that the control column moved to 3.8º ANU, causing the airplane's pitch angle to increase to 17º and resulting in a vertical load of 2.3 Gs. About 2127:26, the flight crew moved the control column 2.5º AND, decreasing the pitch angle to about 6º and the vertical load to 0.3 G about 5 seconds later. Afterward, the flight crew moved the control column 3.4º ANU. Between about 2128:40 and about 2128:43, the flight crew made a left rudder input of 4.2º, a right rudder input of 6.0º, and a left rudder input of 0.4º,[53] resulting in lateral loads of -0.16 G, 0.34 G, and -0.18 G, respectively. About 17 seconds later, the flight crew made a right rudder input of 7.7º.

About 2132:40, when the airplane was in level flight at an altitude of 24,600 feet with the autopilot engaged and a vertical speed of 600 fpm, the third pitch-up maneuver during the ascent began. The flight crew moved the control column 4º ANU, which increased the airplane's pitch angle to more than 10º, resulted in a vertical load of 1.87 Gs, and increased the airplane's vertical speed to 5,000 fpm for several seconds. About 2132:46, the flight crew disconnected the autopilot and moved the control column to 3.8º ANU, which increased the airplane's pitch angle to about 15º. About 2133:10, the flight crew reengaged the autopilot with a vertical speed of 3,000 fpm, which was reduced to 1,400 fpm by 2133:30 and 1,000 fpm by 2134:00.

The autopilot remained engaged in vertical speed mode between the altitudes of 34,000 and 41,000 feet. Between 34,000 and 35,000 feet, the airplane's vertical speed was 1,000 fpm, the calculated Mach number was about 0.60, and the engines maintained N_1 indications of 95.5 percent. As the airplane climbed through 35,000 feet, its vertical speed was reduced to 0. About 2141:00, the airplane leveled off at an altitude of 36,500 feet. Within the next minute, the calculated Mach number increased to 0.64. When the climb resumed, the airplane's vertical speed was 500 fpm, and the engines' N_1 indications were

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[52] According to FDR documentation, the control column has a range from -11.9º (forward) to 13.8º (aft).

[53] On November 10, 2004, about 1 month after this accident, the Safety Board issued Safety Recommendation A-04-59 to the FAA as a result of its findings from the November 2001 American Airlines flight 587 accident in Belle Harbor, New York. Safety Recommendation A-04-59 asked the FAA to "develop and disseminate guidance to transport-category pilots that emphasizes that multiple full deflection, alternating flight control inputs should not be necessary to control a transport-category airplane and that such inputs might be indicative of an adverse aircraft-pilot coupling event and thus should be avoided." On January 9, 2006, the FAA stated that it issued Safety Alerts for Operators 05002, "Multiple Full Deflection, Alternating Flight Control Inputs," which urged directors of safety, directors of operations, and pilots of transport-category airplanes to be familiar with the content of the Airplane Upset Recovery Training Aid and to pay particular attention to the cautions against alternating flight control inputs and aircraft-pilot couplings. As a result, the Board classified Safety Recommendation A-04-59 "Closed—Acceptable Action" on June 9, 2006.

about 95.7 percent. About 2144:00, the airplane was climbing through 37,400 feet. The airplane continued to climb at a vertical speed of 500 fpm during the next 7 minutes until reaching an altitude of 41,000 feet. During this time, the calculated Mach number decreased to 0.57, the pitch angle increased from 3º to 6º, and the engines' N_1 indications decreased to 94.7 percent.

Once the airplane reached the selected altitude of 41,000 feet, the autopilot reduced the airplane's vertical speed to 0, and the airplane leveled off. During the next 3 1/2 minutes, the calculated Mach number decreased to 0.53, the pitch angle and AOA increased to about 7º, and the engines' N_1 indications decreased to 94.2 percent.

1.16.1.2 Aerodynamic Stall and Upset Event

About 2154:34, the airplane's airspeed was 150 knots.[54] About 2 seconds later, the stickshaker activated, causing the autopilot to disconnect; at that point, the airplane's AOA had increased to about 7.5º. Within the next second, the control column moved to about 0º. About 3 1/2 seconds after autopilot disconnect, the flight crew moved the control column 3.5º ANU. The flight crew then moved the control column back toward neutral until it reached about 1.1º ANU. During the next few seconds, the flight crew moved the control column to 4º ANU, which caused the pitch angle to increase to about 8.5º.

By 2154:45, the AOA had increased to the point that both the stickshaker and the stickpusher activated. The control column moved forward rapidly in response to the activation of the stickpusher, decreasing the pitch angle to -3.5º, the AOA to 0º, and the vertical load to 0 G. The stickpusher then deactivated, and the flight crew moved the control column past neutral to about 5º ANU, which caused the pitch angle to increase to 8º and the AOA to increase to 11º.

During the next 8 seconds, while the airspeed was at 160 knots, the stickshaker and stickpusher activated twice. The stickpusher, during both activations, moved the control column forward in response, and, once the AOA decreased, the control column was then moved past neutral to an ANU position.[55] After the stickpusher activations, the control column was moved to about 5.2º and about 5.9º ANU. About 2154:51, the No. 2 engine's N_1 indication decreased from 94 to 84 percent, and the pitch angle decreased to -19.5º about 2154:55. One second later, after the stickpusher had activated and released for the third time, the flight crew moved the control column to 6.8º ANU (which was the largest ANU movement during the pitch oscillations), and the vertical load decreased to -0.8 G.

By 2154:57, the stickshaker had activated for the fifth time, and the stickpusher had activated a fourth time, pushing the control column to full nose down (where it remained for the next 4 1/2 seconds). Despite the activation of the stickpusher, the airplane entered an aerodynamic stall as the motion of the airplane continued to increase the AOA

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[54] All airspeeds in sections 1.16.1.2 through 1.16.1.4 are knots calibrated airspeed.

[55] Public hearing testimony by Bombardier Aerospace indicated that, without pilot input, the control column position would return to near neutral after stickpusher cancellation resulting from the AOA decreasing below the deactivation angle.

to its maximum ANU measurable value of 27º. Both engines' fuel flow indications decreased to near zero by 2154:58, and the airplane's pitch angle reached a maximum ANU value of 29º at 2154:59. During this time, the airplane's recorded airspeed was 74 knots, and its recorded altitude increased from 41,000 to 42,000.[56]

As the pitch angle began to decrease, a left rolling motion began, which eventually reached 82º left wing down. The pitch angle reached a maximum AND value of 32º by about 2155:06. During the next 14 seconds, the flight crew made several control column, control wheel, and rudder inputs to recover the airplane from the upset. During the recovery, the stickpusher activated three more times, both engines' fuel flow indications remained near zero, and both engines' N_1 settings decreased to about 28 percent. The FDR stopped recording data about 2155:20. The last reliable N_2 speed recorded by the FDR before it stopped operating was 46 percent for the No. 1 engine and 51 percent for the No. 2 engine.

1.16.1.3 Descent and Glide Performance

The FDR resumed recording data about 2159:16 when the airplane was at an altitude of 29,200 feet. During the 4-minute gap between recorded FDR data, the engines had stopped operating.

During the initial part of the descent, the airspeed increased, the pitch angle varied between 1º and -4º, and the descent rate reached a maximum of 5,000 fpm. A maximum airspeed of 236 knots was reached about 2202:12 when the airplane descended through an altitude of 20,500 feet. At an altitude of about 20,300 feet, the airplane leveled off for about 20 seconds and then began to descend again at a rate between 1,800 and 2,000 fpm and at an airspeed of about 200 knots.

About 2204:46, the airplane descended through an altitude of 15,000 feet, and the airspeed began to decrease as the pitch angle increased. During the next several minutes, the airspeed remained about 170 knots, and the descent rate was between 1,000 and 2,000 fpm.

About 2209:06, when the airplane was at an altitude of 10,000 feet, the flight crew notified the air traffic controller that the airplane needed to land at the closest airport. At that point, the airspeed varied between 180 and 206 knots, and the descent rate varied between 300 and 3,200 fpm. Also, several short control column movements occurred, causing the pitch angle to vary from 3º AND to 2º ANU and the vertical load to increase to 1.3 Gs.

The Safety Board obtained glide performance calculations for the accident airplane from Bombardier Aerospace. The reference airspeed for the glide performance calculations was 170 knots, which was the best glide airspeed for the accident airplane's

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[56] The recorded airspeed and altitude values may not be accurate because, according to Bombardier, the static source error corrections that are programmed into the air data computers are not calibrated for the high AOA (greater than 27º) experienced at this point in the flight.

estimated gross weight.[57] Data from the accident airplane's FDR showed that the flight spoilers deployed to 5.6º from 28,000 feet until the end of the recording. The glide performance calculations included the drag from the flight spoilers and the air-driven generator (ADG).[58] According to the glide performance calculations, at an altitude of 30,000 feet, six airports (including JEF) were within the airplane's best glide range. JEF was located about 74 miles north-northeast of the upset location.[59] The five other airports were the following:[60]

- Waynesville Regional Airport (TBN), Fort Leonard Wood, Missouri, which was located about 23 miles north-northeast of the upset location;
- Floyd W. Jones Lebanon Airport (LBO), Lebanon, Missouri, which was located about 25 miles northwest of the upset location;
- Lee C. Fine Memorial Airport (AIZ), Kaiser Lake Ozark, Missouri, which was located about 44 miles north of the upset location;
- Springfield-Branson Regional Airport (SGF), Springfield, Missouri, which was located about 50 miles west-southwest of the upset location; and
- Rolla National Airport (VIH), Rolla/Vichy, Missouri, which was located about 53 miles north-northeast of the upset location.

At an altitude of 20,000 feet, five airports (including JEF) were within the airplane's best glide range.[61] At an altitude of 10,000 feet, only one airport (AIZ) was within the airplane's best glide range; JEF was just outside the best glide range at that altitude. Figure 2 shows the glide distances to the six airports for the accident airplane.

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[57] A best glide airspeed provides the airplane with the most distance forward for a given loss of altitude.

[58] The ADG deploys automatically and provides backup power when the engines no longer power the primary electrical generators.

[59] As stated in section 1.16.1.2, the upset event is characterized by the 82º left-wing-down rolling motion and the -32º pitch angle.

[60] These five airports had runways in excess of 5,000 feet.

[61] SGF was no longer within the airplane's best glide range.

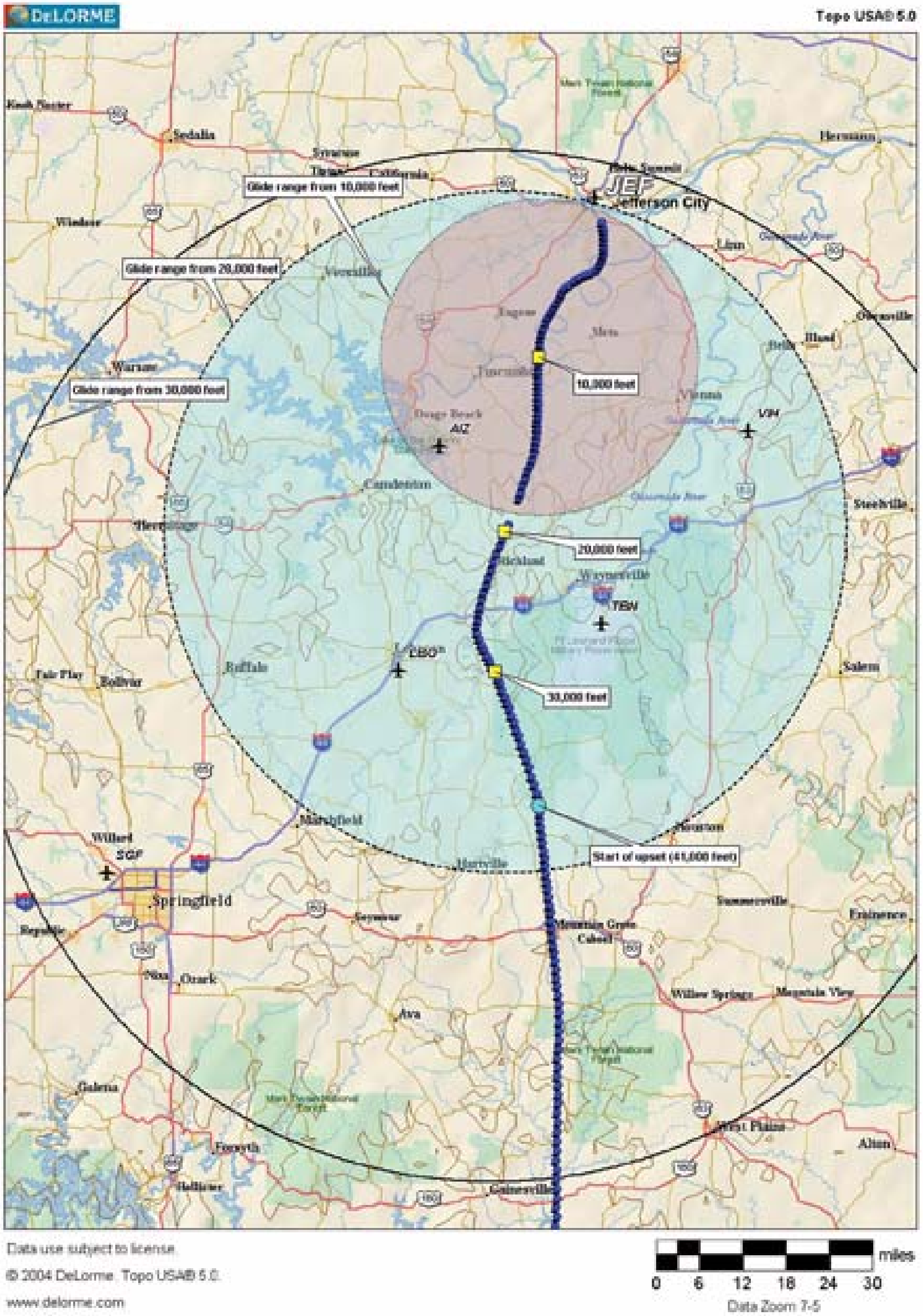

Figure 2. Glide Distances for the Accident Airplane

1.16.2 Cockpit Voice Recorder Studies

The Safety Board conducted a CVR study to determine flight crew seating positions. The study correlated CVR and ATC audio information with FDR microphone key data. The audio communications system on the accident airplane sent pilot station position (but not radio source) information to the FDR for its microphone key parameter. This information and voice identification information from the CVR allowed the Board to determine which pilot was transmitting on the radio from which crew seat position.

The correlation determined that, during takeoff, the captain made radio transmissions from the left seat (the first officer was recorded from the right seat). The correlation also determined that, about 6 minutes into the ascent, through the upset event, and until after several engine restart attempts, the captain made radio transmissions from the right seat (the first officer was recorded from the left seat). Finally, the correlation determined that, after the flight crew requested to land at JEF until the last transmission to the controller, the first officer made radio transmissions from the right seat (the captain was not recorded during this time period). The flight crew seating positions are summarized in table 2.

Table 2. Flight Crew Seating Positions

Time	Left audio panel	Right audio panel
2121:00 to 2124:14	Captain	First officer
2126:43 to 2206:59	First officer	Captain
2209:06 to 2214:39	No information[a]	First officer

Note: In the CRJ-200, the captain is normally seated on the left, and the first officer is normally seated on the right.

[a] Although the CVR and FDR were functioning during this time, they did not record any cockpit audio or microphone key data from the left audio panel after 2205:53. The lack of CVR and FDR information from an audio panel indicates that its dedicated controller board has lost power (even though the rest of the audio communication system remains powered) or that the panel selector switch has been set to "EMER" (emergency).

The CVR study also documented events related to engine checklist use and flight crew oxygen mask use; some of these events are shown in table 3. Oxygen use by the flight crew is further discussed in section 1.18.1.

Table 3. Engine Checklist and Oxygen Mask Use Events

Time	Event
2156:42	Start of double engine failure checklist.
2157:04	Crew alerting system warning of cabin pressure.
2158:21	Comment to use oxygen mask.
2158:41	Sound similar to oxygen flow starting in oxygen mask.
2201:36	Double engine failure checklist—windmill restart procedure.

Time	Event
2202:14	Double engine failure checklist—APU bleed air restart procedure.
2204:06	Comment to use oxygen masks.
2204:09	Sound similar to oxygen flow starting in oxygen mask.
2204:13	Comment regarding cabin altitude of 15,400 feet and need to be on oxygen.
2206:23	Sound similar to oxygen mask removal.
2207:04	Double engine failure checklist—relight attempt of No. 1 engine using APU bleed air procedure.
2207:20	Sound similar to oxygen flow in oxygen masks.
2207:41	Double engine failure checklist—relight attempt of No. 2 engine using APU bleed air procedure.
2208:11	Sound similar to oxygen mask removal.
2208:15	Sound similar to oxygen mask removal.
2209:32	Double engine failure checklist—relight attempt of engine using APU bleed air procedure.
2211:42	Double engine failure checklist—relight attempt of engine using APU bleed air procedure.

In addition, the Safety Board conducted a CVR sound spectrum study to determine whether any noise was recorded by the CVR during the four APU-assisted engine restart attempts that would indicate ATS operation. Each CVR channel was examined across the full frequency range for signal changes, appearances, and disappearances, but nothing associated with any of the engine restart attempts was found.

1.16.3 Engine Tests

The accident FDR showed decreasing engine core-driven accessory parameter indications[62] after the double engine failure. About 15 minutes afterward, engine oil temperature cooling rates leveled off momentarily, and slight engine hydraulic pump pressure indications were noted. This signal activity was inconsistent with the engines' zero N_2 indications.

Engine tests were performed at Pinnacle Airlines' maintenance facility in Memphis and the Bombardier Aerospace Flight Test Center in Wichita, Kansas. A test to evaluate the engine oil temperature anomalies demonstrated that, after a period of normal engine operation, changes in engine oil temperature that were consistent with the accident

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[62] These parameters included fuel flow, oil pressure, oil temperature, and engine hydraulic pressure.

FDR anomalies would result when APU-assisted restarts were attempted with the engine core rotor locked. The test also demonstrated that the FDR could record small hydraulic pressure signals while the engine core was prevented from rotating.

A test to evaluate the slight increases (25 to 30 pounds per square inch gauge [psig]) in core-driven hydraulic pump pressure indications[63] showed that hydraulic pump pressure would begin to indicate on the FDR with about 35 rpm of core rotation. Another test showed that N_2 signals would begin to indicate on the FDR and in the cockpit with about 70 rpm of core rotation.

A test demonstrated that the ATS was capable of rotating an engine core from zero N_2 with 10th stage duct pressures as low as 6 psig (as detected by the EICAS) and that 25- to 30-psig hydraulic pump pressures could be recorded on the FDR as long as engine core rotation was sustained at a speed of about 35 rpm. This test also showed that, by the time that engine core rotation had reached a speed of 75 rpm, hydraulic pump pressures had increased quickly to 1,500 psig.

1.16.4 Load Control Valve Simulation Study

As stated in section 1.6.2, the LCV allows pneumatic power from the APU to become available to each engine during the start sequence. In the pneumatic system, the LCV and its associated ducts are the components that support both engines. Thus, a malfunction of the LCV could result in a failure to achieve indications of engine rotation on either engine. To determine the minimum amount of LCV opening needed to result in initial engine rotation, as indicated by FDR data, and whether a minimum LCV opening value during the four APU-assisted engine restart attempts could be determined, the Safety Board conducted a computer-based simulation study that was validated against existing flight test data provided by Bombardier.

For the simulation study, the Safety Board used the results of previous ground and flight tests that provided data about the minimum torque output required from the ATS to initiate detectable core rotation from 0 rpm. As indicated in section 1.16.3, the tests showed that about 35 rpm of core rotation was needed to detect an indication of hydraulic pump pressures[64] on the FDR and that about 70 rpm of core rotation was needed to detect an indication of N_2 on the FDR and in the cockpit. The tests also showed, and data from Honeywell indicated, that about 6 psig at the ATS inlet with 27.5 pounds per minute of corrected airflow[65] could result in detectable core rotation.

FDR data for the accident flight showed that the LCV was open throughout each APU-assisted restart attempt. Although the LCV normally opens fully (85°) during an

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[63] Normal hydraulic system operating pressure is 3,000 psig, and signals of 25 to 30 psig are outside of the system transducer's validated measurement range.

[64] The hydraulic pump is driven by engine core rotation.

[65] Because airflow changes based on altitude and temperature, corrected airflow provides a common reference point that recalculates airflow in terms of a standard day at sea level (that is, 59° F and 29.92 inches of Hg).

APU-assisted engine restart, the FDR parameter for the LCV position shows that the valve is open once it reaches a position that is greater than 4.8º from its normally closed position.

The simulation showed that, for a normally functioning engine, the LCV needed to be open by about 8º to produce enough torque at the ATS output to initiate detectable core rotation from a stopped condition.[66] However, at this 8º setting, the LCV-supplied air volume that reached the ATS start valve diminished once the start valve opened, and then the LCV and other downstream pneumatic system valves closed because the pressure provided was insufficient to keep them opened. This result was not consistent with the FDR data from the accident flight, which showed that the 10th stage bleed air valves remained open from 25 seconds (in accordance with guidance on the double engine failure checklist, as shown in appendix C) to about 105 seconds during all four engine restart attempts and that the LCV remained open during each restart attempt. Also, the CVR did not include any discussion to indicate that the 10th stage or start valve functions deviated from what the pilots would normally observe during an APU-assisted start on the ground.

The simulation also showed that, with an LCV opening of at least 18º, all of the pneumatic supply valves would be kept open, as was seen on the accident FDR. An LCV opening of at least 18º was also sufficient to initiate and maintain detectable rotation of the core rotor from 0 rpm.[67]

1.17 Organizational and Management Information

Pinnacle Airlines, Inc., is a wholly owned subsidiary of Northwest Airlines, Inc., and is based in Memphis. The airline was established in 1985 as Express Airlines I. Between 1985 and 2000, Express Airlines I operated turboprop airplanes only. In 2001, Express Airlines I began integrating CRJ turbojet airplanes into its fleet and, in 2002, changed its name to Pinnacle Airlines. By 2003, Pinnacle Airlines had phased out turboprop airplanes from its operations and operated CRJ turbojet airplanes only. At the time of the accident, the company employed about 900 pilots and had a fleet of 110 CRJs that provided service to destinations in the United States and Canada.

1.17.1 Ground School and Simulator Training

1.17.1.1 Upset Training

Pinnacle Airlines provided upset training to newly hired pilots during ground school and simulator training. According to a Pinnacle Airlines ground school instructor, pilots received 6 hours of upset training during the general operational subjects module.

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[66] This initiation was based on ground start conditions that were corrected for altitude. However, the pressure, altitude, and temperature did not account for airspeed, which would have reduced the required onboard pneumatic pressure and flow requirements.

[67] The rotation would not likely be fast enough for an engine's starting sequence to be completed.

The subjects covered during this training included swept-wing design characteristics and high altitude aerodynamics.[68] Also, pilots received a copy of the Pinnacle Airlines Jet Upset Student Guide.

A Pinnacle Airlines simulator instructor stated that pilots received about 20 minutes of upset training in the simulator. The training consisted of Mach tuck and Mach buffet demonstrations[69] and unusual attitude recoveries. Also, the simulator instructor discussed operations at high altitudes where low indicated airspeeds yielded high true airspeeds (and a high Mach number) at high AOAs, but the training did not include any maneuvers or stalls at high altitudes.

After the accident, Pinnacle Airlines revised the upset training sections of its ground school instructor guide, ground school curriculum, and the Jet Upset Student Guide to include stalls and airplane maneuvers at an altitude of 37,000 feet. Also, the airline enhanced upset training in the simulator by having pilots perform maneuvers at high altitudes.

1.17.1.2 High Altitude Climbs

According to Pinnacle Airlines ground school instructors, high altitude climbs, recommended climb profiles, and altitude and climb capability charts[70] were discussed with newly hired pilots during the general operational subjects module (specifically, the upset training and performance sections of the module). Simulator instructors stated that they discussed high altitude climbs and recommended climb profiles with newly hired pilots during pre- and postsimulator briefings but did not demonstrate or have the pilots practice high altitude climb techniques.

The Pinnacle Airlines Flight Operational Quality Assurance (FOQA) program[71] manager stated that the CRJ service ceiling of 41,000 feet was discussed during ground school. Company check airmen, simulator instructors, and pilots stated that operations at 41,000 feet were neither discussed nor demonstrated during simulator training. A simulator instructor stated that 41,000 feet was not an altitude at which pilots wanted to operate very often.

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[68] High altitude is 25,000 feet and above.

[69] A Mach tuck is the result of an aft shift in the center of lift, causing a nose-down pitching moment. A Mach buffet is the airflow separation behind a shock wave pressure barrier that results when the airflow over flight surfaces exceeds the speed of sound.

[70] See section 1.17.2.1 for more information about Pinnacle Airlines' altitude and climb capability charts.

[71] A traditional FOQA program is an FAA-approved, voluntary program for the routine collection and analysis of FDR data gathered during aircraft operations. At the time of the accident, Pinnacle Airlines did not have a traditional FOQA program in place; instead, the program was designed to manage the check airmen through flight monitoring. At the time of the June 2005 public hearing for this accident (see appendix A), Pinnacle Airlines was working toward the deployment of a traditional FOQA program. In October 2006, the company reported that it was operating an FAA-approved FOQA program and was collecting an average of 2,000 hours of data each month.

In November 2004, Pinnacle Airlines revised the performance section of its ground school instructor guide to include more specific high altitude climb information and procedures, including a minimum climb profile speed above 10,000 feet of 250 knots or 0.7 Mach, whichever was lower.[72] Also, the company added a high altitude climb scenario to its simulator training.

1.17.1.3 Double Engine Failure

According to postaccident interviews with the CRJ program manager, check airmen, simulator instructors, and pilots at Pinnacle Airlines, the double engine failure checklist items were discussed during ground school and one of the simulator briefings. They stated that the simulator sessions did not include a scenario in which a double engine failure had occurred or a scenario in which the ADG had been deployed. Also, they stated that, during ground school, pilots were required to pass written and oral examinations on all memory checklist items, including those for the double engine failure procedure (see section 1.17.2.2).

In December 2004, Pinnacle Airlines issued a revised simulator instructor guide to include single and double engine failures at 35,000 feet during new hire and captain upgrade simulator training. Pilots are now required to use the ATS-assisted restart procedures for a single engine failure and windmill restart procedures for a double engine failure. These exercises familiarize the pilots with emergency power-only procedures and the effects of ADG deployment. The revised simulator instructor guide also includes an exercise during which the pilots start the APU as the airplane descends through 30,000 feet.

1.17.1.4 Stall Recognition and Recovery Training

Pinnacle Airlines' stall recognition and recovery simulator training was conducted at an altitude of 10,000 feet and with various airplane configurations. For all of the approach-to-stall profiles, the pilot was expected to initiate actions to recover from an impending stall when the first indication of a stall (which was usually the activation of the stickshaker) occurred.[73] One purpose of the training was to ensure that a pilot could prevent a full stall from occurring. Another purpose of the training was to demonstrate that a pilot had mastered the airplane throughout its speed range and was able to initiate a standard recovery using the appropriate flight control inputs and callouts. The training did not include high altitude stalls, full stalls, or recoveries from full stalls.

The Pinnacle Airlines CRJ program manager stated that the company's approach-to-stall profiles did not normally progress to stickpusher activation, which he thought was consistent with industry stall training. He stated that a pilot might experience

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[72] This information was also incorporated into Pinnacle Airlines' CRJ FCOM Operating Limitations section, as indicated in section 1.17.2.1.

[73] The Pinnacle Airlines CRJ FCOM, volume 1, Flight Instruments—Air Data System, dated January 2003, showed that the low speed cue on the airspeed indicator was another indication to the flight crew of an impending stall.

stickpusher activation during simulator training if the pilot overcorrected in response to the stickshaker. According to the program manager, if this situation were to occur, Pinnacle Airlines instructed the pilot to work with the stickpusher upon activation to decrease the AOA and gradually return to the starting altitude for the maneuver. Also, the program manager stated that pilots were required to test the stickpusher before the first flight of each day as part of the preflight check of the SPS.

In December 2004, Pinnacle Airlines issued a revised simulator instructor guide to include, for new hire, captain upgrade, and recurrent simulator training, a high altitude stall demonstration with the autopilot engaged[74] and a high altitude stall buffet margin demonstration.

1.17.1.5 Crew Resource Management Training

At the time of the accident, Pinnacle Airlines provided 8 hours of CRM training to pilots during initial training. The course was presented in lecture format and included PowerPoint slides, scenario-based questions, handouts, and videotapes. The topics covered during the course were resource management, human factors, communication, workload management, team building, and technical proficiency. Accident events and scenarios were also discussed. During recurrent and upgrade training, pilots received a 2-hour version of the course.

Pinnacle Airlines managers, instructors, and pilots stated that CRM concepts were reinforced and evaluated during simulator training. They stated that crew coordination and assertiveness were stressed and that instructors discussed crew performance indicators during debriefings.

The director of flight operations at Pinnacle Airlines stated that the key measures of CRM effectiveness were crew coordination, workload management, communications, and situational awareness. This director also stated that he had seen pilots using good CRM skills during line operations. The Pinnacle Airlines FOQA manager and a first officer with the company stated that CRM training provided first officers with the tools they needed to challenge captains if necessary.

After the accident, Pinnacle Airlines restructured CRM training to provide additional focus on decision-making and the need to adhere to standard operating procedures.

1.17.1.6 Leadership Training

At the time of the accident, Pinnacle Airlines provided a 2-hour leadership training module during the 8-day captain upgrade training course. Topics covered during the training were leadership authority, responsibility, and leadership styles.

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[74] For the training that was in effect at the time of the accident, the autopilot was used only for the approach to stall in the landing configuration.

Pinnacle Airlines had a target of 10 percent for its captain upgrade first-time failure rate. In July 2004, when the rate was 22 percent, FAA and company personnel met to discuss how to reduce the failure rate. Pinnacle Airlines personnel stated that data showed that the most cited reasons for upgrade failure were leadership and judgment. The FAA principal operations inspector (POI) stated that this finding showed that the failures were primarily because of deficiencies in "captain thinking skills" rather than "stick and rudder skills." As a result, Pinnacle Airlines management decided to place more emphasis on leadership during upgrade training[75] and increase the minimum number of hours required for upgrade operational experience[76] from 10 to 25.

A Pinnacle Airlines simulator instructor worked with the company's CRJ lead instructor to develop a new 8-hour leadership course. The course includes modules on leadership, authority, and responsibility; briefing and debriefing scenarios; decision-making processes, including those during an emergency; dry run line-oriented flight training scenarios; and risk management and resource utilization. The FAA observed the leadership course in November 2004 as part of the approval process; afterward, Pinnacle Airlines added the course to upgrade training. In October 2006, the company reported that about 92 percent of the pilots upgrading to captain passed the training the first time and that the overall captain upgrade training pass rate was 95 percent.

1.17.2 Flight Manuals

1.17.2.1 High Altitude Climbs

At the time of the accident, the Pinnacle Airlines CRJ FCOM, volume 2, Maneuvers, page 7, dated June 2004, listed the following three climb profiles: high speed, 320 knots/0.77 Mach; normal speed, 290 knots/0.74 Mach; and long range, 250 knots/0.70 Mach. Pinnacle Airlines indicated that, to maintain an airspeed at or above 250 knots/0.70 Mach, the airplane's vertical speed during the climb should be at least 300 fpm. Also, the Pinnacle Airlines CRJ FCOM, volume 2, Operating Limitations, page 4, dated April 2003, stated that the maximum operating altitude for CRJs was 41,000 feet.

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[75] During postaccident interviews, Pinnacle Airlines' FOQA manager stated that a weakness in captains was their leadership skills, and Pinnacle Airlines' director of flight operations stated that management training would help captains with their decision-making.

[76] Upgrade operational experience, which occurs after a new captain has completed upgrade training, is when the new captain conducts flight operations in the presence of a check airman.

The Pinnacle Airlines CRJ FCOM, volume 2, Performance, pages 50 through 52, dated June 2002, presented altitude and climb capability charts. Pilots were required to consult these charts anytime a flight was operating above 36,000 feet because of a flight management system (FMS) limitation above that altitude.[77] A climb capability chart showed the 300-fpm climb ceiling for an airspeed of 250 knots/0.70 Mach and the maximum cruise thrust limit altitude for cruise speeds of 0.74, 0.77, and 0.80 Mach and long range cruise. This information was provided for airplane weights between 34,000 and 52,000 pounds and outside air temperatures from the International Standard Atmosphere (ISA) temperature to ISA + 10º C.[78]

After the accident, Pinnacle Airlines added the following restriction to its CRJ FCOM volume 2 Operating Limitations section: "minimum climb profile speed above 10,000 feet MSL will be 250/.70M whichever was lower." Also, Pinnacle Airlines added the altitude and climb capability charts to its Quick Reference Handbook (which is required to be on all company airplanes) to make it easier for pilots to reference the information. In addition, on October 22, 2004, Pinnacle Airlines issued Alert Bulletin 04-54, which stated that all company flights were not to exceed an altitude of 37,000 feet and that flight crews were not to accept or request ATC clearance above this altitude. Finally, the Pinnacle Airlines Ground School Instructor's Guide, Performance section, page 35, dated November 2004, stated the following: "when a 300 FPM rate of climb cannot be achieved at the minimum climb speed, the aircraft will be leveled off and a new altitude coordinated with ATC."

1.17.2.2 Double Engine Failure

The Pinnacle CRJ FCOM, volume 2, Emergency Procedures, pages 8 through 13, dated July 2003, detailed the procedure for an in-flight double engine failure.[79] For this procedure, the flying pilot is responsible for calling for the double engine failure checklist memory items, and the nonflying pilot is responsible for performing the memory items and reading and performing the remaining items on the checklist.

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[77] FCOM volume 2, Operating Limitations, pages 30 and 31, dated June 2004, stated that "the FMS calculated thrust setting must not be used if the pressure altitude is greater than 36,000 feet." The Bombardier chief pilot stated that the reason for the FMS limitation above 36,000 feet was because of the inaccurate calculations above that altitude. Further, according to Bombardier, at altitudes above 36,000 feet, the conversion from static air temperature to the International Standard Atmosphere (ISA) deviation is incorrect within the FMS, resulting in an error in the N_1 indication at those altitudes. (A detailed explanation of ISA appears in the next footnote.) Bombardier's Flight Planning and Cruise Control Manual and Quick Reference Handbook contain charts that show the proper N_1 indication for altitudes between 36,000 and 41,000 feet.

[78] The International Civil Aviation Organization defines ISA as a sea-level pressure of 1,013.2 millibars at a temperature of 15º C, with temperature decreasing at a standard rate of 2º C per 1,000 feet until reaching the tropopause (the boundary between the troposphere—the lowest region of the earth's atmosphere—and the stratosphere—the middle region of the earth's atmosphere). In the standard atmosphere, the tropopause is at 36,000 feet. On the night of the accident, the tropopause was at 27,600 feet, and the temperature at 41,000 feet, -47.1º C, was 9.4º C more than the ISA temperature for that altitude.

[79] This information also appeared in the Quick Reference Handbook.

The double engine failure checklist required pilots to establish and maintain an airspeed of 240 knots (a memory item) until they were ready to restart the engines. The double engine failure checklist also required pilots to use the windmill restart procedure if the airplane were at an altitude that was at or below 21,000 feet and above 13,000 feet. Requirements of the procedure included an airspeed of at least 300 knots to achieve an N_2 indication of 12 percent. The double engine failure checklist stated, "an altitude loss of approximately 5,000 feet can be expected when accelerating from 240 to 300 KIAS [knots indicated airspeed]."

The double engine failure checklist also required pilots to use the APU bleed air restart procedure if the airplane were at an altitude of 13,000 feet or below. This procedure required pilots to maintain an airspeed of between 170 and 190 knots until they were ready to initiate the APU-assisted engine restart. The procedure also required pilots to attempt to start one engine at a time and that, if either engine were restarted, an N_2 indication of 28 percent was required before the thrust lever could be moved to idle.

The double engine failure checklist also stated that, if neither engine were restarted, the flight crew should "consider a forced landing or a ditching."

In May 2005, Pinnacle Airlines issued changes to its double engine failure checklist. Specifically, the company rewrote the windmill relight procedure to make it easier for pilots to follow. Also, the company incorporated other changes to the checklist based on revisions made by Bombardier earlier that month to clarify the information within the checklist. For example, the double engine failure checklist that was in effect at the time of the accident indicated that 240 knots was the "target" airspeed to be maintained until the flight crew was ready to restart the engines, but the revised checklist indicated that 240 knots was the "minimum" airspeed to be maintained. Also, the revised checklist included the following caution:

> Failure to maintain positive N_2 may preclude a successful relight. If required, increase airspeed to maintain positive N_2 indication.

In addition, the windmill relight procedure included the following revised note and added the following caution, respectively:

> An altitude loss of approximately 5,000 feet can be expected when accelerating from 240 to 300 KIAS and may require pitch attitudes of 10 degrees nose down.[80]
>
> 300 KIAS or greater is required to achieve sufficient N_2 for start. Airspeed must be maintained until at least one engine relights (stable idle) or start attempts abandoned.

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[80] To this note, Pinnacle Airlines added, "if possible, crews should start accelerating to achieve 300 KIAS upon reaching 21,000 feet."

Appendix C shows Pinnacle Airlines' double engine failure checklist at the time of the accident, and appendix D shows the airline's revised double engine failure checklist.

1.17.2.3 Stall Protection System

The Pinnacle Airlines CRJ FCOM, volume 1, Flight Controls, pages 10-20 and 10-21, dated January 2003, stated the following about the SPS:[81]

> As a high AOA is approached, continuous ignition is activated. If the AOA continues to increase, the stick shakers are activated and the autopilot is disengaged. If the AOA still continues to increase, the stick pusher mechanism is activated, STALL lights on the glareshield panel flash red, and the warbler sounds.

1.17.2.4 Flight Operations

Pinnacle Airlines' Flight Operations Manual, Normal Procedures, section 4.30.1, "Safe Aircraft Operations," dated August 2003, stated the following: "Pilots are prohibited from operating aircraft in a careless or reckless manner so as to endanger life or property. Maneuvers not necessary for the safe and orderly progress of flight are prohibited." Section 4.30.2, "Absence From The Cockpit," dated August 2003, stated that "all flight crewmembers shall remain at their duty stations during takeoff, landing and while enroute."[82]

After the accident, Pinnacle Airlines issued a revision to its Flight Operations Manual. Normal Procedures, section 4.30.6, "Crew Composition," dated May 2005, stated, "the minimum flight crew for all operations shall be a Captain and a First Officer. The Captain must occupy the left seat and the First Officer must occupy the right seat."

1.17.3 Federal Aviation Administration Oversight

The Memphis Flight Standards District Office (FSDO) is responsible for oversight of Pinnacle Airlines. The supervisor of the Pinnacle Airlines certificate management unit stated that, after he was assigned to the position in October 2002, he appointed temporary principal inspectors because he wanted a "fresh set of eyes" to evaluate the airline's compliance with the *Federal Aviation Regulations*. He also stated that, before his assignment, Pinnacle Airlines seemed to not pay much attention to the FAA and that the appointment of temporary principal inspectors would help the FAA achieve a fresh start with the airline. He further stated that, as a result of this action, Pinnacle Airlines agreed to improve its working relationship with the FAA.

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[81] A review of the SPS' performance during the flight matched the system's nominal performance requirements.

[82] According to the document, the only exception to this policy is when the absence of a flight crewmember is necessary for the performance of duties in connection with the operation of the airplane or for physiological needs.

In January 2003, the POI was removed from that position because he did not have a CRJ type rating. Three acting POIs (including the certificate management unit supervisor) were on the Pinnacle Airlines certificate until the POI position was permanently filled in July 2004. The new POI had been the assistant POI for Pinnacle Airlines from July 2003 to January 2004, at which time he began 5 months of inspector training at the FAA Academy in Oklahoma City, Oklahoma. The POI currently has two assistant POIs to help him with his workload.

1.18 Additional Information

1.18.1 Oxygen Mask Use During the Accident Flight

As stated in section 1.6.2, the cabin pressurization system was designed to provide a cabin altitude/cabin pressure warning at a cabin altitude of 10,000 feet. The CVR recorded the first activation of the cabin pressure warning about 2157:04. The FDR did not record the cabin altitude warning signal about this time because FDR operation had temporarily ceased about 2155:20. The cabin altitude signal was recorded when FDR operation resumed about 2159:16; at that time, the airplane was descending from an altitude of 29,200 feet. The FDR showed that the oxygen masks did not deploy until the airplane descended to an altitude of 22,531 feet (about 2201:45).

The CVR recorded, about 2204:06, the captain stating, “get on oxygen,” and, 3 seconds later, a sound similar to oxygen flow in oxygen masks.[83] About 2204:13, the CVR recorded the captain stating, “we’re at cabin altitude … fifteen thousand four hundred. We need to be on oxygen.” About 2204:45, as the airplane descended through an altitude of 16,423 feet, the cabin altitude stopped climbing and started descending. About 2206:23, the CVR recorded a sound similar to oxygen mask removal. The CVR again recorded a sound similar to oxygen flow in oxygen masks about 2207:20 and then a sound similar to oxygen mask removal about 2208:11 and about 2208:15. The cabin altitude warning signal was no longer present in the FDR recording when the airplane descended through an altitude of 10,020 feet (about 2209:05).

1.18.2 Core Lock

During the investigation of this accident, the Safety Board learned that GE CF34-1 and CF34-3 engines[84] had a history of failing to rotate during in-flight restart attempts on airplanes undergoing production acceptance flight testing at Bombardier. The manufacturers referred to this condition as “core lock.” Bombardier first identified this problem in 1983 during Challenger certification tests, and GE attributed the problem to interference contact at an air seal in the high pressure turbine.

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[83] The CVR had previously recorded the first officer stating, “we need our oxygen masks,” about 2158:21 and a sound similar to oxygen flow starting in oxygen masks about 2158:41.

[84] Bombardier airplanes that are powered by either GE CF34-1 or CF34-3 engine models are the Challenger 601, Challenger 604, CRJ-100, CRJ-200, and CRJ-440.

The CF34 high pressure turbine air seals are designed to control cooling and balance airflow. The seals include teeth on the rotating components that grind operating grooves into abradable surfaces on the stationary components. The efficiency of these seals significantly affects engine performance, so the seals are designed to operate with minimal clearances.

Bombardier added a procedure that screened for core lock to the production acceptance flight tests for its airplanes powered by CF34-1 and CF34-3 engines. At the time of the accident, this screening procedure was as follows:

1. Climb to 31,000 feet.
2. Retard the test engine throttle to idle and stabilize for 5 minutes.[85]
3. Shut down the test engine.
4. Descend at 190 knots.
5. Slow the aircraft until N_2 is reduced to 0 percent.
6. At 8 1/2 minutes from shutdown, push over to 320 knots.
7. If N_2 is 0 rpm at 21,000 feet, the engine is declared to be core locked.

Engines that are found to be core locked are reworked using an in-flight "grind-in" procedure that was designed to remove seal material at the interference location. Engines that undergo grind-in rework are then rescreened for core lock. The grind-in procedure is as follows:

1. ATS cross-bleed start.
2. Ascend to 31,000 feet.
3. Repeat core lock screening procedure but descend at an airspeed of about 240 knots to establish 4 percent N_2.
4. Maintain 4 percent N_2 for at least 8 1/2 minutes.
5. Confirm that no core lock exists by repeating screening procedure.

As testimony during the Safety Board's June 2005 public hearing on the Pinnacle Airlines accident indicated, neither Bombardier nor GE considered core lock to be a safety-of-flight issue. The manufacturers claimed that engines that passed the screening procedure, with or without grind-in rework, would not core lock as long as the 240-knot airspeed was maintained.

Bombardier's core lock screening procedure requires a cool-down period before engine shutdown to stabilize internal temperatures and clearances. However, this procedure does not produce the more severe thermal distress associated with the high power, high altitude flameouts that were experienced during the accident flight. As stated in the Safety Board's November 20, 2006, safety recommendation letter to the FAA,[86] the successful

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[85] After the accident, Transport Canada mandated that Bombardier change the engine stabilization time from 5 to 2 minutes.

[86] This letter transmitted Safety Recommendations A-06-70 through -76. For information about these recommendations, see section 1.18.3.1.

demonstration of Bombardier's flight test procedure might not ensure that an engine will not experience core lock if the core is allowed to stop rotating after a high power, high altitude flameout. In its letter, the Board noted that the No. 1 accident engine had successfully passed the screening procedure during initial production acceptance testing.[87] The Board further stated that the successful demonstration of Bombardier's flight test procedure might not ensure that slowing the airplane to an airspeed of 170 to 190 knots is sufficient to maintain core rotation during an attempted APU-assisted restart.

1.18.3 Previous Related Safety Recommendations

1.18.3.1 Core Lock

On November 20, 2006, the Safety Board issued Safety Recommendations A-06-70 through -76 to the FAA to address the safety hazards associated with core lock, which can prevent pilots from restarting an engine after a double engine failure during flight. Safety Recommendations A-06-70 through -76 asked the FAA to do the following:

> For airplanes equipped with CF34-1 or CF34-3 engines, require manufacturers to perform high power, high altitude sudden engine shutdowns; determine the minimum airspeed required to maintain sufficient core rotation; and demonstrate that all methods of in-flight restart can be accomplished when this airspeed is maintained. (A-06-70)
>
> Ensure that airplane flight manuals of airplanes equipped with CF34-1 or CF34-3 engines clearly state the minimum airspeed required for engine core rotation and that, if this airspeed is not maintained after a high power, high altitude sudden engine shutdown, a loss of in-flight restart capability as a result of core lock may occur. (A-06-71)
>
> Require that operators of CRJ-100, -200, and -440 airplanes include in airplane flight manuals the significant performance penalties, such as loss of glide distance and increased descent rate, that can be incurred from maintaining the minimum airspeed required for core rotation and windmill restart attempts. (A-06-72)
>
> Review the design of turbine-powered engines (other than the CF34-1 and CF34-3, which are addressed in Safety Recommendation A-06-70) to determine whether they are susceptible to core lock and, for those engines so identified, require manufacturers of airplanes equipped with these engines to perform high power, high altitude sudden engine shutdowns and determine the minimum airspeed to maintain sufficient core rotation so that all methods of in-flight restart can be accomplished. (A-06-73)

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[87] The No. 2 accident engine was installed new as a spare engine and was not subjected to the core lock screening procedure because it applies only to engines that are installed in Bombardier's production airplanes.

> For those airplanes with engines that are found to be susceptible to core lock (other than the CF34-1 and CF34-3, which are addressed in Safety Recommendation A-06-71), require airplane manufacturers to incorporate information into airplane flight manuals that clearly states the potential for core lock; the procedures, including the minimum airspeed required, to prevent this condition from occurring after a sudden engine shutdown; and the resulting loss of in-flight restart capability if this condition were to occur. (A-06-74)
>
> Require manufacturers to demonstrate, as part of 14 *Code of Federal Regulations* Part 25 certification tests, if restart capability exists from a core rotation speed of 0 indicated rpm after high power, high altitude sudden engine shutdowns. For those airplanes determined to be susceptible to core lock, mitigate the hazard by providing design or operational means to ensure restart capability. (A-06-75)
>
> Establish certification requirements that would place upper limits on the value of the minimum airspeed required and the amount of altitude loss permitted for windmill restarts. (A-06-76)

Appendix E shows the complete safety recommendation letter.

1.18.3.2 Crew Professionalism

On October 8, 1974, the Safety Board issued Safety Recommendations A-74-85 and -86 as a result of the September 27, 1973, Texas International Airlines flight 655 accident in Mena, Arkansas,[88] and the September 11, 1974, Eastern Air Lines flight 212 accident in Charlotte, North Carolina.[89] The Board's final report on the Texas International Airlines accident stated that the captain failed to follow approved procedures. The probable cause of the Eastern Air Lines accident was the flight crew's lack of altitude awareness at critical points during the approach resulting from poor cockpit discipline (specifically, the crew did not follow prescribed procedures).[90] Safety Recommendation A-74-85 asked the FAA to do the following:

> Initiate a movement among the pilots associations to form new professional standards committees and to regenerate old ones. These committees should:
>
> a) monitor their ranks for any unprofessional performance.

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[88] For more information, see National Transportation Safety Board, *Texas International Airlines, Inc., Convair 600, N94230, Mena, Arkansas, September 27, 1973*, Aircraft Accident Report NTSB/AAR-74/04 (Washington, DC: NTSB, 1974).

[89] For more information, see National Transportation Safety Board, *Eastern Air Lines, Inc., Douglas DC-9-31, N8984E, Charlotte, North Carolina, September 11, 1974*, Aircraft Accident Report NTSB/AAR-75/09 (Washington, DC: NTSB, 1975).

[90] The Safety Board's safety recommendation letter cited five previous air carrier accidents as examples of a "casual acceptance" of the flight environment (Martha's Vineyard, Massachusetts, 1971; Fort Lauderdale, Florida, 1972; New Haven, Connecticut, 1972; Toledo, Ohio, 1973; and Boston, Massachusetts, 1973). The letter added that the Eastern Air Lines accident also reflected "serious lapses in expected professional conduct."

> b) alert those pilots who exhibit unprofessionalism to its dangers and try, by example and constructive criticism of performance required, to instill in them the high standards of the pilot group.
>
> c) strengthen the copilot's sense of responsibility in adhering to prescribed procedures and safe practices.
>
> d) circulate the pertinent information contained in accident reports to pilots through professional publications so that members can learn from the experience of others.

On October 17, 1974, the FAA stated that it considered it more appropriate to work with airline management rather than pilot groups to increase and promote crew discipline and professionalism. The FAA also stated that it discussed this subject at length with the Air Transport Association,[91] which provided assurance that efforts would be made to stress the importance of professionalism. On March 10, 1977, the Safety Board classified Safety Recommendation A-74-85 "Closed—Acceptable Action."

Safety Recommendation A-74-86 asked the FAA to do the following:

> Develop an air carrier pilot program, similar to the general aviation accident prevention program (FAA Order 8000.8A), that will emphasize the dangers of unprofessional performance in all phases of flight. The program could be presented in seminar form, using audio/visual teaching aids, to call to the pilots' attention all facets of the problem.

On October 17, 1974, the FAA stated that many airlines have established accident prevention programs and have periodically conducted seminars. The FAA also stated that it has participated in these seminars and would increase its participation in the future. The FAA further stated that it would urge its field offices to emphasize the dangers of unprofessional performance and that it would hold meetings with the Air Transport Association to discuss this subject. On March 10, 1977, the Safety Board classified Safety Recommendation A-74-86 "Closed—Acceptable Action."

1.18.3.3 Flight Data Recorder Data

On May 16, 2003, the Safety Board issued Safety Recommendation A-03-15 to the FAA because of problems with the quality of FDR data recorded by several regional jet airplanes. Safety Recommendation A-03-15 asked the FAA to do the following:

> Require that all Embraer 145, Embraer 135, Canadair CL-600 RJ, Canadair Challenger CL-600, and Fairchild Dornier 328-300 airplanes be modified with a digital flight data recorder system that meets the sampling rate, range, and accuracy requirements specified in 14 *Code of Federal Regulations* Part 121.344, Appendix M.

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[91] The Air Transport Association is the trade organization of the largest U.S. airlines.

On June 9, 2005, the FAA stated the following:

- Regarding the Embraer 145 and 135, Embraer released Service Bulletin (SB) 145-31-0042, Revision 2, to correct known FDR anomalies, and the Brazilian Department of Civil Aviation issued Airworthiness Directive (AD) 2004-12-03, requiring incorporation of the Embraer SB within 18 months. The FAA advised U.S. operators of the Embraer 145 and 135 of the Brazilian AD and planned to release a corresponding AD. (As of December 1, 2006, the FAA had not issued the corresponding AD.)
- Regarding the Canadair CL-600-2B19 (CRJ-100, -200, and -440) and CL-600-2B16 (Challenger 604), the Canadian airworthiness authority, Transport Canada, reported that Bombardier confirmed that the FDR system on these airplanes exhibited low update rates on the normal acceleration and pitch attitude parameters.[92] Bombardier and Rockwell Collins, the supplier of the system that established the parameter update rates on these airplane models, were planning to develop a plan and schedule for correcting this problem. The FAA was working with Transport Canada to get expeditious action from Bombardier on this issue.
- Regarding the Fairchild Dornier 328-300, AvCraft Aviation (which acquired the rights to the 328 program), in cooperation with Honeywell (the manufacturer of the 328-300 FDR system), completed an extensive review of FDR data from two incidents and several flight tests. They concluded that all FDR parameters were updated at a rate equal to or exceeding those required by 14 CFR 121.344, Appendix M, when the data were analyzed with the proper frame rate and at the maximum accuracy.

On September 28, 2005, the Safety Board agreed that no problems existed with the FDR parameters on the Fairchild Dornier 328-300 airplane. The Board also stated that, pending the FAA's issuance of an AD that mandated compliance with Embraer SB 145-31-0042, Revision 2, and an AD that mandated correction to CRJ-100, -200, and -440 and Challenger 604 FDR systems, Safety Recommendation A-03-15 was classified "Open—Acceptable Response."

1.18.4 Federal Aviation Administration Notice

On March 1, 2005, the FAA issued Notice N8000.296, "Pilot Judgment and Decisionmaking," after six accidents that occurred between October and November 2004. These accidents were Pinnacle Airlines flight 3701, Corporate Airlines flight 5966,[93] and

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[92] Bombardier indicated that other recorded parameters on the CRJ-100, -200, and -440 and Challenger 604 airplanes were updated at rates that were in compliance with the regulations. Bombardier also noted that the update rates for all FDR parameters on CL-600-2C10 (CRJ-700) and CL-600-2D24 (CRJ-900) airplanes complied with the regulations.

[93] For more information, see National Transportation Safety Board, *Collision With Trees and Crash Short of the Runway, Corporate Airlines Flight 5966, BAE Systems BAE J3201, N875JX, Kirksville, Missouri, October 19, 2004*, Aircraft Accident Report NTSB/AAR-06/01 (Washington, DC: NTSB, 2006).

accidents involving a Learjet 35A at San Diego, California; a King Air 200 at Stuart, Virginia; a Challenger 600 at Montrose, Colorado; and a Gulfstream III at Houston, Texas.[94]

The notice was issued to POIs of operators of airplanes with 70 or fewer passenger seats, corporate managers and trainers, and individual pilots to encourage the promotion of "soft skills" as a first line of defense against accidents caused by lapses in human performance. The FAA defined soft skills as those that go beyond the technical knowledge and psychomotor skills that are necessary to fly an airplane. Such skills include adherence to standard operating procedures, decision-making, judgment, CRM, and professionalism.

The notice required POIs to convey information about the importance of soft skills in preventing human error and the existing FAA guidance on that topic. The notice also recommended that operators ensure that their programs reflected the human factor principles that were outlined in FAA guidance about CRM and standard operating procedures. In addition, the notice indicated that individual pilots should examine their own decision-making habits in terms of professionalism, thoroughness of preparation, and adherence to standard operating procedures. The notice expired on March 1, 2006.[95] In a November 2006 memorandum to the Safety Board, the FAA stated that it incorporated soft skills into Part 121 CRM training requirements and that a rewrite (which is currently in progress) of FAA Order 8400.10, *Air Transportation Operations Inspector's Handbook*, would emphasize soft skills.

1.18.5 Bombardier All Operator Message

On December 14, 2004, Bombardier issued an all operator message that included the following information about high altitude operations:

> Climb profiles as detailed in the AFM [airplane flight manual] must be strictly adhered to. Climbing below the recommended profile speed may place the airplane behind the energy curve when it arrives at the desired altitude and it may not be capable of remaining at that altitude. This may be evident by an aircraft nose-high attitude and its failure to accelerate.
>
> The autopilot should be engaged and performance closely monitored during the upper portion of the climb and immediately following the level off. When the selected altitude is reached, under normal conditions, the aircraft will accelerate to the desired cruise speed.

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[94] For more information on these accidents, see LAX05FA015, IAD05MA006, DEN05MA029, and DCA05MA011, respectively, at the Safety Board's Web site at <http://www.ntsb.gov>.

[95] All FAA notices expire 1 year after issuance. Because the notices are temporary by nature, they are rarely renewed.

> Situational awareness must be maintained at all times when the aircraft reaches the desired cruising altitude. If the … [AOA] is excessively high, the performance may be such that the aircraft is not capable of maintaining the altitude and the airspeed may begin to decay. Under these circumstances, a descent must be initiated immediately.
>
> Do not wait for the onset of continuous ignition or stick shaker before attempting a descent from an altitude where continued operation is not possible. Descend immediately.
>
> In the event that a stick shaker/approach to stall occurs, the crew should expect that a deliberate loss of altitude will likely be required in order to restore the aircraft to a normal energy state and to prevent an aerodynamic stall and possible departure from controlled flight.

2. Analysis

2.1 General

The captain and the first officer were properly certificated and qualified under Federal regulations. No evidence indicated any medical or behavioral conditions that might have adversely affected their performance during the accident flight. Flight crew fatigue and hypoxia were not factors in this accident.

The accident airplane was properly certified, equipped, and maintained in accordance with Federal regulations. The recovered components showed no evidence of any structural or system failures or any engine failures before the time of the upset event. Weather was not a factor in this accident. The accident was not survivable.

This analysis discusses the accident sequence, including the flight crew's decision to climb to 41,000 feet and the improper climb speed; the crew's improper actions during the stall event; and the crew's failure to restart the engines, inform air traffic controllers of the double engine failure, and initiate an emergency landing in a timely manner. The analysis also addresses flight crew training (in the areas of high altitude climbs, stall recognition and recovery, and double engine failures) as well as flight crew professionalism. In addition, the analysis addresses problems with the quality of some parameters recorded by FDRs on regional jet airplanes, including the CRJ-200.

2.2 Accident Sequence

2.2.1 Climb to 41,000 Feet

The flight plan for the accident flight indicated that the planned cruise altitude was 33,000 feet. However, the ATC and CVR transcripts showed the flight crew's desire to climb to an altitude of 41,000 feet, which is the CRJ maximum operating altitude.[96] During postaccident interviews, Pinnacle Airlines pilots stated that some pilots had expressed curiosity about operating the airplane at 41,000 feet and that a "[flight level] 410 club" existed at the airline.

When the airplane was at an altitude of 450 feet, the first of three aggressive pitch-up maneuvers during the ascent occurred. During the first maneuver, the flight crew moved the control column to 8º ANU, causing the airplane's pitch angle to increase to 22º and resulting in a vertical load of 1.8 Gs. The maneuver also caused the stickshaker and

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[96] It is not known which pilot first suggested that the flight be operated at an altitude of 41,000 feet. However, CVR evidence showed that both pilots were willing participants in the decision to climb to 41,000 feet.

stickpusher to activate. After stickpusher activation, the FDR recorded a full nose-down control column deflection. When the airplane was at an altitude of 15,000 feet, the second pitch-up maneuver occurred. The flight crew moved the control column to 3.8º ANU, causing the airplane's pitch angle to increase to 17º and resulting in a vertical load of 2.3 Gs. Afterward, the flight crew made rudder inputs of 4.2º to the left, 6.0º to the right, and 0.4º to the left followed 17 seconds later by a 7.7º right rudder input. When the airplane was at an altitude of 24,600 feet, the third pitch-up maneuver occurred. The flight crew moved the control column to 4º ANU, causing the pitch angle to increase to more than 10º and resulting in a vertical load of 1.87 Gs. The pilots' intentional maneuvers, which were not required for any operational reason or safety consideration, placed the airplane in a flight regime that likely exceeded the airplane's certificated flight envelope.[97]

The CVR recording showed that both pilots repeatedly expressed excitement before and after reaching the 41,000-foot altitude. For example, the CVR recorded the first officer stating, "man we can do it. Forty one it," "there's four one oh my man," and "this is … great." The CVR also recorded the captain stating, "look how high we are." In addition, when one of the air traffic controllers handling the flight stated to the flight crew, "I've never seen you guys up at forty one there," the captain replied, "we don't have any passengers on board so we decided to have a little fun and come on up here" and "this is actually our service ceiling." The Safety Board concludes that the pilots' aggressive pitch-up and yaw maneuvers during the ascent and their decision to operate the airplane at its maximum operating altitude (41,000 feet) were made for personal and not operational reasons.

Pinnacle Airlines required that a climb to 41,000 feet be conducted at an airspeed of 250 knots (0.70 Mach).[98] However, FDR data showed that the flight crew conducted the climb from 37,000 to 41,000 feet at an airspeed that decreased from 203 knots (0.63 Mach) at the start of the climb to 163 knots (0.57 Mach) as the airplane leveled off at 41,000 feet. FDR data also showed that the flight crew conducted the climb from 37,000 to 41,000 feet with the autopilot vertical speed mode engaged and a commanded vertical speed of 500 fpm. The airplane could not sustain the required airspeed while climbing at 500 fpm, which resulted in the 40-knot loss of airspeed, and, once level at 41,000 feet, the airplane was operating in a "region of reversed command"[99] in which available thrust was not sufficient to increase airspeed. The flight crew should have used the autopilot airspeed mode rather than the vertical speed mode to prevent the loss of airspeed. The Safety Board concludes that the flight crew's inappropriate use of the vertical speed mode during the climb was a misuse of automation that allowed the airplane to reach 41,000 feet in a critically low energy state.

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[97] The pilots were experienced in the airplane, so the maneuvering would not have been the result of improper control inputs by a pilot who was unfamiliar with the airplane's handling characteristics.

[98] Specifically, the climb should be conducted at 250 knots until Mach 0.7 is reached, at which point Mach 0.7 becomes the primary indicator of airspeed.

[99] Region of reversed command is also known as operating "on the back side of the power curve." It occurs when the available engine thrust cannot overcome the increased induced drag associated with low airspeed. As a result, the airplane cannot accelerate and may decelerate.

Statements on the CVR recording indicated that the pilots did not fully understand the aerodynamic and performance considerations associated with operations at an altitude of 41,000 feet. Specifically, about 2154:07, the captain stated, “we’re losing here. We’re gonna be … coming down in a second here.” About 3 seconds later, the captain stated, “this thing ain’t gonna … hold altitude. Is it?” The first officer responded, “it can’t man. We … (cruised/greased) up here but it won’t stay.” About 2154:19, the captain stated, “yeah that’s funny we got up here it won’t stay up here.”[100]

Pinnacle Airlines’ ground school upset training addressed high altitude aerodynamics, swept-wing design characteristics, and the use of performance charts. Also, the company’s ground school performance training provided pilots with instruction on how to use climb capability charts to determine thrust settings for altitudes above 36,000 feet. The CVR recording did not indicate whether the flight crew consulted the company’s altitude and climb ability charts before initiating the climb to 41,000 feet. However, the Safety Board concludes that the improper airspeed during the climb demonstrated that the pilots did not understand how airspeed affects airplane performance and did not realize the importance of conducting the climb according to the published climb capability charts. Section 2.3.1 discusses high altitude training for regional jet operations.

2.2.2 Aerodynamic Stall and Upset Event

Even though the pilots recognized that the airplane’s performance was deteriorating, neither pilot appeared to respond to this situation with urgency. The pilots contacted the controller about 2154:32 and requested a lower altitude; however, during the time that the controller was coordinating the descent, the airplane’s airspeed further deteriorated to Mach 0.53 (150 knots), and the stickshaker activated for the first of five times. Afterward, the stickshaker activated four times, and the stickpusher activated four times, pushing the control column forward automatically.[101] The flight crew responded to the stickpusher each time by pulling back on the control column. These control column inputs caused the airplane’s pitch angle to increase to a maximum ANU value of 29º about 2154:59, and then the airplane entered an aerodynamic stall. Afterward, the airplane’s pitch angle decreased to a maximum AND value of 32º about 2155:06. While the pitch angle was decreasing, a left rolling motion began, which eventually reached 82º left wing down, and the N_1 and fuel flow indications for both engines declined steadily to zero, indicating that both engines had flamed out. The Safety Board concludes that the upset event exposed both engines to inlet airflow disruption conditions that led to engine stalls and a complete loss of engine power. The double engine failure is further discussed in section 2.2.3.

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[100] During postaccident interview, several company pilots stated that, even though they had been able to climb the CRJ to 41,000 feet, the airplane was not able to stay at that altitude for an extended period because the airplane’s performance had deteriorated.

[101] During the public hearing on this accident, a Bombardier engineer testified that the stickpusher had functioned normally during the flight.

During the investigation, the aircraft performance group determined that the stickshaker was functioning normally[102] but that the airspeed indicator's low speed cue was 10 knots low. As a result, at the time of stickshaker activation, the low speed cue was indicating that the airplane's speed was 10 knots above the stickshaker speed. The erroneous information shown by the low speed cue resulted from a software error.[103]

According to Pinnacle Airlines, its flight crewmembers were taught that the top of the low speed cue indicated the airspeed at which the stickshaker would initially activate. However, the flight crews were also trained to respond to stickshaker activation, regardless of whether the airspeed was above the low speed cue, because the stickshaker is the primary warning to pilots of an impending stall. In addition, when an airplane's speed is about 10 knots from the top of the low speed cue, especially when operating at an altitude of 41,000 feet, pilots should realize that the airplane is dangerously close to an impending stall. When the stickshaker activated during the accident flight, the pilots should have immediately attempted to accelerate the airplane to a safe airspeed by descending; sufficient reserve power was not available from the engines while the airplane was at 41,000 feet. Thus, the accident pilots should have responded appropriately to the stickshaker and used the low speed cue only as a secondary indication showing that the airspeed was dangerously slow.

Even though the flight crew was eventually able to recover the airplane from the upset event, the flight control inputs made during the upset were opposite of what was required to recover the airplane. FDR data showed that the flight crew moved the control column aft after the first stickpusher activation and that the crew moved the control column aft with increasing magnitude after the next three activations of the stickpusher.

A reason that might explain why the pilots made these flight control inputs, which exacerbated the upset event, was that Pinnacle Airlines' stall recognition and recovery simulator training focused on recovery with a minimum loss of altitude (which is common throughout the aviation industry). As a result, the pilots were trained to apply power to restore the energy state of the airplane and to maintain altitude.[104] In this accident, the pilots' inputs could have been the result of their attempt to recover using a minimal altitude loss recovery technique, and, as the repeated stall events occurred with increasing nose-down pitch attitude, the pilots could have been instinctively trying to arrest the

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[102] The Safety Board compared the AOA recorded on the FDR at the time of the stickshaker activations with Bombardier's stickshaker design criteria for the flight condition and determined that the stickshaker activated at the expected AOA (about 7.8°) and airspeed (about 150 knots).

[103] In December 2004, the FAA sent a letter to Transport Canada that recommended, among other things, that Bombardier change "the airspeed tape display software to more accurately depict the top of the Low Speed Awareness (top of the red band) at all altitudes and Mach Numbers." In February 2005, Bombardier indicated that it would include an appropriate design change the next time the stall protection computer and the air data computer were modified and that, in the interim, its FCOM would be revised to provide necessary guidance material on changes to the computation required to determine the low speed cue. In November 2006, Bombardier stated that it had not yet scheduled the modification; in December 2006, Bombardier issued the revised FCOM.

[104] The Safety Board could not determine whether the pilots applied power because the throttle lever angle parameter was not recorded on the FDR.

nose-down pitch moment or responding inappropriately to the stickpusher. The Safety Board concludes that the pilots' lack of exposure to high altitude stall recovery techniques contributed to their inappropriate flight control inputs during the upset event. Section 2.3.2 discusses stall recognition and recovery training.

2.2.3 Double Engine Failure

About 2155:06, the flight crew declared an emergency and asked the controller to stand by. CVR evidence showed that the flight crew recognized the nature of the emergency; specifically, about 2155:23, one pilot stated to the other, "we don't have any engines." However, the CVR also showed that the flight crew did not begin the first item of the double engine failure checklist (which is a memory item) until 1 minute 19 seconds after the statement on the CVR recording about the double engine failure. Also, FDR data showed that the pilots did not achieve and maintain the target airspeed of 240 knots (another memory item on the checklist). Because the flight crew did not achieve this airspeed, both engines' cores had decelerated and stopped before the airplane descended through an altitude of 28,000 feet.

The double engine failure checklist indicated that, between the altitudes of 21,000 and 13,000 feet, the windmill restart procedure should be used to relight the engines. This procedure required that the pitch attitude of the airplane be reduced to and maintained at -8° to accelerate the airplane to an airspeed of 300 knots or greater. However, the pitch inputs made by the flight crew were not of sufficient magnitude and were not sustained. As a result, the crew did not achieve the 300-knot or greater airspeed required for the procedure; FDR data showed that the highest airspeed attained during the restart attempt was 236 knots and that the engines' N_2 (core rotation) indications remained at zero. The Safety Board concludes that the captain did not take the necessary steps to ensure that the first officer achieved the 300-knot or greater airspeed required for the windmill engine restart procedure and then did not demonstrate command authority by taking control of the airplane and accelerating it to at least 300 knots. The Safety Board further concludes that the first officer's limited experience in the airplane might have contributed to the failed windmill restart attempt because he might have been reluctant to command the degree of nose-down attitude that was required to increase the airplane's airspeed to 300 knots.

Because the flight crewmembers were unsuccessful in their attempt to relight the engines using the windmill procedure, they elected to descend the airplane to an altitude of 13,000 feet so that they could attempt to restart the engines with the APU. Once the airplane descended to an altitude of 13,000 feet, the flight crew attempted four APU-assisted engine restarts (two attempts per engine) during a 5-minute period (2207:04 to 2212:07) and between the altitudes of about 12,900 and about 5,000 feet. FDR data showed that the N_2 indications for both engines remained at zero during the restart attempts. The Safety Board concludes that, despite their four APU-assisted engine restart attempts, the pilots were unable to restart the engines because their cores had locked. Without core rotation, recovery from the double engine failure was not possible.[105]

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[105] Section 2.2.3.1 discusses the flight crew's performance of the double engine failure checklist.

The Safety Board considered whether engine hardware was a factor contributing to the lack of core rotation. However, engine teardowns found no mechanical failures or evidence of any condition that would have prevented engine core rotation.

The Safety Board then considered whether an electrical or mechanical problem interfered with the ability of the cores to achieve rotation. However, inspection and testing of the APU and other airplane start system components found no conditions that would have prevented torque delivery to either engine during the four APU-assisted restart attempts. Also, FDR data showed that the LCV was open during these restart attempts,[106] and testing showed that it was capable of providing pneumatic power from the APU to start initial rotation in each engine. A systems simulation study (see section 1.16.4) showed that the LCV had likely opened by at least 18º during the flight, which should have resulted in some detectable core rotation if the engine cores were capable of rotation. In addition, the change in engine oil temperatures[107] showed that air was flowing through the ATS. This finding, along with the results of the airplane start system component testing, showed that the LCV was likely fully open.

The Safety Board considered whether the slight increases in core-driven hydraulic pump pressures shown on the FDR during the final minutes of the flight (as described in section 1.16.3) were evidence of engine core rotation. The airplane's start system was operating normally during the restart attempts; thus, if the cores were free to rotate, they would have quickly accelerated. As a result, the Board determined that the slight increases in hydraulic pump pressures that were recorded on the FDR were not the result of engine core rotation.

On the basis of the information discussed in section 1.18.2, the Safety Board concludes that the GE CF34-1 and CF34-3 engines had a history of failing to rotate during in-flight restart attempts on airplanes undergoing production acceptance testing at Bombardier. GE attributed the problem to interference contact at an air seal in the high pressure turbine and, along with Bombardier, referred to this condition as core lock. The lack of core rotation on the accident airplane engines was similar to the instances of core lock experienced by CF34 engines during Bombardier's acceptance testing, except that the accident airplane engines were exposed to more severe thermal distress than the engines on the production airplanes. Specifically, the accident airplane's engines flamed out from high power and high altitude, whereas the engines installed on the production airplanes were shut down only after their internal temperatures were stabilized.[108]

Flameouts at high power and high altitude produce even greater thermal distress because internal temperatures are the hottest at high power settings and the air is colder at high altitudes. The increased thermal shock exacerbates the loss of component clearance

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[106] The FDR parameter for the LCV position shows that the valve is open once it reaches a position that is greater than 4.8º from its normally closed position.

[107] The FDR recorded a steady decline in engine oil temperature after the upset and showed that this steady decline ceased at the time of the engine restart attempts.

[108] On November 20, 2006, the Safety Board issued recommendations to the FAA to address this and other core lock-related issues; see sections 1.18.3.1 and 4.3 for information.

and alignment. Because the accident engines flamed out under these conditions, axial misalignment caused the seal teeth, which were positioned aft of their normal operating grooves, to contact stationary abradable material when radial seal clearances closed down. Once core rotation stopped, binding prevented core rotation from resuming during the windmill and APU-assisted restart attempts. No physical evidence of core lock was found inside the engines because the thermally induced interference occurred after core rotation had stopped and operating clearances were restored afterward as the engine cooled.

The Safety Board concludes that both engines experienced core lock because of the flameout from high power and high altitude, which resulted from the pilot-induced extreme conditions to which the engines were exposed, and the pilots' failure to achieve and maintain the target airspeed of 240 knots, which caused the engine cores to stop rotating; both of these factors were causal to this accident.

2.2.3.1 Performance of the Double Engine Failure Checklist

A critical error made by the flight crew while performing the double engine failure checklist was failing to establish and maintain an airspeed of 240 knots before beginning the procedures to restart the engines. During the public hearing on this accident, a GE manager testified, "as long as core rotation is maintained, you will not have core lock … we have a body of data that shows that 240 knots maintains core rotation."

Another critical error made by the flight crew was failing to increase the airspeed to at least 300 knots before beginning the windmill restart procedure. About 2159:16, when the FDR resumed operation after a loss of power lasting about 4 minutes, the airplane's airspeed was 178 knots. About 2200:38, the captain told the first officer to increase the airspeed to above 300 knots, and the first officer acknowledged this instruction. About 1 minute later, the captain again told the first officer to increase the airspeed to 300 knots. However, FDR data showed that the maximum airspeed achieved during the procedure—236 knots—was achieved only briefly.

Other errors in the performance of the double engine failure checklist included the captain's failure to call out the items using standard phraseology and indicate when the checklist was complete. According to the simulator instructor who conducted part of the captain's upgrade training, the captain did not always perform checklists according to company procedures.[109] This reported behavior in the simulator was consistent with the captain's performance of the double engine failure checklist. Specifically, although the checklist procedures were clear, the captain did not effectively manage the execution of the checklist or ensure that the first officer had achieved the necessary airspeed, which is inconsistent with the basic tenets of CRM and basic airmanship.

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[109] As discussed in section 1.5.1, the instructor stated that the captain would, at times, misstate the status of a checklist item, read a checklist item but not accomplish it, take action on an airplane system that was not the one noted in the checklist, or see the appropriate checklist displayed in an EICAS message but still call for the wrong checklist.

In addition to the captain's previous difficulties in executing checklists, two additional factors likely played a role in the flight crew's performance of the double engine failure checklist. The first factor was the stress associated with the situation. The stress included changes to the cockpit environment, such as the reduced cockpit lighting and the increase in ambient noise associated with the deployment of the ADG. Another stressor was the instrumentation available to the captain during the 4-minute period in which the ADG was the sole source of power—from the right seat, he would not have had a primary flight display showing airspeed and altitude; thus, he would have had to look over to the left side of the instrument panel or use the standby instruments in the center of the panel while performing the double engine failure checklist and other nonflying pilot duties. Also, the stress of the situation might have caused both pilots to experience attentional tunneling, that is, the focusing of attention on a single task or portions of a task, which results in neglecting other critical tasks. For example, the captain did not recognize that the airspeed required for N_2 rotation (which was necessary for restarting the engines) had not been achieved. The second factor was that the pilots had only received ground school instruction on the double engine failure checklist. Thus, it is possible that they were executing it for the first time.

Even though maintaining an airspeed of 240 knots was a memory item on the checklist, it is possible that the pilots did not realize the importance of this airspeed to the success of the restart sequence. The Safety Board concludes that the importance of maintaining a minimum airspeed to keep the engine cores rotating was not communicated to the pilots in airplane flight manuals. For example, at the time of the accident, Bombardier's and Pinnacle Airlines' double engine failure checklists stated that 240 knots was the "target" airspeed for the procedure but did not indicate that this airspeed was essential to the success of the restart procedure. As a result of the accident, Bombardier and Pinnacle Airlines revised their double engine failure checklist to indicate that 240 knots was the "minimum" airspeed and that the failure to maintain positive core rotation might prevent a successful restart. It is also possible that, after the double engine failure, the pilots were attempting to operate the airplane at its best glide speed of 170 knots, which is 70 knots less than the speed needed to maintain engine core rotation.

The Safety Board examined whether the seat swap would have affected the pilots' performance during the double engine failure checklist.[110] The captain, who was responsible for performing the checklist, had significant experience in the right seat of the airplane, so the position of the controls and switches would have been familiar to him. Further, the tasks that the captain was performing for the checklist were not well practiced because of the lack of training in this area (as discussed in section 2.3.3), so he would not have developed any habit patterns or motor memory skills from the left seat that would have interfered with his ability to perform from the right seat. The lack of a flight display on the right side of the cockpit should not have affected the captain's ability to recognize that the required airspeeds had not been achieved because airspeed was clearly presented on the standby instrument and the left-side primary flight display. The first officer was

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[110] It is not known which pilot suggested that the first officer sit in the captain's seat during most of the accident flight. However, both pilots demonstrated poor judgment in allowing the seat swap to occur.

responsible for flying the airplane, and the seat swap should not have affected his ability to achieve the commanded speeds. Thus, the pilots' seat swap, although contrary to standard operating practice, was not a factor that affected the pilots' performance of the double engine failure checklist.[111]

The Safety Board concludes that the captain's previous difficulties in checklist management, the situational stress, and the lack of simulator training involving a double engine failure contributed to the flight crew's errors in performing the double engine failure checklist.

2.2.4 Communications With Air Traffic Controllers and Management of Forced Landing

About 2206:40, the controller (at the sector 53 position) asked the pilots whether they wanted to land. The captain, during his reply to the controller, failed to disclose the true nature of the emergency, stating, "just stand by right now we're gonna start this other engine and see … if everything is okay." About 2209:06, the first officer informed the controller that the airplane was experiencing a double engine failure. This notification happened almost 14 minutes after the flight crew first recognized (according to CVR evidence) that a double engine failure had occurred. During that time, the flight crew had numerous opportunities to notify the controller of the double engine failure. For example, the controller (at the sector 30 position) had earlier asked the flight crew about the nature of the emergency, but the captain responded, "we had an engine failure up there … so we're gonna descend down now to start our other engine." This controller then stated, "understand controlled flight on a single engine right now," but the captain did not correct this information by informing the controller of the actual situation. Thus, the transmissions describing a loss of only one engine indicated that the captain intentionally conveyed information to the controllers that did not represent his own understanding of the situation.

During postaccident interviews, company pilots stated that, if an emergency situation (such as the loss of one or both engines) were to occur, they were instructed to provide relevant information to air traffic controllers, as workload and conditions allowed, about the nature of the emergency and the assistance that was needed. By misleading the controllers about the true nature of the emergency, the captain lost the full use of a valuable resource in an emergency situation.[112] For example, if the captain had notified the controller early in the descent about the double engine failure, the controller would have likely provided the pilots with suggested vectors for a descent to and landing at an airport within the airplane's best glide range.

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[111] About 2208:17, after the sound of oxygen mask use ceased, the CVR recorded the captain stating "switch," indicating that the captain was preparing to return to the left seat and have the first officer return to the right seat.

[112] The captain's inaccurate communications to the controllers about the loss of only one engine were also inconsistent with the basic tenets of CRM.

The company's double engine failure procedure stated that, if neither engine was restarted, the flight crew should consider a forced (emergency) landing. Five airports that were suitable for an emergency landing were located within 60 miles of the upset location (see section 1.16.1.3). However, the flight crew did not consider making an emergency landing at any of these airports. Between the time that the flight crew first realized that a double engine failure had occurred and the time that the captain notified the controller of the actual situation, the airplane had descended from 35,000 to 10,000 feet. When the airplane was at an altitude of 10,000 feet, only one airport (AIZ) was still within the airplane's best glide range, but the pilots had already overflown that airport. At that altitude, JEF was just outside the airplane's best glide range.[113] The aircraft performance study for this accident showed that drag produced by the 5.6º spoiler deployment had a minimal effect on the airplane's ability to reach JEF.

A double engine failure in a two-engine airplane is an emergency situation that requires timely action to stabilize the situation and effective coordination of all available resources and options to ensure a successful outcome. The flight crew's failure to discuss an emergency landing during most of the descent demonstrated the crew's poor judgment. Also, the captain's failure to inform the controllers about the true nature of the situation early in the descent demonstrated the pilots' apparent reluctance to have their deviation from standard operating procedures and their unprofessional behavior detected.

Multiple opportunities existed during the descent for the pilots to talk with controllers and between themselves about the need to make an emergency landing. The pilots acted in a manner that was not consistent with ensuring safety of flight or effectively managing an in-flight emergency. The Safety Board concludes that the pilots' failure to prepare for an emergency landing in a timely manner, including communicating with air traffic controllers immediately after the emergency about the loss of both engines and the availability of landing sites, was a result of their intentional noncompliance with standard operating procedures, and this failure was causal to the accident.

2.2.5 Accident Sequence Summary

This accident was not the result of a single action, decision, or mistake by the flight crew. Instead, the accident was the result of poorly performing pilots who intentionally deviated from standard operating procedures and basic airmanship. Also, CVR evidence showed that the pilots' tone in the cockpit was unprofessional[114] and that their attitude was inconsistent with the demands associated with, and the precision required for, flying a high performance turbojet airplane.

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[113] On the basis of the airplane's location at this point in the flight, the air traffic controller correctly directed the airplane to JEF, which was essentially straight ahead along the airplane's flightpath. If the airplane had been directed to AIZ, a 160º left turn would have been required, which would have cost the airplane altitude, airspeed, and distance.

[114] As indicated in the CVR transcript in appendix B, the flight crew's conversation was generally casual, and sounds of joking and laughing were heard during the recording. Also, the transcript showed that the captain left his duty station unnecessarily to get a soft drink.

According to models of human error, the pilots' performance during the climb and their decision to operate at 41,000 feet can be described as "optimizing violations," which occur when someone disregards defined procedures intentionally to make a job more interesting or engaging, to push limits, or to impress another.[115] For example, the pilots' CVR statements about operating at an altitude of 41,000 feet were consistent with thrill-seeking behavior. It is not possible to determine the specific reasons that the pilots demonstrated these optimizing violations. However, according to situational control theory, the chance that someone will violate a rule increases when such a violation results in personal achievement and is likely to go undetected.[116] In this case, the Part 91 repositioning flight with no passengers or other crewmembers on board presented the pilots with an opportunity to reach personal milestones associated with aggressive maneuvering and operating the airplane at its maximum operating altitude.

The Safety Board's investigation of this accident did not reveal any evidence that the pilots had previously engaged in the unprofessional behavior demonstrated during the accident flight. Also, the CVR recording contained no indication that the pilots anticipated the adverse outcome resulting from their intentional deviations from standard operating procedures. Such intentional deviations can compromise the margins of safety that are in place as a result of procedures established by the company, the manufacturer, and the FAA. A consequence associated with compromising these margins of safety is that the operator becomes more vulnerable to the catastrophic effects of unintentional errors.[117]

Evidence indicated that the critical human performance failures during the flight were the result of intentional behavior and were not consistent with typical errors (slips, lapses, and mistakes) found in most flight crew-involved accidents involving Part 121 operators. Although the pilots demonstrated some performance failures and deficiencies in basic airmanship that were consistent with the more typical errors found in accidents, such as their failure to achieve required airspeeds during the descent (see section 2.2.3), the pilots' overall actions during the accident flight were not consistent with the degree of discipline, maturity, and responsibility required of professional pilots. The Safety Board concludes that the pilots' unprofessional operation of the flight was intentional and causal to this accident because the pilots' actions led directly to the upset and their improper reaction to the resulting in-flight emergency exacerbated the situation to the point that they were unable to recover the airplane.

The Safety Board is concerned about the willful misconduct demonstrated by the pilots during the accident flight. The Board has investigated other recent accidents in which pilots did not adhere to standard operating procedures and demonstrated a lack of cockpit discipline. Section 2.4 discusses this problem and the need for broad industry action involving pilots, operators, and the FAA to address the problem.

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[115] J.T. Reason, *Human Error* (New York: Cambridge University Press, 1990).

[116] D. Huntzinger, "Pilots Behaving Badly," *Vector* (New Zealand: Civil Aviation Authority, January/February 2001).

[117] P.T.W. Hudson, W.L.G. Verschuur, D. Parker, R. Lawton, and G. van der Graff, "Bending the Rules: Managing Violation in the Workplace." For more information about this paper, see <http://www.energyinst.org.uk/heartsandminds/docs/bending.pdf>.

2.3 Flight Crew Training

2.3.1 High Altitude Training

High altitude climbs were not practiced during Pinnacle Airlines' simulator training. The circumstances of the accident flight and the actions taken by Pinnacle Airlines and Bombardier after the accident to increase awareness of CRJ performance capabilities and limitations during high altitude operations[118] indicate that high altitude training at regional jet operators may not be adequate.

Regional airlines are typically the journeyman career step for professional pilots seeking employment with major air carriers. Until the advent of the regional jet, pilots at regional airlines typically operated turboprop airplanes. Because turboprop airplanes do not have the performance capabilities of, or operate at the same speeds and flight levels as, a regional jet, it is possible that some regional airline pilots were not adequately trained to make the transition to a turbojet airplane. Also, regional airline pilots with military flight training may have received more thorough high altitude training compared with civilian pilots; however, the number of regional airline pilots who had previously received military flight training has decreased since the 1980s.[119]

Because of advances in airplane equipment (turboprop to turbojet airplanes) at regional airlines and changes in the pilot force transitioning to regional jet operations, the current training methods and syllabuses for high altitude training at these operators may be in need of an industrywide revision. The Safety Board concludes that revised high altitude training syllabuses for pilots who operate regional jet airplanes would help ensure that these pilots possess a thorough understanding of the airplanes' performance capabilities, limitations, and high altitude aerodynamics. Therefore, the Safety Board believes that the FAA should work with members of the aviation industry to enhance the training syllabuses for pilots conducting high altitude operations in regional jet airplanes. The syllabuses should include methods to ensure that these pilots possess a thorough understanding of the airplanes' performance capabilities, limitations, and high altitude aerodynamics. The Safety Board further believes that the FAA should determine whether the changes to be made to the high altitude training syllabuses for regional jet airplanes, as requested in Safety Recommendation A-07-1, would also enhance the high altitude

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[118] As previously stated, Bombardier issued an all operator message to remind pilots of the importance of adhering to prescribed performance charts when operating at high altitudes and to inform them that climbing at a too-slow airspeed might result in performance deterioration once altitude is achieved. Pinnacle Airlines revised its FCOM to limit the minimum climb speed above 10,000 feet to 250 knots/0.70 Mach, whichever was lower. The company also placed altitude and climb capability charts into the Quick Reference Handbook for easy access during flight and issued guidance to pilots regarding the need to limit operation of the airplane to 37,000 feet or below. In addition, the company's ground training now includes additional emphasis on these issues in the performance and high altitude training segments and a demonstration of these areas during simulator training.

[119] During the 1980s, about 80 percent of the pilots hired by all commercial airlines had military flight training, but, according to the FAA in 2001, this number has decreased to about 40 percent.

training syllabuses for all other transport-category jet airplanes and, if so, require that these changes be incorporated into the syllabuses for those airplanes.

2.3.2 Stall Recognition and Recovery Training

The stall recognition and recovery training at Pinnacle Airlines, as well as elsewhere in the aviation industry, focuses on approach to stalls and recovery with minimum loss of altitude. Because most stalls occur when the airplane is maneuvering at lower altitudes,[120] recoveries are practiced during training by applying power to restore the energy state of the airplane and maintaining pitch. Although this strategy can be effective at lower altitudes where the airplane has excess thrust, it is not effective when the airplane is at high altitudes, as demonstrated by the circumstances of this accident, or when a full stall has developed with resulting disruption of airflow to the engines, as demonstrated by the circumstances of the 1996 ABX Air accident in Narrows, Virginia.[121]

After the accident, Pinnacle Airlines added to its simulator training a high altitude buffet demonstration that emphasizes the need to get the airplane's nose down to increase airspeed when engine thrust is marginal. Also, Bombardier's all operator message that was issued after the accident stated, in part, the following: "in the event that a stick shaker/approach to stall occurs, the crew should expect that a deliberate loss of altitude will likely be required to restore the aircraft to a normal energy state and to prevent an aerodynamic stall and possible departure from controlled flight." The Safety Board concludes that, because most training for stalls occurs with the airplane at low altitudes, the training methods may introduce a bias in stall recovery techniques by encouraging pilots to minimize altitude loss and not fully recognizing other available recovery techniques. Therefore, the Safety Board believes that the FAA should require that air carriers provide their pilots with opportunities to practice high altitude stall recovery techniques in the simulator during which time the pilots demonstrate their ability to identify and execute the appropriate recovery technique.

Another factor that might have contributed to the improper control inputs during the stall event was the flight crew's unfamiliarity with the stickpusher system on this airplane. The crew would have been exposed to stickpusher activation during systems training and the first-flight-of-the-day operational checks of the system, and, in the case of the accident flight, the crew experienced the system's activation during one of the pitch-up maneuvers made during the climb. However, it is unclear the extent to which either pilot

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[120] At the time of the accident, Pinnacle Airlines conducted its stall recognition and recovery simulator training at an altitude of 10,000 feet.

[121] During that accident investigation, the Safety Board found that the flying pilot applied inappropriate control column back pressure during the stall recovery attempt and that his performance of the stall recovery procedure, which was established in the company's operations manual, was inadequate. In its final report on the accident, the Safety Board stated that the probable causes included "the inappropriate control inputs applied by the flying pilot during a stall recovery attempt" and "the failure of the nonflying pilot-in-command to recognize, address, and correct these inappropriate control inputs." For more information, see National Transportation Safety Board, *Uncontrolled Flight Into Terrain, ABX Air (Airborne Express), Douglas DC-8-63, N827AX, Narrows, Virginia, December 22, 1996*, Aircraft Accident Report NTSB/AAR-97/05 (Washington, DC: NTSB, 1997).

had experience with the stickpusher system during simulator training because the industry standard for stall training was to initiate recovery at the onset of the stickshaker, which, during a proper recovery, would preclude stickpusher activation.

During the Safety Board's public hearing on this accident, a Bombardier training pilot testified that he had seen pilots during training respond incorrectly to stickpusher activation because "they are scared, and they don't know what to do [or] how to react." He added, "proper training is a huge factor, to make sure that if you end up on a pusher, this is what you need to do."

The Safety Board acknowledges that additional training may be required to improve pilot response to stickpusher activation. However, current training protocols and FAA standards train pilots to initiate stall recovery before stickpusher activation. As a result, there may be unintended consequences and negative transfer associated with the inclusion of stickpusher training into simulator training protocols without careful and deliberate study. Because of these concerns, the Safety Board concludes that additional training might improve pilot response to stickpusher activation, but such training, if not provided correctly, could have an adverse impact on existing stall recognition and recovery protocols. Therefore, the Safety Board believes that the FAA should convene a multidisciplinary panel of operational, training, and human factors specialists to study and submit a report on methods to improve flight crew familiarity with and response to stickpusher systems and, if warranted, establish training requirements for stickpusher-equipped airplanes based on the findings of this panel.

2.3.3 Double Engine Failure Training

At the time of the accident, double engine failure scenarios were not practiced during Pinnacle Airlines' simulator training. After the accident, the company incorporated a double engine failure scenario into its simulator training syllabus. During this scenario, a double engine failure occurs at an altitude of 35,000 feet, and flight crews are required to use the windmill restart procedure to relight the engines. The Pinnacle Airlines CRJ program manager stated that this scenario would help familiarize the crew with the emergency power-only procedures and the effects of an ADG deployment.

Also, in May 2005, Pinnacle Airlines made changes to its double engine failure checklist based on the changes made by Bombardier earlier that month. These changes highlighted the airspeeds required for the procedure. For example, the revised checklist stated that a minimum (rather than target) airspeed of 240 knots must be maintained until the pilot was ready to restart the engines. Also, the changes indicated that 300 knots or greater was required to achieve a sufficient N_2 for the windmill restart and that this airspeed must be maintained until at least one engine was restarted or restart attempts were abandoned. Further, the revised checklist recognized the need to sacrifice altitude for airspeed by indicating that the 5,000-foot altitude loss that could be expected when accelerating from 240 to 300 knots might require pitch attitudes of 10º AND and that pilots should start accelerating to achieve 300 knots at an altitude of 21,000 feet.

In addition, Pinnacle Airlines' revised double engine failure checklist placed the following information in a box labeled "CAUTION": "failure to maintain positive N_2 may preclude a successful relight. If required, increase airspeed to maintain N_2 indication." According to the FAA's guidance on checklist design,[122] a caution is defined as "an instruction concerning a hazard that if ignored could result in damage to an aircraft component or system – which would make continued safe flight improbable." The FAA's guidance defines a warning as "an instruction about a hazard that, if ignored, could result in injury, loss of aircraft control, or loss of life." Because of the circumstances of this accident, the Safety Board questions the appropriateness of placing information about the consequences of not maintaining positive N_2 into a cautionary note when the FAA's definitions suggest that a warning box would be a more appropriate transmission of that information to pilots.

Pinnacle Airlines' revised simulator training provides company pilots with an opportunity to reinforce the knowledge they obtained in ground school on the double engine failure checklist items, and the company's revised checklist generally highlights the information that is necessary for pilots to successfully perform the double engine failure procedure. The Safety Board concludes that some of the changes made by Pinnacle Airlines to its double engine failure training and checklist guidance would benefit pilots at other air carriers that operate the CRJ because such training would provide pilots with the opportunity to practice double engine failure restart procedures in the simulator and the guidance would ensure that pilots were aware of the minimum airspeeds needed during the procedures. Therefore, the Safety Board believes that the FAA should verify that all CRJ operators incorporate guidance in their double engine failure checklist that clearly states the airspeeds required during the procedure and require the operators to provide pilots with simulator training on executing this checklist.

2.4 Flight Crew Professionalism

2.4.1 Part 91 Operations

As stated in section 2.2.5, the accident flight, a Part 91 repositioning flight with no passengers or other crewmembers on board, presented the pilots with an opportunity to aggressively maneuver the airplane and operate it at the CRJ maximum operating altitude. Section 2.2.5 also noted that these behaviors were examples of optimizing violations, which occur when someone disregards defined procedures intentionally to make a job more interesting or engaging, to push limits, or to impress another. Although Pinnacle Airlines had protections in place for minimizing errors and unprofessional behavior during line operations,[123] the company did not have effective protections in place for preventing optimizing violations during Part 91 operations. For example, even though the

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[122] Federal Aviation Administration, *Human Performance Considerations in the Use and Design of Aircraft Checklists* (Washington, DC: FAA, 1995).

[123] These protections included pilot selection criteria, pilot training, company policies and procedures, and pilot oversight (line checks and pilot reports).

accident pilots were generally described favorably by instructors, check airmen, and other pilots,[124] the FAA's operations supervisor of the Memphis FSDO stated, during the Safety Board's public hearing on the accident, that, before this accident, "we had no idea that anybody would ever switch seats during a flight and not operate in accordance with the standard operating procedures for the company."[125]

After the accident, Pinnacle Airlines began to review FDR data for all nonrevenue flights.[126] The company's decision to examine FDR data from these flights directly addressed the vulnerability of these operations to optimizing violations. During the Safety Board's public hearing for this accident, the company's chief pilot stated that the review of FDR data would serve as oversight for Part 91 flights because "the pilots will know that they're being monitored." Also, the company's vice president of safety and regulatory compliance testified, "we want to make sure the aircraft is being operated in non-revenue operations exactly the way it's being operated in [Part] 121 operations."

During the investigation of this accident, a management pilot from another company with a CRJ fleet stated that "repositioning flights seemed to bring out the worst in their company's pilots." This pilot also stated that a review of FDR data from his company's repositioning flights showed that high bank angles and steep descents occurred often and that pilots were taking the opportunity to perform excessive maneuvers that they could not perform with passengers on board.

The Safety Board investigated an April 1993 accident in which an airplane operated by two GP Express Airlines pilots (with no passengers or other crewmembers aboard) crashed during a Part 91 training flight while the pilots were attempting to execute a prohibited aerobatic maneuver at night. The Board determined that the probable causes of that accident included the pilots' deliberate disregard for company and Federal

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[124] There were a few exceptions to these favorable comments. For example, the simulator instructor who conducted part of the captain's upgrade training stated that, in addition to the captain's problems performing checklists in accordance with company procedures (as discussed in section 2.2.3.1), his biggest weaknesses were his critical decision-making and judgment. Also, the first officer was described as average by the captain who flew with him during his last trip before the accident flight.

[125] The Safety Board notes that, during the investigation of the January 1983 takeoff accident at DTW involving United Airlines flight 2885 (a cargo flight), the Board determined that the second officer had occupied the seat of the first officer and conducted the takeoff. The Board also determined that, on the basis of postaccident interviews with United Airlines pilots, seat swapping was not a prevalent practice at the airline. In its final report on this accident, the Board stated its concern about the flight crew's "disregard of federal and company rules and regulations." The Board determined that the probable cause of the accident included the flight crew's failure to follow procedural checklist requirements. Contributing to the cause of the accident was the captain's decision to allow the second officer, who was not qualified to act as a pilot, to occupy the seat of the first officer and to conduct the takeoff. For more information, see National Transportation Safety Board, *United Airlines Flight 2885, Detroit, Michigan, January 11, 1983, N8053U, McDonnell Douglas DC-8-54F*, Aircraft Accident Report NTSB/AAR-83/07 (Washington, DC: NTSB, 1983).

[126] In October 2006, Pinnacle Airlines stated that it was sampling random Part 91 flights and that a review of these data showed no abnormalities associated with these flights.

procedures and the company's failure to instill in their pilots professionalism that is consistent with the highest levels of safety.[127]

The circumstances of the Pinnacle Airlines and the GP Express Airlines accidents and the statements of a management pilot from another company with a CRJ fleet demonstrate the opportunity for pilots to behave unprofessionally during Part 91 operations that are conducted without passengers or other crewmembers. Even when protections are in place to mitigate risks during regional airline operations, unprofessional behavior by pilots during Part 91 flights still occurs for multiple reasons, including the perception of a low risk of detection.

The airplanes used by regional airlines are lighter, smaller, and more agile than those used by larger air carrier operators, which may increase the potential for unprofessional behavior during Part 91 flights. For regional operators that have the ability to download FDR data, routine monitoring of Part 91 flights can be an effective method to ensure that the flights are conducted according to standard operating procedures. For those operators that do not have the ability to review FDR data from Part 91 flights, alternative methods to mitigate risk include specific guidance to pilots on the expectations of performance for these flights and additional oversight for flight crews conducting the flights.

The Safety Board concludes that more scrutiny of regional air carrier pilots during nonrevenue flights would minimize the opportunity for unprofessional behavior to occur. Therefore, the Safety Board believes that the FAA should require regional air carriers operating under 14 CFR Part 121 to provide specific guidance on expectations for professional conduct to pilots who operate nonrevenue flights. The Safety Board further believes that, for those regional air carriers operating under 14 CFR Part 121 that have the capability to review FDR data, the FAA should require that the air carriers review FDR data from nonrevenue flights to verify that the flights are being conducted according to standard operating procedures.

2.4.2 Industrywide Issues

In addition to the Pinnacle Airlines accident, the Safety Board has investigated recent accidents involving the lack of cockpit discipline and adherence to standard operating procedures. These accidents include the following:

- Corporate Airlines flight 5966, Kirksville, Missouri, October 19, 2004. The flight crew did not follow established procedures for a nonprecision approach at night in instrument meteorological conditions, did not adhere to the

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[127] National Transportation Safety Board, *Controlled Flight Into Terrain, GP Express Airlines, Inc., N115GP, Beechcraft C-99, Shelton, Nebraska, April 28, 1993*, Aircraft Accident Report NTSB/AAR-94/01 SUM (Washington, DC: NTSB, 1994).

established division of duties between the flying and nonflying pilot, and did not adhere to the sterile cockpit rule.[128]

- Air Tahoma flight 185, Covington, Kentucky, August 13, 2004. The captain did not follow crossfeed procedures for balancing the fuel in the airplane's fuel tanks, which led to fuel starvation in the left tank.[129]
- Executive Airlines flight 5401, San Juan, Puerto Rico, May 9, 2004. The captain failed to execute proper techniques to recover from bounced landings and failed to execute a go-around.[130]
- Aviation Charter King Air A100, Eveleth, Minnesota, October 25, 2002. The flight crew was not adhering to company approach procedures and was not effectively applying CRM techniques during the approach segment of the flight.[131]
- Federal Express Flight 1478, Tallahassee, Florida, July 26, 2002. The flight crew failed to adhere to company procedures for flying and monitoring a stabilized approach.[132]

Pilots and operators have responsibility for a flight crew's cockpit discipline and adherence to standard operating procedures, as discussed in sections 2.4.2.1 and 2.4.2.2.

2.4.2.1 Pilot Responsibilities

The Safety Board has long been concerned about issues of crew professionalism and adherence to standard operating procedures. For example, on October 8, 1974, as a result of several fatal air carrier accidents involving pilot performance (as described in section 1.18.3.2), the Board issued Safety Recommendation A-74-85, which asked the FAA to initiate a movement among pilot associations to form new, and regenerate old, professional standards committees to promote crew discipline and professionalism. (The Safety Board classified Safety Recommendation A-74-85 "Closed—Acceptable Action" on March 10, 1977.)

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[128] In its final report on this accident, the Safety Board concluded that the pilots' nonessential conversation below 10,000 feet msl "was contrary to established sterile cockpit regulations and reflected a demeanor and cockpit environment that fostered deviation from established standard procedures, crew resource management discipline, division of duties, and professionalism, reducing the margin of safety well below acceptable limits during the accident approach and likely contributing to the pilots' degraded performance." For more information, see NTSB/AAR-06/01.

[129] National Transportation Safety Board, *Crash During Approach to Landing, Air Tahoma, Inc., Flight 185, Convair 580, N586P, Covington, Kentucky, August 13, 2004,* Aircraft Accident Report NTSB/AAR-06/03 (Washington, DC: NTSB, 2006).

[130] National Transportation Safety Board, *Crash During Landing, Executive Airlines (doing business as American Eagle) Flight 5401, Avions de Transport Regional 72-212, N438AT, San Juan, Puerto Rico, May 9, 2004*, Aircraft Accident Report NTSB/AAR-05/02 (Washington, DC: NTSB, 2005).

[131] National Transportation Safety Board, *Loss of Control and Impact With Terrain, Aviation Charter, Inc., Raytheon (Beechcraft) King Air A100, N41BE, Eveleth, Minnesota, October 25, 2002*, Aircraft Accident Report NTSB/AAR-03/03 (Washington, DC: NTSB, 2003).

[132] National Transportation Safety Board, *Collision With Trees on Final Approach, Federal Express Flight 1478, Boeing 727-232, N497FE, Tallahassee, Florida, July 26, 2002*, Aircraft Accident Report NTSB/AAR-04/02 (Washington DC: NTSB, 2004).

Most pilot unions have professional standards committees, which are peer consultation programs that are designed to, among other things, provide counseling and support to pilots who have demonstrated behavior that might adversely affect their ability to perform their duties in a professional manner. Trained volunteer pilots who are members of these committees provide peer support, counseling, intervention, and mediation to pilots at the airlines that the unions represent. Airline pilots can seek these services on their own, or they can be referred to the professional standards committee by, for example, company managers who have become aware of a potential problem.

Pilot union professional standards committees appear to be an effective structure to help promote and ensure professionalism among pilots. However, not all air carrier pilots have access to these professional standards committees. For those pilots without such access, communications about the importance of professionalism can be delivered through company and FAA personnel.

It is clear, on the basis of the overall safety and reliability of the National Airspace System, that most pilots conduct operations with a high degree of professionalism. Nevertheless, a problem still exists in the aviation industry with some pilots acting unprofessionally and not adhering to standard operating procedures, as demonstrated by the recent accidents investigated by the Safety Board that are cited in section 2.4.2.

After a series of six accidents between October and November 2004, the FAA issued Notice N8000.296, "Pilot Judgment and Decisionmaking" (see section 1.18.4). The notice, among other things, highlighted the pilot's role in ensuring safety of flight. Specifically, the notice recommended that individual pilots examine their own decision-making habits in terms of professionalism, thoroughness of preparation, and adherence to standard operating procedures. The FAA stated that it has since incorporated soft skills into Part 121 CRM training requirements and that a rewrite of FAA Order 8400.10, *Air Transportation Operations Inspector's Handbook*, would emphasize soft skills.

Pilots are ultimately responsible for safely conducting a flight and for recognizing the importance of adhering to standard operating procedures and acting professionally. Although broad, systemwide interventions can be applied to help address the problem of pilots not adhering to standard operating procedures or acting unprofessionally, the most direct intervention is to address any deficiencies in these areas at the level of the pilot. Because pilot unions have expertise in safety, training, and operations and have a vested interest in advancing professional standards among the pilots they represent, these groups are well positioned to take a leadership role to establish new educational approaches for reinforcing professionalism in the aviation industry. The Safety Board concludes that providing additional education to pilots on the importance of professionalism could help reduce the instances of pilots not maintaining cockpit discipline or not adhering to standard operating procedures. Therefore, the Safety Board believes that the FAA should work with pilot associations to develop a specific program of education for all air carrier pilots that addresses professional standards and their role in ensuring safety of flight. The program should include associated guidance information and references to recent accidents involving pilots acting unprofessionally or not following standard operating procedures.

2.4.2.2 Operator Responsibilities

Operators also are responsible for monitoring their pilots' adherence to standard operating procedures and reinforcing expectations for professional standards of behavior. Operators have traditionally identified nonstandard performance in line operations during checkrides or line observations conducted by company check airmen or management personnel. A problem with this method of oversight is that pilots might perform differently during a checkride or a line observation because of the presence of a company check airman in the cockpit.

To help evaluate pilot performance during line operations, air carriers can implement voluntary safety programs, such as the FOQA program. This program is especially well suited for detecting exceedances that may occur during flight, such as high bank angles and unstabilized approaches, and assessing whether crews are conducting flights according to standard operating procedures. However, the FOQA program requires equipment and support structures that some air carriers may not be able to maintain, such as the capability to download FDR data. According to the FAA, as of November 2006, 18 air carriers operating under Part 121 had implemented approved FOQA programs.

Another FAA-approved, voluntary safety program is the Aviation Safety Action Program (ASAP). This program encourages pilots to report safety concerns in a nonpunitive environment, which allows the air carrier and the FAA to act on this information before an accident or an incident occurs.[133] Although an ASAP does not have the technical requirements associated with a FOQA program, an ASAP depends on the willingness of pilots to voluntarily submit reports about other pilots or themselves. The FAA stated that, as of November 2006, it had accepted 51 ASAP memorandums of understanding for pilots.[134] (Of these ASAP memorandums of understanding, 49 were for Part 121 operators, and 2 were for Part 135 operators.)

In addition to the FOQA program and the ASAP, operators can assess pilot performance during line operations with the Line Operations Safety Audit (LOSA), which was developed in 1994 through FAA-sponsored research, known as the Human Factors Research Project, at the University of Texas at Austin.[135] The LOSA program is an observational process that assesses CRM practices, the management of threats to safety, and human error during flight operations. Trained personnel associated with the project conduct line observations under conditions of confidentiality so that the operator is provided only with details of the observations and no information about the pilots who

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[133] At the time of the June 2005 public hearing, Pinnacle Airlines had committed to establishing an ASAP for its pilots. In October 2006, the company reported that it was operating an FAA-approved ASAP for its pilots.

[134] The ASAP also includes dispatchers, flight attendants, and mechanics. Pinnacle Airlines reported that it planned to expand its ASAP to the company's maintenance department during 2007.

[135] For more information, see <http://homepage.psy.utexas.edu/homepage/group/HelmreichLAB>.

were involved. As a result, in contrast to a company line check, LOSA observations do not result in adverse actions against pilots who did not perform well during their observation.

LOSA methodology is well suited to assess the soft skills used by air carrier pilots (see section 1.18.4), and the observations can be used to identify intentional deviations from standard operating procedures or prescribed rules and allow the operator to identify reasons for these deviations. Notably, LOSA can address and document these issues to a greater extent than the FOQA program or the ASAP because, as previously stated, FOQA programs require the capability to download FDR data and an ASAP requires the willingness of pilots to submit reports about fellow pilots or themselves.[136] Also, LOSA observations have identified rule violations and deviations from procedures, which suggests that the pilots being observed do not view the LOSA observers as a threat (as they might view company check airmen) and would be likely to perform in the same manner as they would without an observer present.

After the accident, and as a result of a high initial failure rate for upgrading captains before the accident (see section 1.17.1.6), Pinnacle Airlines made several changes to its training program to address professionalism. These changes included increasing the minimum number of hours (from 10 to 25) that are required for upgrade operational experience, restructuring CRM training to provide additional focus on decision-making and the need to adhere to standard operating procedures, and placing additional emphasis on leadership during upgrade training. However, the effectiveness of these changes in increasing professionalism, leadership, and adherence to standard operating procedures would be difficult to evaluate fully without LOSA observations.[137]

On April 27, 2006, the FAA issued Advisory Circular (AC) 120-90, Line Operations Safety Audits. The AC provides the rationale and procedures for conducting a LOSA observation at an air carrier and explains that the program is distinct from, but complementary to, the FOQA program and the ASAP. By incorporating LOSA observations into their internal oversight programs, Part 121 air carriers would have another method to monitor their pilots' adherence to standard operating procedures and standards of professionalism. The Safety Board concludes that LOSA observations can provide operators with increased knowledge about the behavior demonstrated by pilots during line operations. Therefore, the Safety Board believes that the FAA should require that all 14 CFR Part 121 operators incorporate into their oversight programs periodic LOSA observations and methods to address and correct findings resulting from these observations.

In addition to the need for air carriers to incorporate LOSA observations into their oversight methods, air carriers need to ensure safety through a formalized system safety

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[136] Despite these issues, the Safety Board recognizes that the FOQA program and the ASAP provide air carriers with valuable information about the quality of their operations.

[137] The LOSA program samples all activities in normal operations, whereas the FOQA program and the ASAP rely on outcomes (flight parameter exceedances and adverse pilot-reported events, respectively) to generate data.

process. One such process is a safety management system (SMS) program, which incorporates proactive safety methods for air carriers to identify hazards, mitigate risk, and monitor the extent that the carriers are meeting their objectives. Program components include safety policy, safety risk management, safety assurance, and safety promotion. Tools such as the FOQA, ASAP, and LOSA programs are relevant to the safety assurance component of an SMS program because they provide a direct means for air carriers to evaluate the quality of their training and operations. These tools can also be used in the safety risk management component of an SMS program because they can help uncover hazards to system operation.

SMS program initiatives have been developed in the international aviation industry. For example, the European Joint Aviation Authorities recommend, but do not require, air carriers to establish an SMS program. Also, in June 2005, Transport Canada passed regulations requiring that air carriers operating under *Canadian Aviation Regulations* Part 705 (Part 121 equivalent) fully implement an approved SMS program by September 2008. In addition, International Civil Aviation Organization (ICAO) Annex 6, "Operation of Aircraft," states the following: "from January 1, 2009, [Member] States shall require, as part of their safety program, that an operator implements a safety management system acceptable to the State of the Operator that, at a minimum: (a) identifies safety hazards; (b) ensures that remedial action necessary to maintain an acceptable level of safety is implemented; (c) provides for continuous monitoring and regular assessment of the safety level achieved; and (d) aims to make continuous improvement to the overall level of safety."[138]

In June 2006, the FAA published AC 120-92, "Introduction to Safety Management Systems for Air Operators." The AC provides guidance for SMS program development for air carriers and others in the aviation industry. The guidance was based on the FAA's review of existing SMS programs worldwide, its own internal SMS programs, and other system safety approaches. An appendix to the AC contains a listing of functional requirements for operators to use as minimum standards when creating an SMS program.

During a December 14, 2006, briefing to the Safety Board, the FAA stated that it intended to comply with the ICAO requirement for Member States to require that operators implement an SMS program by January 1, 2009. A rulemaking project team has been formed, and the rulemaking project team leader stated that the team's first meeting was held in December 2006. In addition to these initial rulemaking activities, the FAA stated that it planned to initiate a series of SMS proof-of-concept trials in late 2007. During these trials, the FAA intends to work with a few operators that have voluntarily implemented SMS to gather the data needed for additional guidance material and to support the agency's rulemaking efforts. The Board is encouraged by the FAA's initial activities to implement an SMS program. However, until the FAA issues a notice of proposed rulemaking, the Board cannot fully evaluate whether the FAA will meet ICAO's minimum requirements for an SMS program.

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[138] In November 2005, ICAO asked Member States to provide the organization with information about the development of SMS programs. During 2006, ICAO published a safety management manual that addressed concepts and processes required to implement an SMS program.

Historically, the FAA's approach to its oversight of air carriers has emphasized surveillance to ensure regulatory compliance. However, in 1998, the FAA established the Air Transportation Oversight System (ATOS), a systems safety approach to air carrier oversight. The ATOS program was initially deployed at the 10 largest U.S. air carriers. The benefits of the ATOS program's system safety approach to air carrier oversight, compared with the oversight conducted as part of the National Work Program Guidelines,[139] include a more integrated approach to oversight that better identifies risks to system safety and a more effective allocation of oversight resources to problem areas.[140]

The Safety Board has previously expressed concerns about the ATOS program. In its March 12, 2001, letter to the FAA about Safety Recommendation A-98-51,[141] the Board stated its concern that the FAA had not addressed how the ATOS program would ensure that systemic problems were identified and corrected before they resulted in an accident. As a result, the Board classified Safety Recommendation A-98-51 "Open—Unacceptable Response." Also, in its report on the Alaska Airlines accident, the Board addressed its concerns about ATOS implementation and the program's ability to detect problem areas.[142]

Other concerns about the FAA's implementation of ATOS have been noted. For example, according to a Government Accountability Office (GAO) report,[143] the FAA's ATOS transition plan, dated March 1, 2004, did not set dates beyond fiscal year 2005 for moving additional air carriers to the ATOS program, and, as of September 2005, 15 air carriers were under the ATOS program. Also, the GAO testified in November 2005 that the National Work Program Guidelines were still being used at those passenger airlines that were not covered under ATOS.[144]

The FAA acknowledged that staffing and budgetary resources were affecting ATOS deployment. During October 2005, the FAA initiated its System Approach for Safety Oversight CFR Part 121 Pilot Project. The objectives of the project are to revise ATOS so that the program can handle all Part 121 air carriers; provide new policies, processes, and tools for measuring safety; and roll out the latest version of the ATOS program to all Part 121 air carriers by December 31, 2007.[145] The FAA stated that

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[139] The National Work Program Guidelines are part of a traditional inspection program to ensure that airlines comply with safety regulations. The guidelines have been in effect since 1985.

[140] To apply some benefits of the system safety approach used in the ATOS program to those air carriers that were not covered by ATOS, the FAA deployed the Surveillance and Evaluation Program during 2002 to augment the oversight conducted as part of the National Work Program Guidelines.

[141] This recommendation, which was issued as a result of the Safety Board's investigation of the August 7, 1997, Fine Airlines flight 101 accident, can be found on the Board's Web site.

[142] National Transportation Safety Board, *Loss of Control and Impact With Pacific Ocean, Alaska Airlines Flight 261, McDonnell Douglas MD-83, N963AS, About 2.7 Miles North of Anacapa Island, California, January 31, 2000*, Aircraft Accident Report NTSB/AAR-02/01 (Washington, DC: NTSB, 2002).

[143] Government Accountability Office, *Aviation Safety: System Safety Approach Needs Further Integration Into FAA's Oversight of Airlines*, GAO-05-726 (Washington, DC: GAO, 2005)

[144] Government Accountability Office, *Aviation Safety: FAA's Safety Oversight System Is Effective but Could Benefit From Better Evaluation of Its Programs' Performance*, GAO-06-266T (Washington, DC: GAO, 2005).

preparations were underway to keep this transition on schedule. Even if this project is completed according to its intended timetable, it will still take time to determine whether ATOS is an effective oversight method.

The Safety Board is concerned about the delay in deploying ATOS to additional Part 121 air carriers because they are not receiving the benefits of a system safety approach to oversight.[146] Although the ATOS and SMS programs are complementary and are designed to work in an integrated manner, an air carrier does not need to be under ATOS oversight to effectively develop its own SMS program. The FAA's initial guidance in AC 120-92 should facilitate the process of developing and implementing an SMS program. Existing voluntary system safety tools, such as the FOQA, ASAP, and LOSA programs, have demonstrated their effectiveness in monitoring flight operations and are considered integral safety assurance components to an SMS program, but these programs do not have universal application in the aviation industry. The Safety Board concludes that all air carriers would benefit from SMS programs because they would require the carriers to incorporate formal system safety methods into the carriers' internal oversight programs. Therefore, the Safety Board believes that the FAA should require that all 14 CFR Part 121 operators establish SMS programs.

The Safety Board acknowledges that it may take time for the FAA to complete SMS rulemaking and for air carrier SMS programs to become fully operational. In its review of air carriers with FOQA programs at the end of 2006, the Board found that, besides Pinnacle Airlines, only one other regional air carrier had a FOQA program. (The Board is aware of at least one other regional air carrier that is working toward implementing a FOQA program.) Although system safety tools such as FOQA and ASAP have demonstrated safety benefits, the Board is concerned that these programs are not used more widely by regional air carriers. Because of the limited number of regional air carriers in the lists of approved ASAP and FOQA programs, the Safety Board concludes that the establishment of an ASAP and a FOQA program at regional air carriers would provide the carriers with a means to evaluate the quality of their operations. Therefore, the Safety Board believes that the FAA should strongly encourage and assist all regional air carriers operating under 14 CFR Part 121 to implement an approved ASAP and an approved FOQA program.

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[145] For more information, see System Approach for Safety Oversight Program Update, dated July 7, 2006, at <http://www.faa.gov/safety/programs_initiatives/oversight/saso/update>. Also, in December 2006, the FAA stated that 46 air carriers operating under Part 121 were under the ATOS program.

[146] The Safety Board notes that some air carriers that are not covered under ATOS, including Pinnacle Airlines, have begun using ATOS job aids and inspection guidelines generated for FAA inspectors in their own internal audit programs.

2.5 Quality of Flight Data Recorder Data for Regional Jet Airplanes

On May 16, 2003, the Safety Board issued Safety Recommendation A-03-15 to the FAA because of problems with the quality of FDR data recorded by several regional jet airplanes. Safety Recommendation A-03-15 asked the FAA to do the following:

> Require that all Embraer 145, Embraer 135, Canadair CL-600 RJ, Canadair Challenger CL-600, and Fairchild Dornier 328-300 airplanes[147] be modified with a digital flight data recorder system that meets the sampling rate, range, and accuracy requirements specified in 14 *Code of Federal Regulations* Part 121.344, Appendix M.

On June 9, 2005, the FAA stated that Embraer had released an SB to correct known FDR anomalies on the Embraer 145 and 135 and that the Brazilian Department of Civil Aviation issued an AD that required incorporation of the Embraer SB within 18 months. The FAA also stated that it planned to release a corresponding AD. In addition, the FAA stated that it was working with Transport Canada to get expeditious action from Bombardier regarding the problem of low update rates on the normal acceleration and pitch attitude parameters for Canadair CL-600-2B19 (CRJ-100, -200, and -440) and CL-600-2B16 (Challenger 604) airplanes. On September 28, 2005, the Safety Board stated that, pending the FAA's issuance of ADs that mandated correction to the Embraer 145 and 135 and CRJ-100, -200, and -440 and Challenger 604 FDR systems, Safety Recommendation A-03-15 was classified "Open—Acceptable Response."

Since the time of the Pinnacle Airlines accident, the Safety Board has downloaded FDR data from seven events involving CL-600-2B19 airplanes—the most recent of which occurred on August 27, 2006.[148] All of these downloads showed that the FDRs recorded the vertical acceleration and pitch parameters from sources that did not meet the recording intervals required by 14 CFR 121.344, Appendix M, as was the case with the FDR installed on the Pinnacle Airlines accident airplane.

In November 2006, Bombardier told the Safety Board that production of Challenger 604 airplanes had ceased and that the Challenger 605 model had replaced the Challenger 604 model. Bombardier also stated that the sampling rate problem had been corrected in the FDRs installed on Challenger 605 airplanes. However, the Board notes that Challenger 604 airplanes that are currently in service will still have FDRs with sampling rate problems.

Bombardier further stated that, for FDRs installed on CRJ-100, -200, and -440 airplanes, the sampling rate problem would be corrected during the next applicable digital

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[147] As stated in section 1.18.3.3, on September 28, 2005, the Safety Board stated that no problems existed with the FDR parameters on the Fairchild Dornier 328-300 airplane.

[148] This FDR was installed aboard the Comair Airlines flight 5191 accident airplane, which crashed in Lexington, Kentucky, after the pilots attempted to take off from the wrong runway. For information about this accident, see DCA06MA064 at the Safety Board's Web site at <http://www.ntsb.gov>.

control unit update, which was scheduled for the second or third quarter of 2007, and that airplanes would be retrofitted within the 18 months that followed. Thus, if this schedule were maintained, the sampling rate problem would not be fixed on all CL-600-2B19 airplanes until late 2008 or early 2009. Also, as of December 1, 2006, the FAA had not issued an AD to correct FDR anomalies on Embraer 145 and 135 airplanes. The Safety Board concludes that the parameter quality problems with the FDR systems installed on Canadair CL-600-2B19, Challenger 604, and Embraer 145 and 135 airplanes need to be corrected so that future investigations involving these airplane models are not hindered by inaccurate or incomplete data. Therefore, the Safety Board reiterates Safety Recommendation A-03-15. Further, the Board classifies Safety Recommendation A-03-15 "Open—Unacceptable Response."

3. Conclusions

3.1 Findings

1. The captain and the first officer were properly certificated and qualified under Federal regulations. No evidence indicated any medical or behavioral conditions that might have adversely affected their performance during the accident flight. Flight crew fatigue and hypoxia were not factors in this accident.

2. The accident airplane was properly certified, equipped, and maintained in accordance with Federal regulations. The recovered components showed no evidence of any structural or system failures or any engine failures before the time of the upset event.

3. Weather was not a factor in this accident.

4. The accident was not survivable.

5. The pilots' aggressive pitch-up and yaw maneuvers during the ascent and their decision to operate the airplane at its maximum operating altitude (41,000 feet) were made for personal and not operational reasons.

6. The flight crew's inappropriate use of the vertical speed mode during the climb was a misuse of automation that allowed the airplane to reach 41,000 feet in a critically low energy state.

7. The improper airspeed during the climb demonstrated that the pilots did not understand how airspeed affects airplane performance and did not realize the importance of conducting the climb according to the published climb capability charts.

8. The upset event exposed both engines to inlet airflow disruption conditions that led to engine stalls and a complete loss of engine power.

9. The pilots' lack of exposure to high altitude stall recovery techniques contributed to their inappropriate flight control inputs during the upset event.

10. The captain did not take the necessary steps to ensure that the first officer achieved the 300-knot or greater airspeed required for the windmill engine restart procedure and then did not demonstrate command authority by taking control of the airplane and accelerating it to at least 300 knots.

11. The first officer's limited experience in the airplane might have contributed to the failed windmill restart attempt because he might have been reluctant to command the degree of nose-down attitude that was required to increase the airplane's airspeed to 300 knots.

12. Despite their four auxiliary power unit-assisted engine restart attempts, the pilots were unable to restart the engines because their cores had locked. Without core rotation, recovery from the double engine failure was not possible.

13. The General Electric CF34-1 and CF34-3 engines had a history of failing to rotate during in-flight restart attempts on airplanes undergoing production acceptance testing at Bombardier.

14. Both engines experienced core lock because of the flameout from high power and high altitude, which resulted from the pilot-induced extreme conditions to which the engines were exposed, and the pilots' failure to achieve and maintain the target airspeed of 240 knots, which caused the engine cores to stop rotating; both of these factors were causal to this accident.

15. The importance of maintaining a minimum airspeed to keep the engine cores rotating was not communicated to the pilots in airplane flight manuals.

16. The captain's previous difficulties in checklist management, the situational stress, and the lack of simulator training involving a double engine failure contributed to the flight crew's errors in performing the double engine failure checklist.

17. The pilots' failure to prepare for an emergency landing in a timely manner, including communicating with air traffic controllers immediately after the emergency about the loss of both engines and the availability of landing sites, was a result of their intentional noncompliance with standard operating procedures, and this failure was causal to the accident.

18. The pilots' unprofessional operation of the flight was intentional and causal to this accident because the pilots' actions led directly to the upset and their improper reaction to the resulting in-flight emergency exacerbated the situation to the point that they were unable to recover the airplane.

19. Revised high altitude training syllabuses for pilots who operate regional jet airplanes would help ensure that these pilots possess a thorough understanding of the airplanes' performance capabilities, limitations, and high altitude aerodynamics.

20. Because most training for stalls occurs with the airplane at low altitudes, the training methods may introduce a bias in stall recovery techniques by encouraging pilots to minimize altitude loss and not fully recognizing other available recovery techniques.

21. Additional training might improve pilot response to stickpusher activation, but such training, if not provided correctly, could have an adverse impact on existing stall recognition and recovery protocols.

22. Some of the changes made by Pinnacle Airlines to its double engine failure training and checklist guidance would benefit pilots at other air carriers that operate the Canadair regional jet because such training would provide pilots with the opportunity to practice double engine failure restart procedures in the simulator and the guidance would ensure that pilots were aware of the minimum airspeeds needed during the procedures.

23. More scrutiny of regional air carrier pilots during nonrevenue flights would minimize the opportunity for unprofessional behavior to occur.

24. Providing additional education to pilots on the importance of professionalism could help reduce the instances of pilots not maintaining cockpit discipline or not adhering to standard operating procedures.

25. Line Operations Safety Audit observations can provide operators with increased knowledge about the behavior demonstrated by pilots during line operations.

26. All air carriers would benefit from Safety Management System programs because they would require the carriers to incorporate formal system safety methods into the carriers' internal oversight programs.

27. The establishment of an Aviation Safety Action Program and a Flight Operational Quality Assurance program at regional air carriers would provide the carriers with a means to evaluate the quality of their operations.

28. The parameter quality problems with the flight data recorder systems installed on Canadair CL-600-2B19, Challenger 604, and Embraer 145 and 135 airplanes need to be corrected so that future investigations involving these airplane models are not hindered by inaccurate or incomplete data.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable causes of this accident were (1) the pilots' unprofessional behavior, deviation from standard operating procedures, and poor airmanship, which resulted in an in-flight emergency from which they were unable to recover, in part because of the pilots' inadequate training; (2) the pilots' failure to prepare for an emergency landing in a timely manner, including communicating with air traffic controllers immediately after the emergency about the loss of both engines and the availability of landing sites; and (3) the pilots' improper management of the double engine failure checklist, which allowed the engine cores to stop rotating and resulted in the core lock engine condition. Contributing to this accident were (1) the core lock engine condition, which prevented at least one engine from being restarted, and (2) the airplane flight manuals that did not communicate to pilots the importance of maintaining a minimum airspeed to keep the engine cores rotating.

4. Safety Recommendations

4.1 New Recommendations

As a result of the investigation of this accident, the National Transportation Safety Board makes the following recommendations to the Federal Aviation Administration:

> Work with members of the aviation industry to enhance the training syllabuses for pilots conducting high altitude operations in regional jet airplanes. The syllabuses should include methods to ensure that these pilots possess a thorough understanding of the airplanes' performance capabilities, limitations, and high altitude aerodynamics. (A-07-1)
>
> Determine whether the changes to be made to the high altitude training syllabuses for regional jet airplanes, as requested in Safety Recommendation A-07-1, would also enhance the high altitude training syllabuses for all other transport-category jet airplanes and, if so, require that these changes be incorporated into the syllabuses for those airplanes. (A-07-2)
>
> Require that air carriers provide their pilots with opportunities to practice high altitude stall recovery techniques in the simulator during which time the pilots demonstrate their ability to identify and execute the appropriate recovery technique. (A-07-3)
>
> Convene a multidisciplinary panel of operational, training, and human factors specialists to study and submit a report on methods to improve flight crew familiarity with and response to stickpusher systems and, if warranted, establish training requirements for stickpusher-equipped airplanes based on the findings of this panel. (A-07-4)
>
> Verify that all Canadair regional jet operators incorporate guidance in their double engine failure checklist that clearly states the airspeeds required during the procedure and require the operators to provide pilots with simulator training on executing this checklist. (A-07-5)
>
> Require regional air carriers operating under 14 *Code of Federal Regulations* Part 121 to provide specific guidance on expectations for professional conduct to pilots who operate nonrevenue flights. (A-07-6)

> For those regional air carriers operating under 14 *Code of Federal Regulations* Part 121 that have the capability to review flight data recorder (FDR) data, require that the air carriers review FDR data from nonrevenue flights to verify that the flights are being conducted according to standard operating procedures. (A-07-7)
>
> Work with pilot associations to develop a specific program of education for air carrier pilots that addresses professional standards and their role in ensuring safety of flight. The program should include associated guidance information and references to recent accidents involving pilots acting unprofessionally or not following standard operating procedures. (A-07-8)
>
> Require that all 14 *Code of Federal Regulations* Part 121 operators incorporate into their oversight programs periodic Line Operations Safety Audit observations and methods to address and correct findings resulting from these observations. (A-07-9)
>
> Require that all 14 *Code of Federal Regulations* Part 121 operators establish Safety Management System programs. (A-07-10)
>
> Strongly encourage and assist all regional air carriers operating under 14 *Code of Federal Regulations* Part 121 to implement an approved Aviation Safety Action Program and an approved Flight Operational Quality Assurance program. (A-07-11)

4.2 Previously Issued Recommendation Reiterated and Classified in This Report

The Safety Board reiterates the following recommendation to the Federal Aviation Administration:

> Require that all Embraer 145, Embraer 135, Canadair CL-600 RJ, Canadair Challenger CL-600, and Fairchild Dornier 328-300 airplanes be modified with a digital flight data recorder system that meets the sampling rate, range, and accuracy requirements specified in 14 *Code of Federal Regulations* Part 121.344, Appendix M. (A-03-15)

Further, Safety Recommendation A-03-15 (previously classified “Open—Acceptable Response”) is classified “Open—Unacceptable Response” in section 2.5 of this report.

For information about this recommendation, see sections 1.18.3.3 and 2.5 of this report.

4.3 Previously Issued Recommendations Resulting From This Accident Investigation

As a result of the investigation into this accident, the Safety Board issued the following recommendations to the Federal Aviation Administration on November 20, 2006:

> For airplanes equipped with CF34-1 or CF34-3 engines, require manufacturers to perform high power, high altitude sudden engine shutdowns; determine the minimum airspeed required to maintain sufficient core rotation; and demonstrate that all methods of in-flight restart can be accomplished when this airspeed is maintained. (A-06-70)
>
> Ensure that airplane flight manuals of airplanes equipped with CF34-1 or CF34-3 engines clearly state the minimum airspeed required for engine core rotation and that, if this airspeed is not maintained after a high power, high altitude sudden engine shutdown, a loss of in-flight restart capability as a result of core lock may occur. (A-06-71)
>
> Require that operators of CRJ-100, -200, and -440 airplanes include in airplane flight manuals the significant performance penalties, such as loss of glide distance and increased descent rate, that can be incurred from maintaining the minimum airspeed required for core rotation and windmill restart attempts. (A-06-72)
>
> Review the design of turbine-powered engines (other than the CF34-1 and CF34-3, which are addressed in Safety Recommendation A-06-70) to determine whether they are susceptible to core lock and, for those engines so identified, require manufacturers of airplanes equipped with these engines to perform high power, high altitude sudden engine shutdowns and determine the minimum airspeed to maintain sufficient core rotation so that all methods of in-flight restart can be accomplished. (A-06-73)
>
> For those airplanes with engines that are found to be susceptible to core lock (other than the CF34-1 and CF34-3, which are addressed in Safety Recommendation A-06-71), require airplane manufacturers to incorporate information into airplane flight manuals that clearly states the potential for core lock; the procedures, including the minimum airspeed required, to prevent this condition from occurring after a sudden engine shutdown; and the resulting loss of in-flight restart capability if this condition were to occur. (A-06-74)

> Require manufacturers to determine, as part of 14 *Code of Federal Regulations* Part 25 certification tests, if restart capability exists from a core rotation speed of 0 indicated rpm after high power, high altitude sudden engine shutdowns. For those airplanes determined to be susceptible to core lock, mitigate the hazard by providing design or operational means to ensure restart capability. (A-06-75)
>
> Establish certification requirements that would place upper limits on the value of the minimum airspeed required and the amount of altitude loss permitted for windmill restarts. (A-06-76)

For additional information about these recommendations, see section 1.18.3.1 of this report.

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Adopted: January 9, 2007

5. Appendixes

Appendix A
Investigation and Hearing

Investigation

The National Transportation Safety Board was initially notified of this accident on October 14, 2004, after air traffic controllers lost contact with the airplane. A go-team was assembled and departed for Jefferson City, Missouri, on the morning of October 15, 2004, and arrived on scene later that day. Accompanying the team to Jefferson City was former Member Carol Carmody.

The following investigative teams were formed: Aircraft Operations, Human Performance, Aircraft Structures, Aircraft Systems, Powerplants, Air Traffic Control, Meteorology, Aircraft Performance, Maintenance Records, Cockpit Voice Recorder, and Flight Data Recorder. While the investigative team was in Jefferson City, specialists were assigned to conduct the readout of the flight data recorder and transcribe the recording from the cockpit voice recorder at the Safety Board's laboratory in Washington, D.C.

Parties to the investigation were the Federal Aviation Administration (FAA), Pinnacle Airlines, the Air Line Pilots Association (ALPA), the National Air Traffic Controllers Association, General Electric (GE) Engines, Honeywell, Hamilton Sunstrand, and Rockwell Collins. In accordance with the provisions of Annex 13 to the Convention on International Civil Aviation, the Transportation Safety Board of Canada (the Safety Board's counterpart agency in Canada) participated in the investigation as the representative of the State of Design and Manufacture. Transport Canada and Bombardier Aerospace participated in the investigation as technical advisors to the Transportation Safety Board of Canada, as provided in Annex 13.

Public Hearing

A public hearing was held from June 13 to 15, 2005, in Washington, D.C. Member Deborah A.P. Hersman presided over the hearing. The issues discussed at the public hearing were aircraft and engine certification and operator and FAA oversight of flight operations and flight crew training. Parties to the public hearing were the FAA, Pinnacle Airlines, ALPA, Bombardier Aerospace, GE Engines, and Honeywell.

Appendix B

Cockpit Voice Recorder

The following is the transcript of the Fairchild A100S cockpit voice recorder, serial number 02804, installed on Pinnacle Airlines flight 3701, a Bombardier CL-600-2B19, N8396A, which crashed in Jefferson City, Missouri, on October 14, 2004.

CVR Quality Rating Scale

The levels of recording quality are characterized by the following traits of the cockpit voice recorder information:

Excellent Quality	Virtually all of the crew conversations could be accurately and easily understood. The transcript that was developed may indicate only one or two words that were not intelligible. Any loss in the transcript is usually attributed to simultaneous cockpit/radio transmissions that obscure each other.
Good Quality	Most of the crew conversations could be accurately and easily understood. The transcript that was developed may indicate several words or phrases that were not intelligible. Any loss in the transcript can be attributed to minor technical deficiencies or momentary dropouts in the recording system or to a large number of simultaneous cockpit/radio transmissions that obscure each other.
Fair Quality	The majority of the crew conversations were intelligible. The transcript that was developed may indicate passages where conversations were unintelligible or fragmented. This type of recording is usually caused by cockpit noise that obscures portions of the voice signals or by a minor electrical or mechanical failure of the CVR system that distorts or obscures the audio information.
Poor Quality	Extraordinary means had to be used to make some of the crew conversations intelligible. The transcript that was developed may indicate fragmented phrases and conversations and may indicate extensive passages where conversations were missing or unintelligible. This type of recording is usually caused by a combination of a high cockpit noise level with a low voice signal (poor signal-to-noise ratio) or by a mechanical or electrical failure of the CVR system that severely distorts or obscures the audio information.
Unusable	Crew conversations may be discerned, but neither ordinary nor extraordinary means made it possible to develop a meaningful transcript of the conversations. This type of recording is usually caused by an almost total mechanical or electrical failure of the CVR system.

LEGEND

CAM	Cockpit area microphone voice or sound source
INT	Flight crew audio panel intercom voice or sound source
CAS	Aircraft's crew alert system mechanical voice sound source
RDO	Radio transmissions from N8396A
CTR-A	Radio transmission from first Kansas City center controller (R29 position)[§]
CTR-B	Radio transmission from second Kansas City center controller (R30 position)
CTR-C	Radio transmission from third Kansas City center controller (R53 position)
-1	Voice identified as the Captain
-2	Voice identified as the First Officer
-?	Voice unidentified
*****	Unintelligible word
#	Expletive
…	Pause or interruption
( )	Questionable insertion
[ ]	Editorial insertion

Note 1: Times are expressed in central daylight time (CDT).

Note 2: Generally, only radio transmissions to and from the accident aircraft were transcribed.

Note 3: Words shown with excess vowels, letters, or drawn out syllables are a phonetic representation of the words as spoken.

[§] See Air Traffic Control Group Chairman's Factual Report for more information on controller position.

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2144:44 **START OF RECORDING** **START OF TRANSCRIPT**			
2144:48 **CAM**	[unintelligible conversation]		
2145:16 **CAM-?**	*** you got that man.		
2145:49 **CAM-1**	we're riding the green # line there.		
2145:51 **CAM-2**	[sound of laughing] # dude.		
2146:09 **CAM-1**	* Alpha two.		
2146:12 **CAM-2**	is that where we're going?		
2146:13 **CAM-1**	yeah.		
2146:16 **CAM-1**	(where/what) the # is this.		
2146:22 **CAM-2**	is ahh.		

INTRA-COCKPIT COMMUNICATION			AIRCRAFT-TO-GROUND COMMUNICATION		
Time (CDT)	**SOURCE**	**CONTENT**	Time (CDT)	**SOURCE**	**CONTENT**
2146:27	**CAM-2**	[sound of laughing] look at the # fuel flow man.			
2146:30	**CAM-1**	ah # dude they're both almost a thou- almost under a thousand and (flying/in climb) that's # unreal.			
2146:31	**CAM-2**	[sound of laughing]			
2146:36	**CAM-1**	# dude.			
2146:37	**CAM-2**	dude I've seen this thing eat up like four thousand pounds an hour.			
2146:39	**CAM-1**	I know (it).			
2146:40	**CAM-2**	[sound of laughing]			
2146:42	**CAM-1**	ooh. look at that.			
2146:44	**CAM-1**	under two thousand # **… in a climb.			

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2146:49 **CAM-2**	that # crazy.		
2146:57 **CAM-1**	anyway the green line is one point two V-S one so we still have you know * stall **…		
2147:00 **CAM-2**	I think what you have * one point two seven isn't it?		
2147:01 **CAM-1**	…yeah one two seven right yeah.		
2147:06 **CAM-?**	*.		
2147:08 **CAM-2**	couple of knots.		
2147:12 **CAM-1**	the red line's where it can stall so.		
2147:15 **CAM-2**	three nine oh.		
2147:47 **CAM**	[sound of thumps]		

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2147:49 **CAM**	[sound of thump]		
2147:52 **CAM-1**	doesn't look much different though.		
2147:53 **CAM**	[sound of laughing]		
2147:55 **CAM-1**	still pretty cool.		
2147:58 **CAM-2**	yeah I'd have to say that yeah.		
2148:00 **CAM-1**	***.		
2148:05 **CAM**	[sound of clunks]		
2148:44 **CAM-2**	man we can do it. forty one it.		
2148:46 **CAM-?**	* baby.		
2148:54 **CAM-?**	**.		

INTRA-COCKPIT COMMUNICATION

AIRCRAFT-TO-GROUND COMMUNICATION

Time (CDT) SOURCE	CONTENT
2148:57 **CAM-2**	hundred and eighty knots still cruising at mach point six four.
2148:59 **CAM-1**	I know dude.
2149:00 **CAM-2**	[sound of laughing]
2149:04 **CAM-?**	minute **. two minutes to go.
2149:07 **CAM-1**	forty thousand baby.
2149:09 **CAM-2**	come on.
2149:24 **CAM-1**	look at that cabin altitude man.
2149:25 **CAM-2**	[sound of laughing]
2149:26 **CAM**	[sound of tone, similar to altitude alert]

Time (CDT) SOURCE	CONTENT

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2149:27 **CAM-1**	thousand to go.		
2149:28 **CAM-1**	should be at eight thousand feet moving… slowly (going up).		
		2149:30 **CTR-A**	Flagship thirty seven zero one would you like to go direct KASPR.
2149:30 **CAM-2**	[sound of laughing]		
2149:33 **CAM-1**	sure.		
2149:34 **CAM-2**	* might as well.		
		2149:36 **RDO-2**	yeah that'll be great thirty seven zero one direct KASPR.
		2149:39 **CTR-A**	all right cleared direct KASPR ah Flagship thirty seven zero one.
		2149:44 **RDO-2**	thank you sir appreciate that thirty seven zero one going direct KASPR you saved us two minutes.

INTRA-COCKPIT COMMUNICATION *7 of 61* **AIRCRAFT-TO-GROUND COMMUNICATION**

Time (CDT) **SOURCE**	**CONTENT**	Time (CDT) **SOURCE**	**CONTENT**
2149:48 **CAM-1**	[sound of laughing]		
2149:51 **CAM**	[sound of click]		
2150:04 **CAM-2**	[sound of laughing]		
2150:04 **CAM-1**	that # (crazy/funny).		
2150:05 **CAM-2**	[sound of laughing]		
2150:09 **CAM-?**	**.		
2150:28 **CAM-2**	aw yeah.		
2150:30 **CAM-?**	[sound of whistling]		
2150:43 **CAM**	[sound similar to paper rustling]		
2150:59 **CAM**	[sound similar to paper rustling]		

INTRA-COCKPIT COMMUNICATION		AIRCRAFT-TO-GROUND COMMUNICATION	
Time (CDT) **SOURCE**	**CONTENT**	Time (CDT) **SOURCE**	**CONTENT**
2151:01 **CAM-1**	I'm saying don't let it get below one seventy eh we're leveling off here anyways so.		
2151:18 **CAM-2**	dang. [sound of laughing] our arrival fuel's supposed to be three point five.		
2151:24 **CAM-1**	* I can't believe that # man that's crazy.		
2151:26 **CAM-2**	[sound of laughing]		
2151:27 **CAM-1**	we've saved a ton of # fuel.		
2151:31 **CAM-2**	#. [sound of laughing]		
2151:32 **CAM-1**	that's what I mean. I'll leave the power up 'til we get… (to level off) ***.		
2151:39 **CAM-2**	we're at V-T.		
2151:41 **CAM-?**	*.		

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2151:49 **CAM-1**	take a while for the thing to get started up.		
2151:51 **CAM-2**	there's four one oh my man.		
2151:53 **CAM-2**	made it man…		
2151:54 **CAM-1**	yeah…		
2151:55 **CAM-2**	…(five thousand) (feet/complete)…		
2151:56 **CAM-1**	…(five/nine) thousand feet per minute.		
2151:56 **CAM-2**	…(you) can see [sound of laughing]		
		2151:58 **CTR-A**	Flagship thirty seven zero one contact Kansas City one two five point six seven.
		2152:02 **RDO-1**	twenty five sixty seven you have a good night thirty seven oh one.

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2152:04 **CAM-2**	[sound of laughing] this is * great.		
		2152:09 **RDO-1**	Kansas City center good evening Flagship thirty seven zero one four one oh.
		2152:12 **CTR-B**	Flagship thirty seven zero one Kansas City center roger.
2152:12 **CAM-2**	[sound of laughing]		
2152:16 **CAM-1**	you'll get the you'll do the next one to say four one oh. * yeah baby.		
2152:18 **CAM**	[sound of clunk]		
2152:18 **CAM-2**	[sound of laughing] * four one oh # four one oh.		
2152:22 **CAM-1**	want anything to drink?		

INTRA-COCKPIT COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**
2152:24 **CAM-2**	aw yeah actually I'll take a pepsi.		
2152:26 **CAM**	[sound of clunks]		
2152:27 **CAM-1**	want anything?		
2152:28 **CAM-2**	hmm?		
2152:28 **CAM-1**	you do want?		
2152:29 **CAM-2**	a pepsi if you don't mind.		
2152:30 **CAM-1**	a pepsi? I thought you said a beer man. yeah I'd like one too **.		
2152:31 **CAM-2**	[sound of laughing]		
2152:35 **CAM-2**	is that seal on the liquor cabinet? [sound of laughing]		

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2152:47 **CAM**	[sound of click]		
2152:49 **CAM-?**	***. [lower volume]		
2153:01 **CAM**	[sound of click]		
2153:07 **CAM**	[sound of thump]		
2153:14 **CAM-2**	#. [sound of laughing] this is the greatest thing no way. [sound of laughing]		
2153:19 **CAM-1**	you want a can you want a cup we don't have any ice…		
2153:20 **CAM-2**	that's fine.		
2153:21 **CAM-1**	…they're cold as # dude.		
2153:23 **CAM-2**	(yeah that's cool).		

INTRA-COCKPIT COMMUNICATION

Time (CDT) SOURCE	CONTENT
2153:24 **CAM-1**	accelerating up at all?
2153:26 **CAM**	[sound of click, similar to soda can opening]
2153:27 **CAM-2**	[sound of laughing] no man…
2153:28 **CAM-1**	nothing dude…
2153:28 **CAM-2**	…it ain't speeding up worth #.
2153:28 **CAM-1**	…look how high we are.
2153:29 **CAM-2**	[sound of laughing]
2153:30 **CAM-1**	this # nose is. look at how nose high we are.
2153:32 **CAM-2**	I know that's #. dude the # ball's way off man. dude the ball's full off.

AIRCRAFT-TO-GROUND COMMUNICATION

Time (CDT) SOURCE	CONTENT

INTRA-COCKPIT COMMUNICATION			AIRCRAFT-TO-GROUND COMMUNICATION		
Time (CDT)	SOURCE	CONTENT	Time (CDT)	SOURCE	CONTENT
2153:39	**CAM-1**	no #. look at this (ball/bug) dude.			
2153:40	**CAM-2**	it's ***.			
2153:42	**CAM**	[sound of laughing]			
			2153:42	**CTR-B**	Flagship thirty seven zero one are you a RJ two hundred?
2153:44	**CAM**	[sound of clunks]			
			2153:47	**RDO-1**	thirty seven zero one that's affirmative.
2153:49	**CAM-2**	forty four hundred.			
			2153:50	**CTR-B**	I've never seen you guys up at forty one there.
2153:51	**CAM-2**	[sound of laughing]			

INTRA-COCKPIT COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**	**AIRCRAFT-TO-GROUND COMMUNICATION** Time (CDT) **SOURCE**	**CONTENT**
		2153:51 **RDO-1**	yeah we're actually a ah. there's ah. we don't we don't have any passengers on board so we decided to have a little fun and come on up here.
		2153:58 **CTR-B**	I gotcha.
		2153:59 **RDO-1**	this is our actually our service ceiling.
2154:05 **CAM-1**	# thing's losing it…		
2154:06 **CAM-2**	[sound of laughing]		
2154:07 **CAM-1**	…we're losing here. we're gonna be # coming down in a second here dude.		
2154:09 **CAM-2**	[sound of laughing]		
2154:10 **CAM-1**	this thing ain't gonna # hold altitude. is it?		
2154:16 **CAM-2**	it can't man. we # (cruised/greased) up here but it won't stay.		

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2154:19 **CAM-1**	yeah that's funny we got up here it won't stay up here.		
2154:22 **CAM-2**	dude it's # losing it. [sound of laughing]		
2154:23 **CAM-1**	yeah.		
		2154:29 **RDO-1**	and center thirty seven oh one.
		2154:31 **CTR-B**	go ahead.
		2154:32 **RDO-1**	yeah just as you said it looks like we're not even going to be able to stay up here ah look for maybe ah three nine oh or three seven.
		2154:38 **CTR-B**	Flagship thirty seven oh one stand by.
2154:38 **CAM**	[sound similar to stick shaker]		
2154:39 **CAM**	[sound similar to auto pilot disconnect]		

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2154:43 **CAM-2**	what'd he say?		
2154:44 **CAM-1**	I dunno.		
		2154:45 **RDO-1**	say again for thirty seven oh one.
2154:47 **CAM**	[sound similar to stick shaker]		
2154:48 **CAM**	[sound of warbler, similar to stick pusher warning]		
2154:49 **CAM-1**	#.		
2154:51 **CAM-2**	I got it.		
2154:52 **CAM**	[sound similar to stick shaker]		
2154:52 **CAM**	[sound of warbler, similar to stick pusher warning]		

INTRA-COCKPIT COMMUNICATION		AIRCRAFT-TO-GROUND COMMUNICATION	
Time (CDT) **SOURCE**	**CONTENT**	Time (CDT) **SOURCE**	**CONTENT**
		2154:53 **CTR-B**	and Flagship thirty seven zero one. I was off frequency say again?
2154:53 **CAM**	[sound of tone, similar to altitude alert]		
2154:55 **CAM**	[sound of triple chime, similar to master warning alert]		
2154:56 **CAM**	[sound similar to stick shaker]		
2154:56 **CAM**	[sound of warbler, similar to stick pusher warning]		
2154:56 **CAM-1**	#.		
2154:57 **CAS**	engine oil.		
2154:59 **CAM-1**	#.		
2154:59 **CAS**	engine oil.		

INTRA-COCKPIT COMMUNICATION		AIRCRAFT-TO-GROUND COMMUNICATION	
Time (CDT) **SOURCE**	**CONTENT**	Time (CDT) **SOURCE**	**CONTENT**
2155:00 **CAM**	[sound of warbler, similar to stick pusher warning, continues for nine seconds]		
2155:00 **CAM**	[sound of increased background noise]		
2155:01 **CAS**	engine oil.		
2155:01 **CAM-1**	come on. come on.		
2155:03 **CAS**	engine oil.		
2155:02 **CAM**	[sound of unidentified chirps]		
		2155:04 **CTR-B**	Flagship thirty seven zero one say.
2155:05 **CAM**	[sound of chime, similar to master caution alert]		
		2155:06 **RDO-1**	declaring emergency. stand by.

INTRA-COCKPIT COMMUNICATION			AIRCRAFT-TO-GROUND COMMUNICATION		
Time (CDT)	**SOURCE**	**CONTENT**	Time (CDT)	**SOURCE**	**CONTENT**
2155:07	**CAM**	[sound of tone, similar to altitude alert]			
2155:08	**CAM-1**	aw #.			
2155:09	**CAM**	[sound of triple chime, similar to master warning alert]			
2155:11	**CAM**	[sound of warbler, similar to stick pusher warning]			
2155:11	**CAS**	engine oil.			
2155:12	**CAM**	[sound similar to decreasing engine RPM]			
			2155:12	**CTR-B**	Flagship thirty seven zero one…
2155:13	**CAS**	engine oil.			
			2155:14	**CTR-B**	…descend at pilot's discretion maintain…
2155:15	**CAS**	engine oil.			

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
		2155:15 **CTR-B**	…flight level two four zero.
2155:17 **CAM**	[sound of warbler, similar to stick pusher warning]		
2155:17 **CAS**	engine oil.		
2155:19 **CAS**	engine oil.		
2155:19 **CAM-1**	two four zero flight two four zero.		
2155:21 **CAS**	engine oil.		
2155:22 **CAM-1**	the important thing is.		
2155:23 **CAS**	engine oil.		
2155:23 **CAM-?**	we don't have any engines.		
2155:24 **CAS**	engine oil.		

INTRA-COCKPIT COMMUNICATION		AIRCRAFT-TO-GROUND COMMUNICATION	
Time (CDT) **SOURCE**	**CONTENT**	Time (CDT) **SOURCE**	**CONTENT**
2155:25 **INT**	[channel one, sound of two unidentified beeps]		
2155:25 **CAM**	[sound of increased background noise, similar to air driven generator deployment]		
2155:26 **CAM**	[sound of clunk]		
2155:26 **CAM-1**	#.		
2155:26 **CAS**	engine oil.		
2155:28 **CAM**	[sound of increased background noise, similar to air driven generator operation]		
2155:29 **CAS**	engine oil.		
2155:29 **CAM-1**	A-D-G.		
2155:30 **CAS**	engine oil.		

INTRA-COCKPIT COMMUNICATION Time (CDT)	SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT)	SOURCE	CONTENT
2155:31	**CAM-1**	pull. pull the handle.			
2155:32	**CAS**	engine oil.			
			2155:32	**CTR-B**	everybody standby. Flagship thirty seven zero one the frequency's open.
2155:34	**CAS**	engine oil.			
2155:38	**CAM-1**	#.			
2155:38	**CAM-2**	* (got deploy/plane). (we got deployment).			
2155:39	**CAM-1**	got the airplane?			
2155:39	**CAM**	[sound of chime, similar to master caution alert]			
			2155:40	**RDO-1**	stand by for thirty seven oh one.

INTRA-COCKPIT COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**	**AIRCRAFT-TO-GROUND COMMUNICATION** Time (CDT) **SOURCE**	**CONTENT**
2155:44 **CAM-?**	got the A-D-G?		
2155:46 **CAM-?**	got the A-D-G.		
2155:53 **CAM**	[sound of clunks]		
2155:57 **CAM-1**	you gotta be kidding me.		
2155:58 **CAM**	[sound of clunk]		
2156:00 **CAM-2**	all right ahh… (stand by for)/(map light and) dome.		
2156:05 **CAM**	[sound of click]		
2156:05 **CAM**	[sound of chime, similar to passenger seat belt/no smoking sign]		
2156:07 **CAM-?**	#.		

Time (CDT) SOURCE	CONTENT	Time (CDT) SOURCE	CONTENT
2156:07 **CAM-1**	we're still descending aren't we? are we holding altitude?		
2156:10 **CAM-2**	ahh yeah we got it.		
2156:11 **CAM-1**	okay.		
2156:12 **CAM-2**	we've got a little bit of engine (windmill) in one of them.		
2156:14 **CAM-1**	(really)? okay we gotta go to emergency *.		
2156:17 **CAM-2**	we're not holding alt- altitude.		
2156:18 **CAM-1**	we're not?		
2156:19 **CAM-2**	no we're not.		
2156:19 **CAM-1**	okay. ahh flashlights. # (dude).		
2156:24 **CAM-2**	flashlight's in my bag… my bag.		

INTRA-COCKPIT COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**
2156:26 **CAM-1**	there's bags all…** look back here.		
2156:30 **CAM**	[sound of clunk]		
2156:33 **CAM-1**	double engine failure… you holding altitude?		
2156:39 **CAM-2**	ahh no I'm not.		
2156:42 **CAM-1**	okay. continuous ignition on.		
2156:45 **CAM-1**	thrust levers shut off. restart(ed)? shut off.		
2156:52 **CAM-1**	A-D-G power's established. how do you know A-D-G power is established?		
2156:56 **CAM-2**	see select A-C A-D-G.		
2156:59 **CAM-1**	okay then we're gonna' pull. and then you're gonna try stab two trim engage.		

INTRA-COCKPIT COMMUNICATION

Time (CDT)
SOURCE **CONTENT**

AIRCRAFT-TO-GROUND COMMUNICATION

Time (CDT)
SOURCE **CONTENT**

2157:02
CAM [sound of triple chime, similar to master warning alert]

2157:04
CAS cabin pressure.

2157:06
CAM-1 stab trim channel two.

2157:07
CAS cabin pressure.

2157:08
CAM-1 engaged.

2157:09
CAS cabin pressure.

2157:09
CAM-1 target airspeed established above flight level three four oh.

2157:11
CAS cabin pressure.

2157:12
CAM-1 we're below.

2157:13
CAS cabin pressure.

INTRA-COCKPIT COMMUNICATION		AIRCRAFT-TO-GROUND COMMUNICATION	
Time (CDT) **SOURCE**	**CONTENT**	Time (CDT) **SOURCE**	**CONTENT**
2157:13 **CAM-1**	point seven Mach.		
2157:14 **CAM**	[sound of tone, similar to gear warning horn, continues until 2200:43]		
2157:17 **CAM-1**	so look for point seven Mach. a hundred eighty.		
2157:18 **CAM-1**	A-D-G. below thirty thousand feet. okay descend below thirty thousand feet.		
2157:26 **CAM**	[sound similar to page turning]		
2157:29 **CAM-?**	okay ***.		
2157:36 **CAM-1**	# dude.		
2157:46 **CAM-2**	* # gear's unsafe ***.		
2157:52 **CAM-1**	I'll worry about that later.		

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2157:54 **CAM-?**	is the gear down or *** unsafe?		
2157:58 **CAM-1**	okay go go descend still.		
2158:00 **CAM-?**	all right.		
2158:03 **CAM-1**	you got a question on (why/what) *.		
2158:07 **CAM**	[sound of clunk]		
2158:09 **CAM-2**	that was a dutch roll I believe.		
2158:12 **CAM-1**	*** it was pulling and pushing…		
2158:13 **CAM-2**	sure.		
2158:13 **CAM-1**	…see the plane start to roll on us.		
2158:15 **CAM-2**	we were descending at two thousand feet per minute.		

INTRA-COCKPIT COMMUNICATION		AIRCRAFT-TO-GROUND COMMUNICATION	
Time (CDT) **SOURCE**	**CONTENT**	Time (CDT) **SOURCE**	**CONTENT**
2158:21 **CAM-2**	we need our oxygen masks.		
2158:23 **CAM-1**	okay as soon as we're abov- below thirty thousand we can start the A-P-U.		
2158:30 **CAM-?**	there you go.		
2158:34 **CAM**	[sound of click]		
2158:35 **CAM**	[sound of chime, similar to master caution alert]		
2158:37 **CAM-2**	go on oxygen?		
2158:39 **CAM-1**	you know what. yeah we need to go on oxygen.		
2158:41 **CAM**	[sound similar to oxygen flow starting in oxygen mask]		
2158:52 **CAM-?**	A-P-U.		

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2158:52 **CAM**	[sound of chime, similar to master caution alert]		
2159:17 **CAM**	[sound similar to increased frequency of background noise from air driven generator]		
2159:19 **CAM**	[sound of chime, similar to master caution alert]		
2159:21 **CAM**	[sound similar to oxygen flow in oxygen mask]		
2159:23 **CAM**	[sound of clicks]		
2159:24 **CAM-1**	okay we have power.		
2159:25 **CAM**	[sound of clicks]		
2159:33 **CAM-1**	stow it away.		
2159:37 **CAM**	[sound of clicks]		

INTRA-COCKPIT COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**
2159:44 **CAM**	[sound of chime, similar to master caution alert]		
2159:46 **CAM**	[sound of chime, similar to master caution alert]		
		2159:46 **RDO-1**	and center Flagship thirty seven oh one.
		2159:48 **CTR-B**	Flagship thirty seven oh one go American seven fifty one standby.
		2159:51 **RDO-1**	yeah we're still descending we're gonna need to descend down ah probably lower probably gonna descend down to right now to about thirteen thousand feet is that okay?
		2159:58 **CTR-B**	Flagship thirty seven oh one affirmative descend and maintain one three thousand your local altimeter setting is ah… oh stand by.
		2200:07 **CTR-B**	two niner six five and ah one three thousand is approved Flagship thirty seven zero one.
		2200:12 **RDO-1**	all right two nine six five thirty seven zero one.

INTRA-COCKPIT COMMUNICATION

Time (CDT)
SOURCE **CONTENT**

AIRCRAFT-TO-GROUND COMMUNICATION

Time (CDT)
SOURCE **CONTENT**

2200:17
CAM-1 two nine six five your side.

2200:19
CAM-1 ahh no no no.

2200:22
CAM-2 no no no what do you got… oh heading.

2200:25
CAM-1 yeah.

2200:25
CAM-2 see what you got.

2200:27
CAM-1 yeah yeah it's two nine six five on altimeter setting.

2200:27
CAM-2 okay.

2200:28
CAM-1 when we come through.

2200:30
CAM [sound similar to page turning]

2200:31
CAM-1 we're gonna have to descend down to ah.

INTRA-COCKPIT COMMUNICATION Time (CDT)	**SOURCE**	**CONTENT**	**AIRCRAFT-TO-GROUND COMMUNICATION** Time (CDT)	**SOURCE**	**CONTENT**
2200:33	**CAM**	[sound similar to page turning]			
2200:34	**CAM-1**	thirteen thousand feet.			
2200:35	**CAM**	[sound similar to page turning]			
2200:38	**CAM-1**	th- thirteen okay actually push the nose over. push it over. let's get above three hundred knots.			
2200:43	**CAM**	[sound of tone, similar to gear warning horn ceases]			
2200:46	**CAM-2**	okay.			
2200:47	**CAM-1**	twenty one thousand feet. we need we need… ** check our airspeed and altitude.			
2200:48	**CAM-?**	three hundred.			
			2200:57	**CTR-B**	and Flagship ah thirty seven zero one are you able to take a frequency change at this point?

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
		2201:01 **RDO-1**	ah thirty seven oh one stand by.
		2201:03 **CTR-B**	roger.
2201:05 **CAM-1**	I-T-T is ninety degrees Celsius or less. I-T-T is ninety degrees Celsius? no. 'kay it's getting to it. yeah its coming down now.		
2201:11 **CAM-?**	***.		
2201:31 **CAM-1**	I don't think we're gonna need that.		
2201:36 **CAM-1**	* ignition on…		
2201:38 **CAM-2**	yep.		
2201:39 **CAM-1**	…airspeed not less than three hundred knots. you wanna push it up there three hundred knots. altitude loss approximately can be expected from two hundred forty to three hundred knots. I-T-T ninety degrees or less. N two is at least twelve percent… N two…		

Time (CDT) **SOURCE**	**CONTENT**	Time (CDT) **SOURCE**	**CONTENT**
2201:51 **CAM-1**	…no we're not getting any N two at all. so we're gonna have to. gonna have to go to here. thirteen thousand feet we gotta go down here dude. we're going to use the A-P-U bleed air procedures.		
2202:00 **CAM**	[sound of chime, similar to master caution alert]		
2202:04 **CAM-?**	***.		
2202:09 **CAM-?**	oh #.		
2202:10 **CAM-1**	we need to slow it down. slow the rate of descent down.		
2202:14 **CAM-1**	** target airspeed is established. target airspeed is a hundred ninety knots. hundred and seventy knots. go ahead and pull back to a hundred seventy knots. left and right tenth stage. tenth stage bleeds closed. left and right tenth stage bleeds closed. A-P-U load control valve open. continuous ignition.		
2202:31 **CAM**	[sound of chime, similar to master caution alert]		

INTRA-COCKPIT COMMUNICATION

Time (CDT)
SOURCE **CONTENT**

2202:34
CAM-1 no… keep us going down… oh you know what. actually we can't do that yet.

2202:48
CAM [sound of clunks]

2202:52
CAM-? ***.

2202:58
CAM-? the gear?

2202:59
CAM [sound of clunks]

2203:00
CAM [sound of clunk]

AIRCRAFT-TO-GROUND COMMUNICATION

Time (CDT)
SOURCE **CONTENT**

2203:00
RDO-1 and thirty seven oh one we can change frequency at this time.

2203:06
RDO-1 center thirty seven oh one you there.

2203:09
CTR-B Flagship thirty seven zero one ah roger I'll have a frequency change for you in just a moment. before I send you what was the nature of your emergency please?

INTRA-COCKPIT COMMUNICATION Time (CDT)	SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT)	SOURCE	CONTENT
			2203:15	**RDO-1**	ah we had an engine failure up there at altitude it at ah airplane ah went into a stall and one of our engine's failure…
2203:22	**CAM**	[sound of chime, similar to master caution alert]			
			2203:22	**RDO-1**	…so we're gonna descend down now to start our other engine.
			2203:25	**CTR-B**	okay that's kinda what we were figuring there and ah understand you're controlled flight and ah you're gonna be able to return to normal when you get to lower altitude.
			2203:30	**RDO-1**	ah right now we're not we're- stand by for that. we're descending down to thirteen thousand to start this other engine. we'll tell you.
			2203:35	**CTR-B**	Flagship thirty seven zero one roger. understand controlled flight on a single engine right now and ah I'll go ahead and relay that. you can contact Kansas City center on one three four point five. just advise ah her of your intentions. one three four point five. good day.
			2203:50	**RDO-1**	thirty four five good day.

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
		2203:52 **RDO-1**	center Flagship thirty seven zero one's with you ah coming through eighteen thousand for thirteen.
		2203:59 **CTR-C**	Flagship thirty seven zero one Kansas City center roger and advise of any further help you might need.
		2204:02 **RDO-1**	will do thirty seven oh one.
2204:06 **CAM-1**	okay (don mask) get on oxygen.		
2204:09 **CAM**	[sound similar to oxygen flow in oxygen mask]		
2204:13 **INT-1**	yeah get on oxygen dude. we're at cabin altitude. I got it. fifteen thousand four hundred. we need to be on oxygen.		
2204:26 **INT-1**	okay it's gonna be from thirteen thousand feet and below target airspeed established it's a hundred seventy knots. left and right tenth bleed will be closed. A-P-U open. continuous ignition check it's on. continuous ignition is on. left or right engine start. let's start number two first. * push. thrust lever at idle. * 'kay yeah th- these are off right now.		

INTRA-COCKPIT COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**
2204:51 **INT-1**	got another thirteen- three thousand feet to go.		
2205:33 **INT-1**	as soon as we get a thousand you want a hundred and seventy knots like we. that's all we need. so we can pull it up a little bit and slow the rate of descent okay? you with me on this? you clear? you clear? all right we're gonna get this going. don't worry bro. all right? you okay? seriously? all right.		
2205:52 **INT-1**	there you go.		
2205:53 **INT**	[channel three audio ceases through end of recording]		
2205:55 **INT-1**	okay fourteen thousand keep it coming down. don't wanna get too slow on airspeed. look for about a hundred and seventy. it's at least a hundred and seventy. that's your min. thirteen thousand feet okay. right left tenth visually closed.		
2206:13 **CAM**	[sound of tone, similar to gear warning horn]		
2206:23 **CAM**	[sound similar to oxygen mask removal]		

INTRA-COCKPIT COMMUNICATION Time (CDT)	 SOURCE	 CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT)	 SOURCE	 CONTENT
			2206:26	**RDO-1**	and cent- center thirty seven oh one we're gonna need a little lower ah to start this other engine up so we're gonna go down to about twelve or eleven is that cool?
			2206:33	**CTR-C**	Flagship thirty seven zero one affirmative ah descend and maintain ah you wanna go down to eleven or twelve?
			2206:38	**RDO-1**	ah we'll go down to at least eleven thousand thirty seven oh one.
			2206:40	**CTR-C**	Flagship thirty seven zero one roger descend and maintain one one thousand and just advise you you want to go back to KASPR? do you want to land? what do you want to do?
			2206:48	**RDO-1**	ah just stand by right now we're gonna start this other engine and see make sure if everything's okay.
			2206:51	**CTR-C**	okay.
2206:53	**CAM-1**	back to KASPR?			
			2206:54	**CTR-C**	have a lot of choices up ahead Columbia's right up ahead. JEF's up ahead. and they're the best to accommodate you.

INTRA-COCKPIT COMMUNICATION		AIRCRAFT-TO-GROUND COMMUNICATION	
Time (CDT) **SOURCE**	**CONTENT**	Time (CDT) **SOURCE**	**CONTENT**
		2206:59 **RDO-1**	roger * thirty seven oh one thank you.
2207:01 **CAM**	[sound of clunk]		
2207:02 **CAM-1**	okay thirteen thousand feet.		
2207:04 **CAM-1**	it says… right left tenth stage closed. they're closed. (A-P-O's/A-P-U isolation's) valve's open. it's open. dude let's check ** ready to start. here goes number one.		
2207:17 **CAM-1**	start. time started.		
2207:20 **INT**	[sound similar to oxygen flow in oxygen mask]		
2207:34 **INT-1**	#.		
2207:38 **INT-1**	let's stop it.		

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2207:41 **INT-1**	it says. * right left tenth stage closed. A-P-U L-C valve's open. A-P-U valve's open. right or left tenth stage ah push. right or left engine start push. there goes number two.		
2207:59 **INT-1**	it's starting. right engine start.		
2208:04 **INT-1**	we're not getting any N two.		
2208:10 **INT-1**	aw #.		
2208:11 **INT**	[sound similar to oxygen mask removal]		
2208:13 **CAM-1**	off oxygen.		
2208:15 **CAM**	[sound similar to oxygen mask removal]		
2208:17 **CAM-1**	um. switch.		
2208:20 **CAM-2**	yeah *.		

INTRA-COCKPIT COMMUNICATION **AIRCRAFT-TO-GROUND COMMUNICATION**

Time (CDT)
SOURCE **CONTENT**

Time (CDT)
SOURCE **CONTENT**

2208:24
CAM [sound of clunks]

2208:24
CAM-1 put it over there.

2208:26
CAM [sound of clunks]

2208:30
CAM [sound of chime, similar to master caution alert]

2208:33
CAM-2 (start switch).

2208:35
CAM-1 hold this.

2208:38
CAM-1 it's still on.

2208:43
CAM-2 you got it?

2208:43
CAM-1 I got it.

2208:46
CAM-? **.

INTRA-COCKPIT COMMUNICATION		AIRCRAFT-TO-GROUND COMMUNICATION	
Time (CDT) **SOURCE**	**CONTENT**	Time (CDT) **SOURCE**	**CONTENT**
2208:49 **CAM-1**	go to that check pull that check list up.		
2208:52 **CAM-2**	okay.		
2208:53 **CAM-1**	tell her.		
2208:55 **CAM-1**	that's it.		
		2209:00 **CTR-C**	Flagship thirty seven zero one what altitude do you want to go down to?
2209:02 **CAM-1**	tell her we need to get direct to airport neither engine's started right now.		
2209:07 **CAM**	[sound of chime, similar to master caution alert]		
		2209:06 **RDO-2**	thirty seven zero one we need direct to any airport. we have a double engine failure.
		2209:12 **CTR-C**	all right you want to go direct to JEF?

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2209:14 **CAM-1**	any airport and closest airport.		
		2209:15 **RDO-2**	closest air- air- airport. we're descending fifteen hundred feet per minute we have ah nine thousand five hundred feet left.
		2209:21 **CTR-C**	Flagship thirty seven zero one cleared direct JEF.
		2209:23 **RDO-2**	what is the three letter identifier?
		2209:26 **CTR-C**	J-E-F.
		2209:28 **RDO-2**	K-J-E-F.
2209:32 **CAM-1**	okay let me see ** start *** both engines.		
2209:38 **CAM-1**	they're closed. tenth stage closed. A-P-U is on.		
2209:44 **CAM-1**	*** getting power.		

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2209:46 **CAM-2**	no.		
2209:48 **CAM-1**	*.		
2209:49 **CAM-2**	* right there.		
2209:49 **CAM-1**	power override.		
2209:52 **CAM-1**	** power.		
2209:52 **CAM-2**	okay.		
2209:54 **CAM-1**	let's try this.		
2209:56 **CAM-2**	# *.		
2210:00 **CAM-1**	(nah/dead).		
2210:05 **CAM-1**	**. this #. where do we have to go?		

INTRA-COCKPIT COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**
2210:06 **CAM-2**	JEF. J-K-J-E-F.		
2210:08 **CAM-1**	*.		
2210:09 **CAM-2**	right in front of you fifteen miles.		
2210:10 **CAM**	[sound of clicks]		
2210:11 **CAM-1**	seat belt on?		
2210:14 **CAM**	[sound of clunks, similar to crew seat movement]		
2210:19 **CAM**	[sound of clunks]		
		2210:21 **CTR-C**	Flagship thirty seven zero one descend at pilot's discretion maintain three thousand they're landing I-L-S runway three zero and…
2210:30 **CAM-1**	get a frequency. gotta get a frequency.		

INTRA-COCKPIT COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**
		2210:28 **CTR-C**	…the winds are two niner zero at six knots.
2210:32 **CAM-?**	# *.		
		2210:36 **RDO-2**	I-L-S three zero. what is the frequency please.
		2210:40 **CTR-C**	let me give you the frequency for Mizzou approach is one two four point one.
		2210:54 **RDO-2**	the approach frequency is one two four one or what is the I-L-S frequency?
		2210:58 **CTR-C**	let me get you the I-L-S frequency.
2211:00 **CAM-1**	**.		
2211:00 **CAM-2**	that isn't it.		
2211:02 **CAM-1**	no what is it? say again?		

INTRA-COCKPIT COMMUNICATION		AIRCRAFT-TO-GROUND COMMUNICATION	
Time (CDT) **SOURCE**	**CONTENT**	Time (CDT) **SOURCE**	**CONTENT**
		2211:03 **RDO-2**	what is the I-L-S frequency again?
2211:06 **CAM**	[sound of tone, similar to gear warning horn until 2211:37]		
2211:10 **CAM-1**	ask her… #.		
2211:15 **CAM-1**	(we're in the middle of the) # dark here.		
2211:17 **CAM-2**	yeah we're running.		
2211:19 **CAM-1**	you get her on the radio? talk to her.		
		2211:20 **CTR-C**	it's ah one one zero point five.
		2211:22 **RDO-2**	thank you much.
2211:24 **CAM-1**	one one zero five.		
		2211:25 **CTR-C**	Flagship did you get that? one one zero point five.

INTRA-COCKPIT COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) **SOURCE**	**CONTENT**
		2211:27 **RDO-2**	one one zero five.
2211:30 **CAM-2**	going to green needles?		
2211:31 **CAM-1**	yeah.		
2211:33 **CAM**	[sound of click]		
2211:34 **INT**	[channel three, low volume, morse code identifier for ILS three zero at JEF]		
2211:37 **CAM-2**	okay should we try starting her up?		
2211:39 **CAM-1**	yeah. yeah you might as well. try it dude.		
2211:42 **CAM-2**	* (open).		
2211:43 **CAM-1**	I dunno. #.		

Time (CDT) SOURCE	CONTENT	Time (CDT) SOURCE	CONTENT
2211:44 **CAM-2**	I dunno if this thing is still starting.		
		2211:46 **CTR-C**	Flagship thirty seven zero one M-I-A is twenty seven hundred.
		2211:51 **RDO-2**	roger that thanks.
2211:52 **CAM-1**	what is M-I-A?		
2211:55 **CAM-2**	(I don't know man). ** # (start).		
2211:59 **INT**	[sound of squeal, similar to microphone feedback]		
2212:01 **CAM-?**	* #.		
2212:03 **CAM-?**	* #.		
2212:05 **CAM-2**	why isn't the # engine going anywhere?		

INTRA-COCKPIT COMMUNICATION		AIRCRAFT-TO-GROUND COMMUNICATION	
Time (CDT) **SOURCE**	**CONTENT**	Time (CDT) **SOURCE**	**CONTENT**
2212:07 **CAM-1**	I dunno. we're not getting any N two.		
2212:08 **INT**	[sound of squeal, similar to microphone feedback]		
2212:09 **CAM-2**	we're not?		
2212:10 **CAM-1**	left engine oil pressure. for some reason it's shut down. I-T-T N two.		
2212:16 **CAM-1**	I don't get it either.		
2212:19 **CAM-1**	ask her how we look.		
2212:24 **CAM-1**	ask her how we look.		
		2212:24 **RDO-2**	thirty seven zero one. how do we look for the airport?
		2212:27 **CTR-C**	okay the airport is at your twelve o'clock and okay let's let's…

INTRA-COCKPIT COMMUNICATION

AIRCRAFT-TO-GROUND COMMUNICATION

Time (CDT) **SOURCE**	**CONTENT**	Time (CDT) **SOURCE**	**CONTENT**
2212:31 **CAM-1**	** here.		
		2212:32 **CTR-C**	…make that eleven o'clock… and eight miles…
2212:37 **CAM-1**	how do we look for the runway?		
		2212:40 **CTR-C**	…okay from you it is a three sixty heading.
2212:44 **INT**	[sound of squeal, similar to microphone feedback]		
2212:45 **CAM-1**	three sixty heading. * turn in now?		
		2212:51 **CTR-C**	Flagship thirty seven zero one three sixty heading eight miles.
2212:54 **CAM-1**	we're turning left.		
2212:57 **CAM**	[sound of clunks]		

INTRA-COCKPIT COMMUNICATION		AIRCRAFT-TO-GROUND COMMUNICATION	
Time (CDT) **SOURCE**	**CONTENT**	Time (CDT) **SOURCE**	**CONTENT**
2212:59 **CAM-1**	turn left three sixty heading. are we gonna make this airport? **.		
2213:04 **CAM**	[sound of clunks]		
2213:06 **CAM-2**	* # runway.		
2213:07 **INT**	[sound of squeal, similar to microphone feedback]		
2213:09 **CAM-1**	we don't have the airport in sight. we're heading three six zero now. do you have anything further information.		
2213:14 **CAM**	[sound of clunks]		
2213:17 **CAM-1**	you try yours. I'm not getting in t- through to her.		
		2213:20 **RDO-2**	how do we look now three six heading we do not have airport in sight.
		2213:24 **CTR-C**	and keep turning left. it's now about a three fifty heading.

INTRA-COCKPIT COMMUNICATION Time (CDT)	SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT)	SOURCE	CONTENT
			2213:28	**RDO-2**	turning three fifty.
			2213:32	**RDO-2**	I have the beacon in sight…
2213:33	**CAM-1**	where? where?			
			2213:34	**RDO-2**	…twelve o'clock.
2213:35	**CAM-2**	straight ahead.			
			2213:36	**RDO-2**	* head.
2213:36	**CAM-1**	straight ahead. where's the runway?			
			2213:36	**CTR-C**	*ship thirty seven zero one roger.
2213:37	**CAM-1**	are we lined up for the runway?			
			2213:38	**RDO-2**	I do not see the runway. I have the beacon…

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2213:40 **CAM**	[sound of tone, similar to gear warning horn]		
		2213:41 **RDO-2**	…where is the runway?
2213:44 **CAM-1**	come on lady.		
2213:47 **CAM-1**	talk to her again.		
		2213:49 **RDO-2**	Flagship thirty seven zero one have the beacon twelve o'clock the runway is at heading zero three zero?
		2213:55 **CTR-C**	Flagship thirty seven zero one the beacon is on the far side of the runway.
		2213:59 **RDO-2**	okay I think I have the approach end in.
2214:02 **CAM-2**	sight. here it is at twelve o'clock right.		
2214:03 **CAM-1**	(right)? where?		

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2214:03 **CAM-2**	straight ahead.		
2214:04 **CAM-1**	straight ahead. we're on the approach?		
2214:07 **CAM-2**	yes.		
2214:08 **CAM-2**	just.		
2214:10 **CAM-2**	turn turn to the right a little bit.		
2214:11 **CAM-1**	turn to the right a little bit?		
2214:12 **CAM-2**	stay right there.		
2214:14 **CAM-1**	right here?		
2214:14 **CAM-2**	yeah.		
2214:17 **CAM-1**	dude we're not gonna make this # thing.		

INTRA-COCKPIT COMMUNICATION		AIRCRAFT-TO-GROUND COMMUNICATION	
Time (CDT) SOURCE	CONTENT	Time (CDT) SOURCE	CONTENT
2214:25 **CAM-2**	think we're okay.		
2214:25 **CAM**	[sound of clicks]		
2214:34 **CAM-1**	where is it? I don't know.		
2214:36 **CAM-2**	we're not gonna make it man we're not gonna make it.		
2214:38 **CAM-1**	is there a road? tell her we're not gonna make this runway.		
		2214:39 **RDO-2**	we're not gonna make the runway. is there a road?
2214:43 **CAS**	too low gear.		
2214:46 **CAM-1**	let's keep the gear up. #. I don't want to go into houses here.		
2214:51 **CAM-2**	# road right there.		

INTRA-COCKPIT COMMUNICATION Time (CDT) SOURCE	CONTENT	AIRCRAFT-TO-GROUND COMMUNICATION Time (CDT) SOURCE	CONTENT
2214:52 **CAM-1**	where?		
2214:52 **CAM-2**	turn turn…		
2214:53 **CAM-1**	turn where?		
2214:53 **CAM-2**	…turn to your left turn to your left.		
2214:54 **CAS**	too low gear.		
2214:56 **CAM-1**	(I see it/I can't).		
2214:58 **CAS**	too low terrain terrain…		
2214:59 **CAM-1**	can't make it.		
2215:00 **CAS**	…whoop whoop pull up. whoop whoop pull up…		

INTRA-COCKPIT COMMUNICATION

Time (CDT)
SOURCE **CONTENT**

AIRCRAFT-TO-GROUND COMMUNICATION

Time (CDT)
SOURCE **CONTENT**

2215:03
CAM-1 aw #. we're gonna hit houses dude.

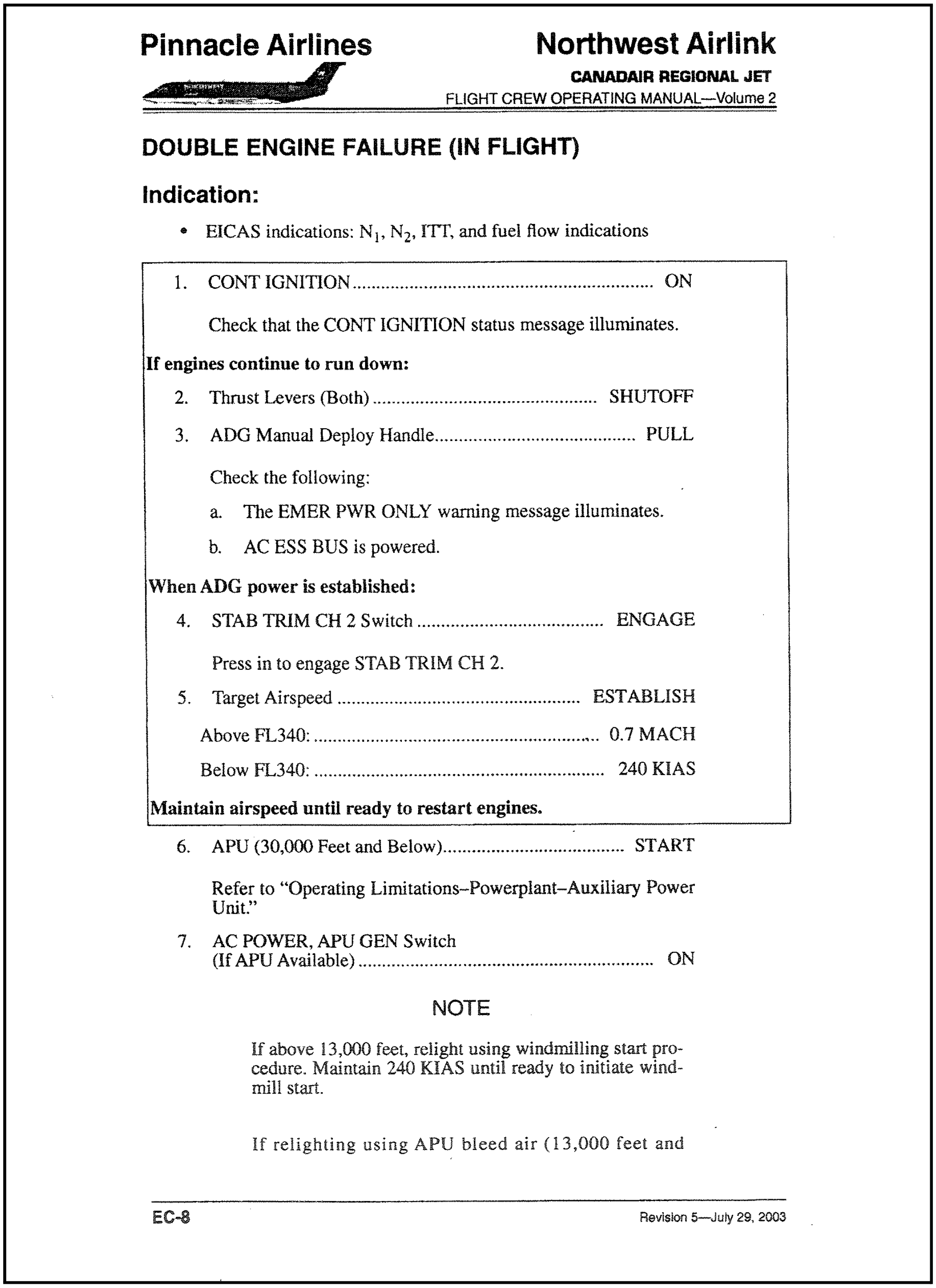
2215:05
CAS …whoop whoop pull up.

2215:06
CAM [sound similar to impacts]

2215:07
END OF TRANSCRIPT
END OF RECORDING

Appendix C

Pinnacle Airlines' Double Engine Failure Checklist at the Time of the Accident



Pinnacle Airlines **Northwest Airlink**

CANADAIR REGIONAL JET

FLIGHT CREW OPERATING MANUAL—Volume 2

DOUBLE ENGINE FAILURE (IN FLIGHT)

Indication:

- EICAS indications: N_1, N_2, ITT, and fuel flow indications

1. CONT IGNITION .... ON

   Check that the CONT IGNITION status message illuminates.

If engines continue to run down:

2. Thrust Levers (Both) .... SHUTOFF
3. ADG Manual Deploy Handle.. PULL

   Check the following:

   a. The EMER PWR ONLY warning message illuminates.
   b. AC ESS BUS is powered.

When ADG power is established:

4. STAB TRIM CH 2 Switch .... ENGAGE

   Press in to engage STAB TRIM CH 2.

5. Target Airspeed .... ESTABLISH

   Above FL340: .... 0.7 MACH

   Below FL340: .... 240 KIAS

Maintain airspeed until ready to restart engines.

6. APU (30,000 Feet and Below)..................................... START

   Refer to "Operating Limitations–Powerplant–Auxiliary Power Unit."

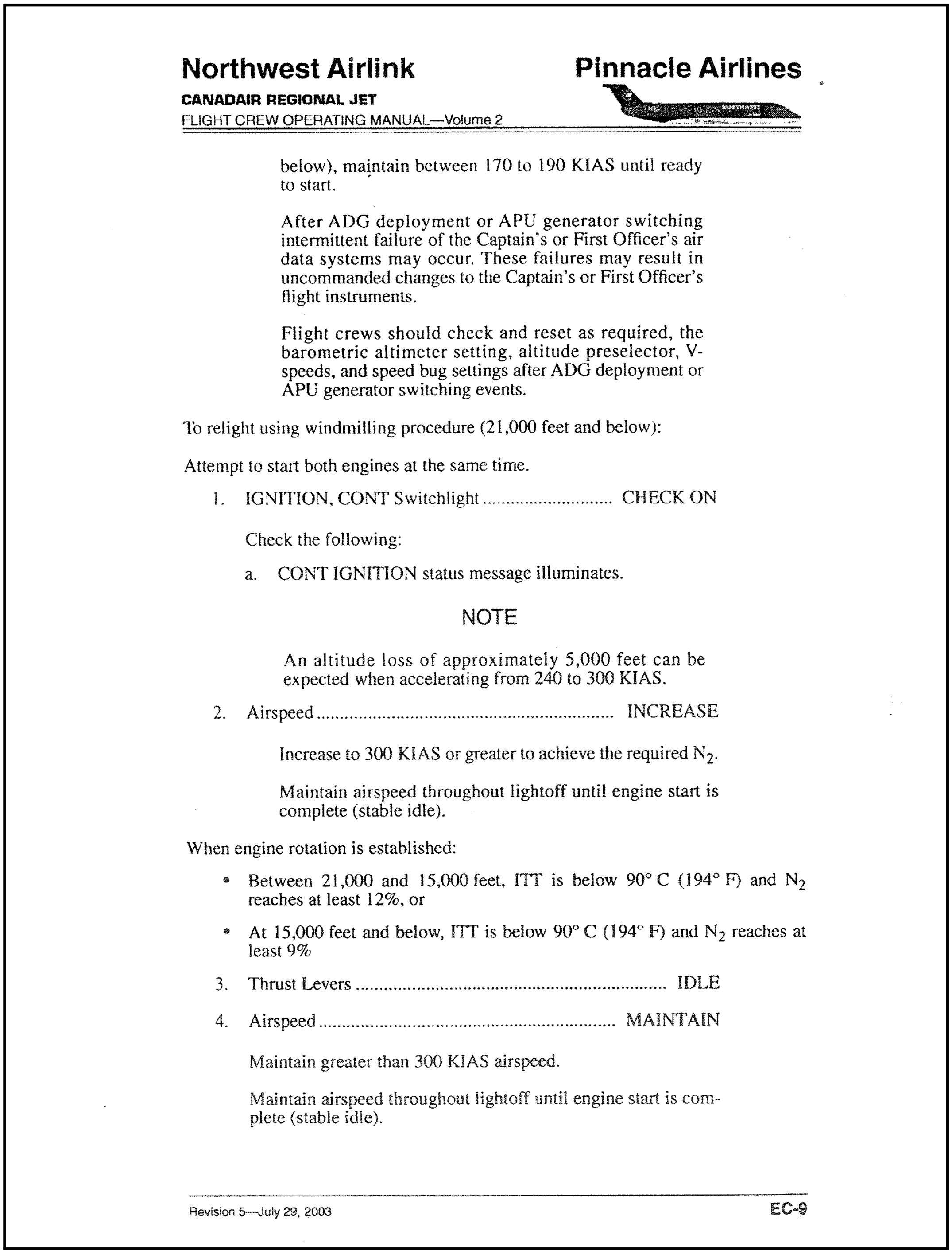
7. AC POWER, APU GEN Switch
   (If APU Available) .... ON

NOTE

If above 13,000 feet, relight using windmilling start procedure. Maintain 240 KIAS until ready to initiate windmill start.

If relighting using APU bleed air (13,000 feet and

EC-8 Revision 5—July 29, 2003



below), maintain between 170 to 190 KIAS until ready to start.

After ADG deployment or APU generator switching intermittent failure of the Captain's or First Officer's air data systems may occur. These failures may result in uncommanded changes to the Captain's or First Officer's flight instruments.

Flight crews should check and reset as required, the barometric altimeter setting, altitude preselector, V-speeds, and speed bug settings after ADG deployment or APU generator switching events.

To relight using windmilling procedure (21,000 feet and below):

Attempt to start both engines at the same time.

1. IGNITION, CONT Switchlight .... CHECK ON

   Check the following:

   a. CONT IGNITION status message illuminates.

NOTE

An altitude loss of approximately 5,000 feet can be expected when accelerating from 240 to 300 KIAS.

2. Airspeed .... INCREASE

   Increase to 300 KIAS or greater to achieve the required N_2.

   Maintain airspeed throughout lightoff until engine start is complete (stable idle).

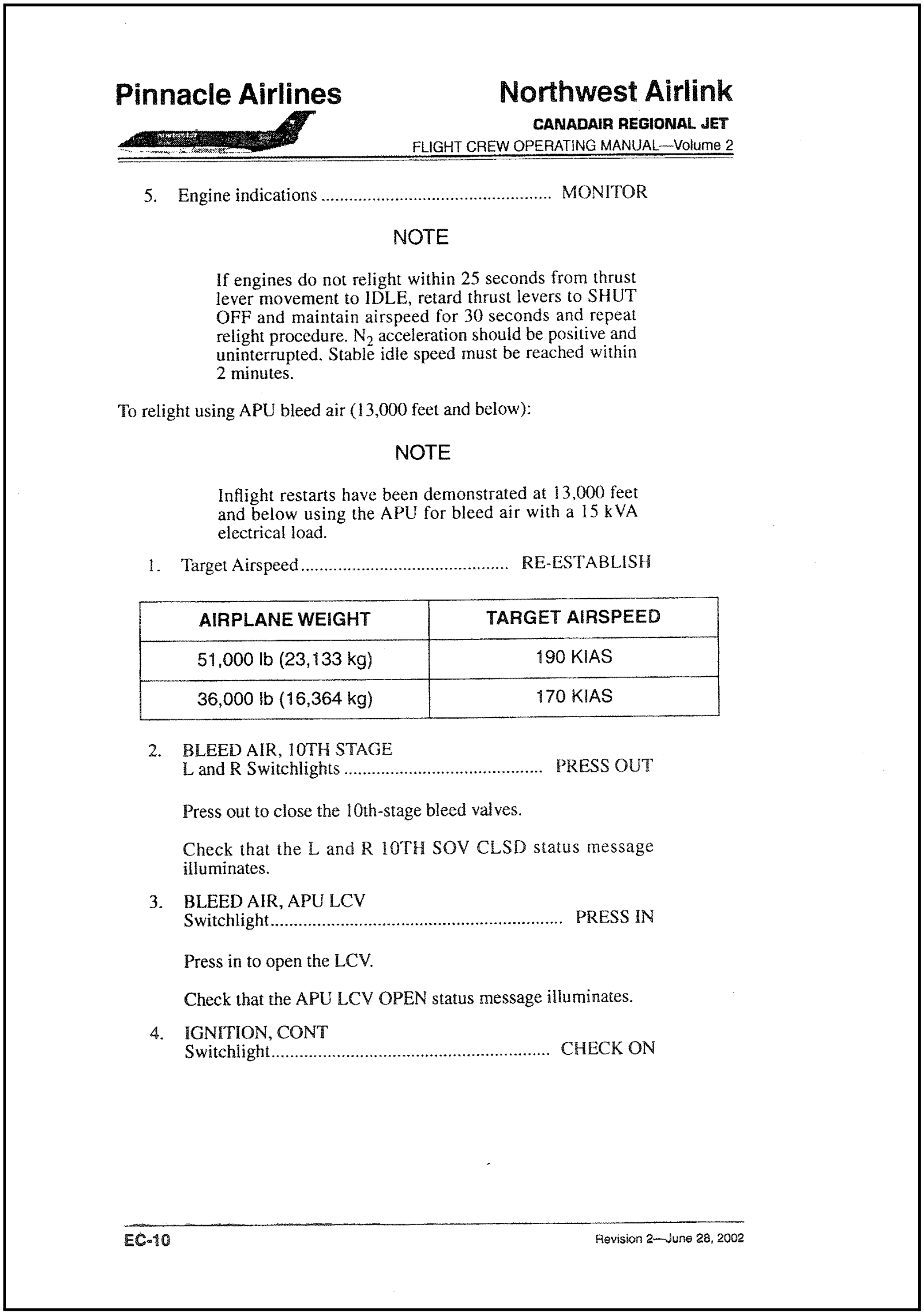
When engine rotation is established:

- Between 21,000 and 15,000 feet, ITT is below 90° C (194° F) and N_2 reaches at least 12%, or
- At 15,000 feet and below, ITT is below 90° C (194° F) and N_2 reaches at least 9%

3. Thrust Levers .... IDLE
4. Airspeed .... MAINTAIN

   Maintain greater than 300 KIAS airspeed.

   Maintain airspeed throughout lightoff until engine start is complete (stable idle).



Pinnacle Airlines

Northwest Airlink
CANADAIR REGIONAL JET
FLIGHT CREW OPERATING MANUAL—Volume 2

5. Engine indications .... MONITOR

NOTE

> If engines do not relight within 25 seconds from thrust lever movement to IDLE, retard thrust levers to SHUT OFF and maintain airspeed for 30 seconds and repeat relight procedure. N_2 acceleration should be positive and uninterrupted. Stable idle speed must be reached within 2 minutes.

To relight using APU bleed air (13,000 feet and below):

NOTE

> Inflight restarts have been demonstrated at 13,000 feet and below using the APU for bleed air with a 15 kVA electrical load.

1. Target Airspeed .... RE-ESTABLISH

AIRPLANE WEIGHT	TARGET AIRSPEED
51,000 lb (23,133 kg)	190 KIAS
36,000 lb (16,364 kg)	170 KIAS

2. BLEED AIR, 10TH STAGE
   L and R Switchlights .... PRESS OUT

   Press out to close the 10th-stage bleed valves.

   Check that the L and R 10TH SOV CLSD status message illuminates.

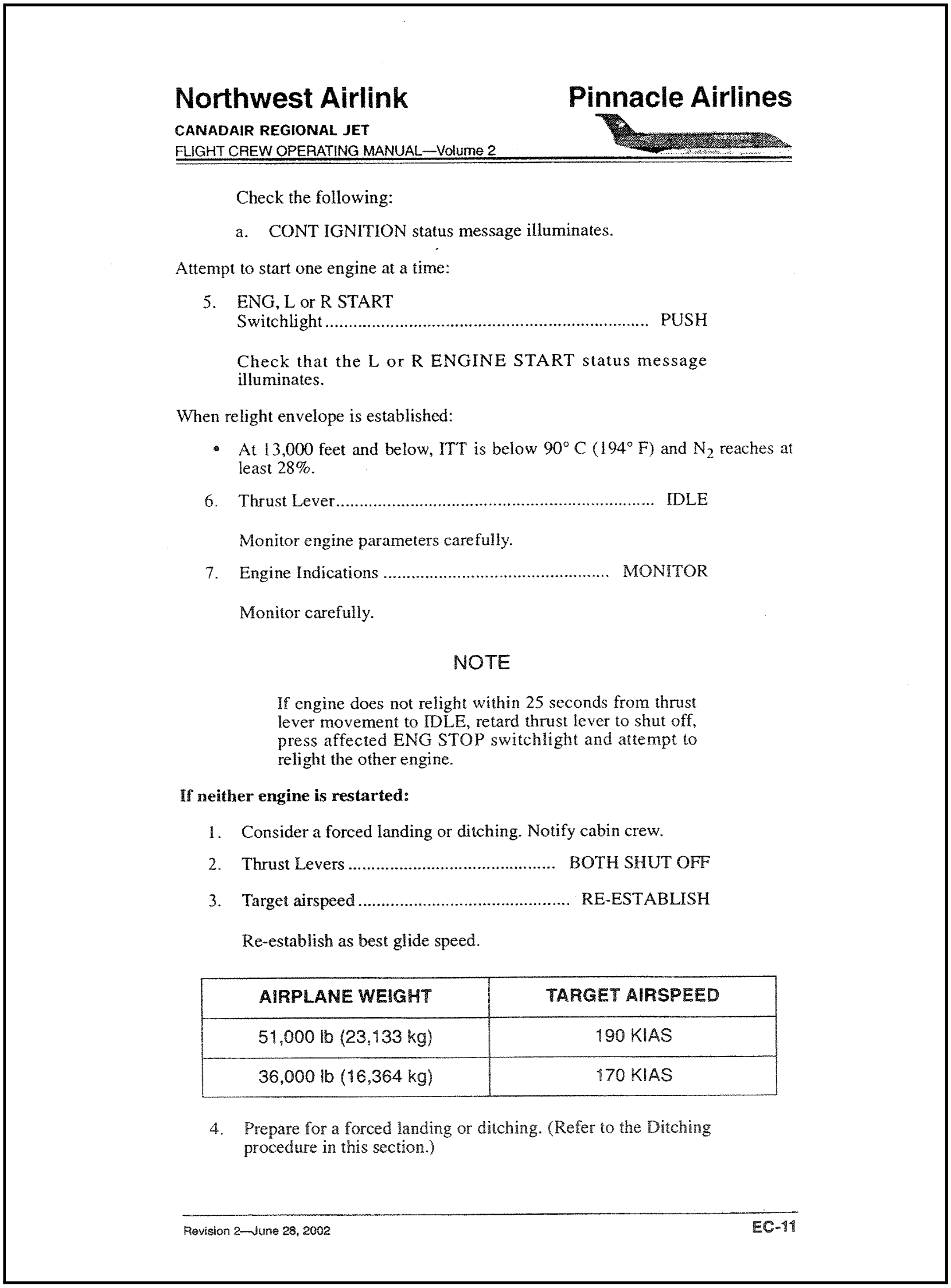
3. BLEED AIR, APU LCV
   Switchlight.. PRESS IN

   Press in to open the LCV.

   Check that the APU LCV OPEN status message illuminates.

4. IGNITION, CONT
   Switchlight... CHECK ON

EC-10 Revision 2—June 28, 2002



Northwest Airlink **Pinnacle Airlines**

CANADAIR REGIONAL JET
FLIGHT CREW OPERATING MANUAL—Volume 2

Check the following:

a. CONT IGNITION status message illuminates.

Attempt to start one engine at a time:

5. ENG, L or R START Switchlight .... PUSH

Check that the L or R ENGINE START status message illuminates.

When relight envelope is established:

- At 13,000 feet and below, ITT is below 90° C (194° F) and N_2 reaches at least 28%.

6. Thrust Lever .... IDLE

Monitor engine parameters carefully.

7. Engine Indications .... MONITOR

Monitor carefully.

NOTE

If engine does not relight within 25 seconds from thrust lever movement to IDLE, retard thrust lever to shut off, press affected ENG STOP switchlight and attempt to relight the other engine.

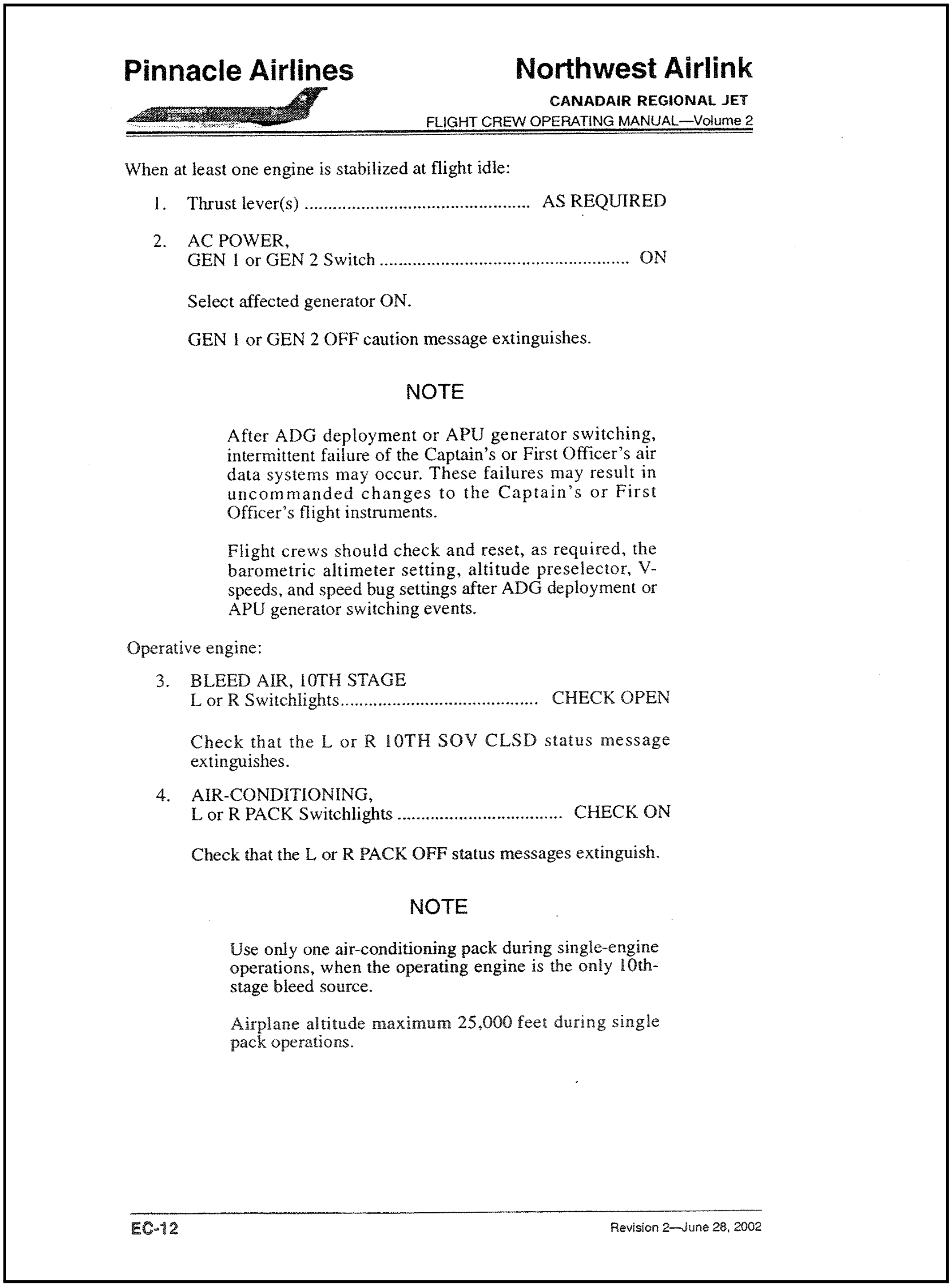
If neither engine is restarted:

1. Consider a forced landing or ditching. Notify cabin crew.
2. Thrust Levers .... BOTH SHUT OFF
3. Target airspeed .... RE-ESTABLISH

Re-establish as best glide speed.

AIRPLANE WEIGHT	TARGET AIRSPEED
51,000 lb (23,133 kg)	190 KIAS
36,000 lb (16,364 kg)	170 KIAS

4. Prepare for a forced landing or ditching. (Refer to the Ditching procedure in this section.)



When at least one engine is stabilized at flight idle:

1. Thrust lever(s) .... AS REQUIRED
2. AC POWER,
   GEN 1 or GEN 2 Switch .... ON

   Select affected generator ON.

   GEN 1 or GEN 2 OFF caution message extinguishes.

NOTE

After ADG deployment or APU generator switching, intermittent failure of the Captain's or First Officer's air data systems may occur. These failures may result in uncommanded changes to the Captain's or First Officer's flight instruments.

Flight crews should check and reset, as required, the barometric altimeter setting, altitude preselector, V-speeds, and speed bug settings after ADG deployment or APU generator switching events.

Operative engine:

3. BLEED AIR, 10TH STAGE
   L or R Switchlights.. CHECK OPEN

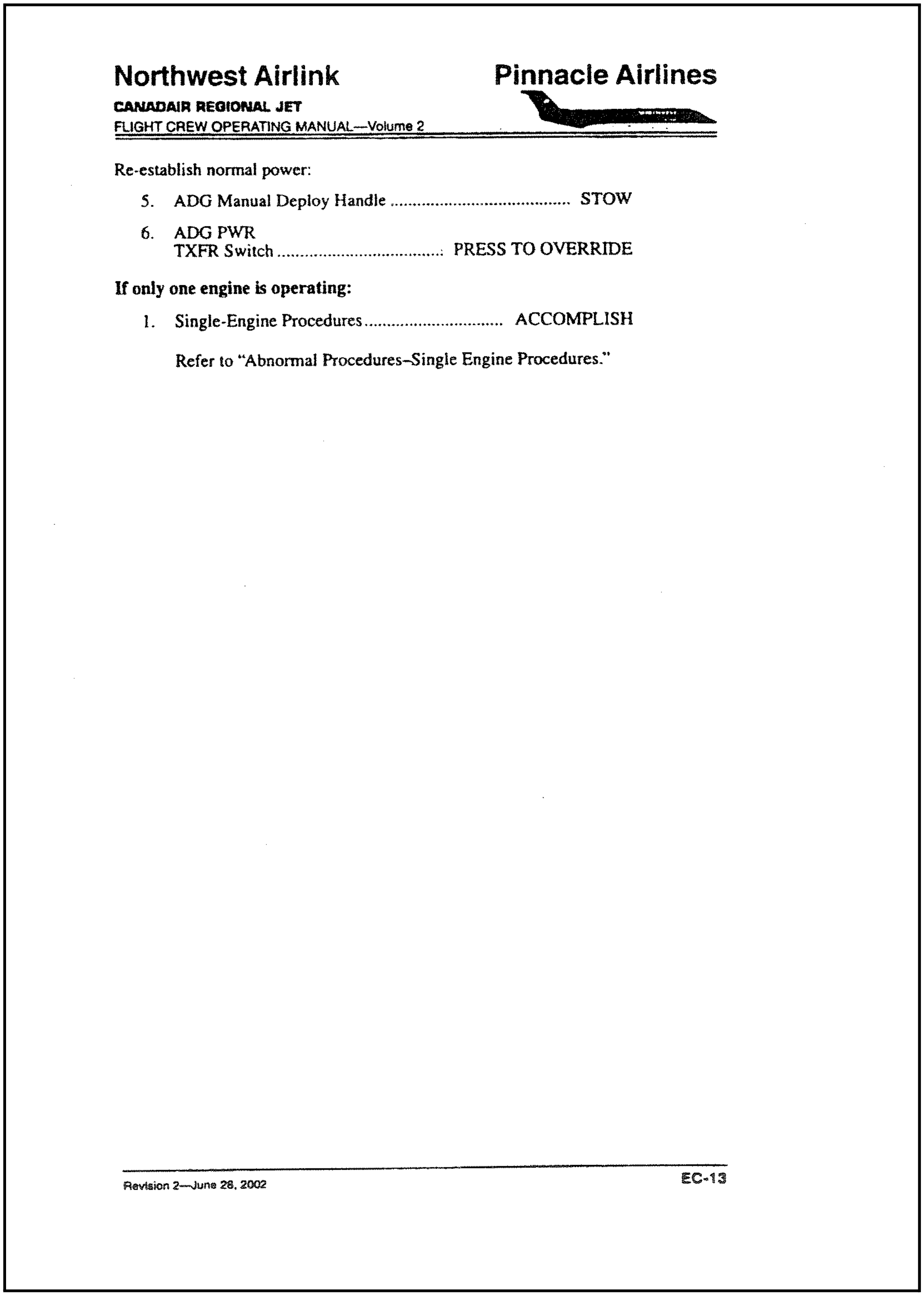
   Check that the L or R 10TH SOV CLSD status message extinguishes.
4. AIR-CONDITIONING,
   L or R PACK Switchlights .... CHECK ON

   Check that the L or R PACK OFF status messages extinguish.

NOTE

Use only one air-conditioning pack during single-engine operations, when the operating engine is the only 10th-stage bleed source.

Airplane altitude maximum 25,000 feet during single pack operations.



Re-establish normal power:

5. ADG Manual Deploy Handle .... STOW
6. ADG PWR
   TXFR Switch .... PRESS TO OVERRIDE

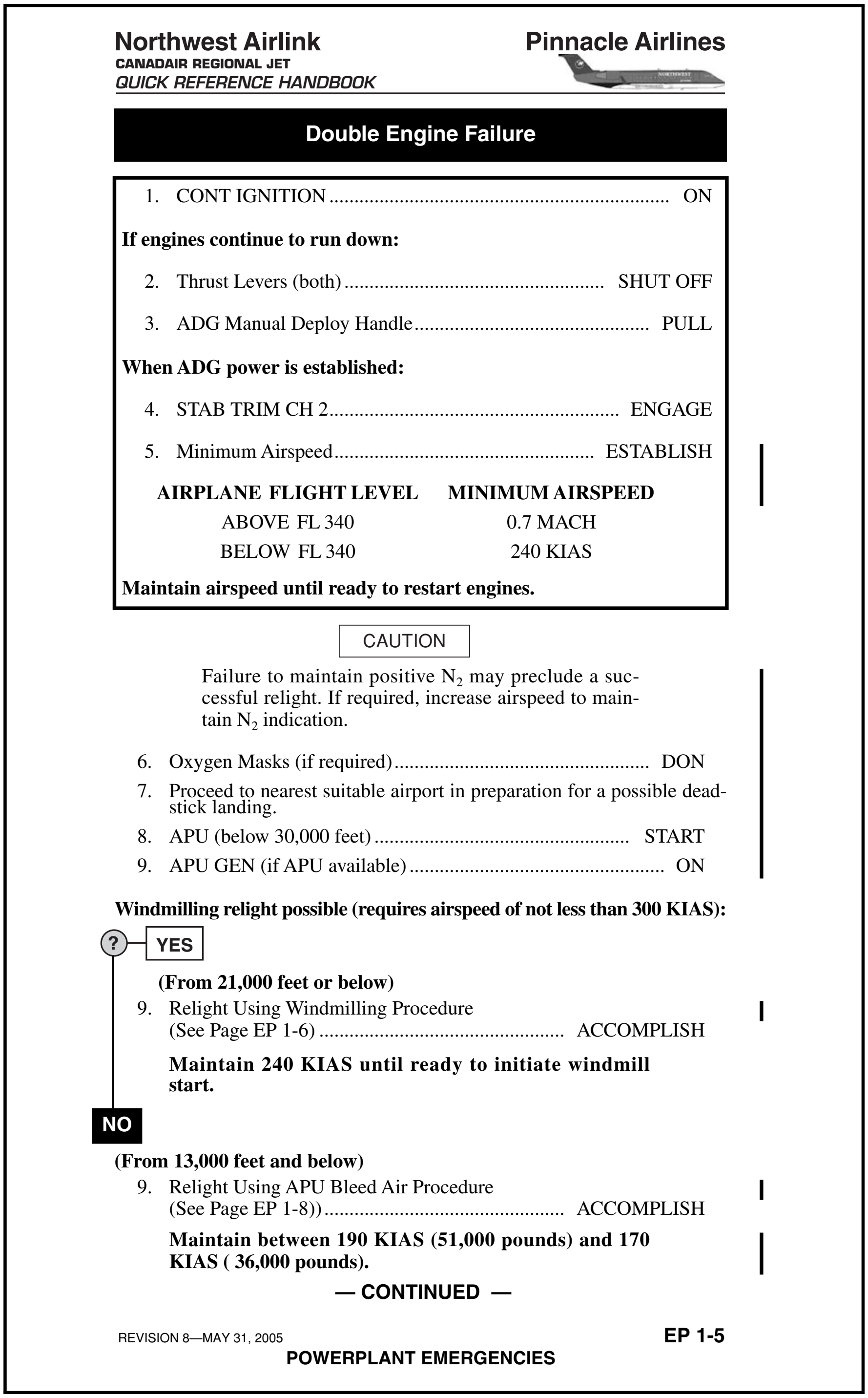
If only one engine is operating:

1. Single-Engine Procedures .... ACCOMPLISH

   Refer to "Abnormal Procedures–Single Engine Procedures."

Appendix D

Pinnacle Airlines' Revised Double Engine Failure Checklist



Northwest Airlink
CANADAIR REGIONAL JET
QUICK REFERENCE HANDBOOK

Pinnacle Airlines

Double Engine Failure

1. CONT IGNITION .... ON

If engines continue to run down:

2. Thrust Levers (both) .... SHUT OFF
3. ADG Manual Deploy Handle .... PULL

When ADG power is established:

4. STAB TRIM CH 2 .... ENGAGE
5. Minimum Airspeed .... ESTABLISH

AIRPLANE FLIGHT LEVEL	MINIMUM AIRSPEED
ABOVE FL 340	0.7 MACH
BELOW FL 340	240 KIAS

Maintain airspeed until ready to restart engines.

CAUTION

Failure to maintain positive N_2 may preclude a successful relight. If required, increase airspeed to maintain N_2 indication.

6. Oxygen Masks (if required) .... DON
7. Proceed to nearest suitable airport in preparation for a possible dead-stick landing.
8. APU (below 30,000 feet) .... START
9. APU GEN (if APU available) .... ON

Windmilling relight possible (requires airspeed of not less than 300 KIAS):

? YES

(From 21,000 feet or below)

9. Relight Using Windmilling Procedure
(See Page EP 1-6) .... ACCOMPLISH

Maintain 240 KIAS until ready to initiate windmill start.

NO

(From 13,000 feet and below)

9. Relight Using APU Bleed Air Procedure
(See Page EP 1-8)) .... ACCOMPLISH

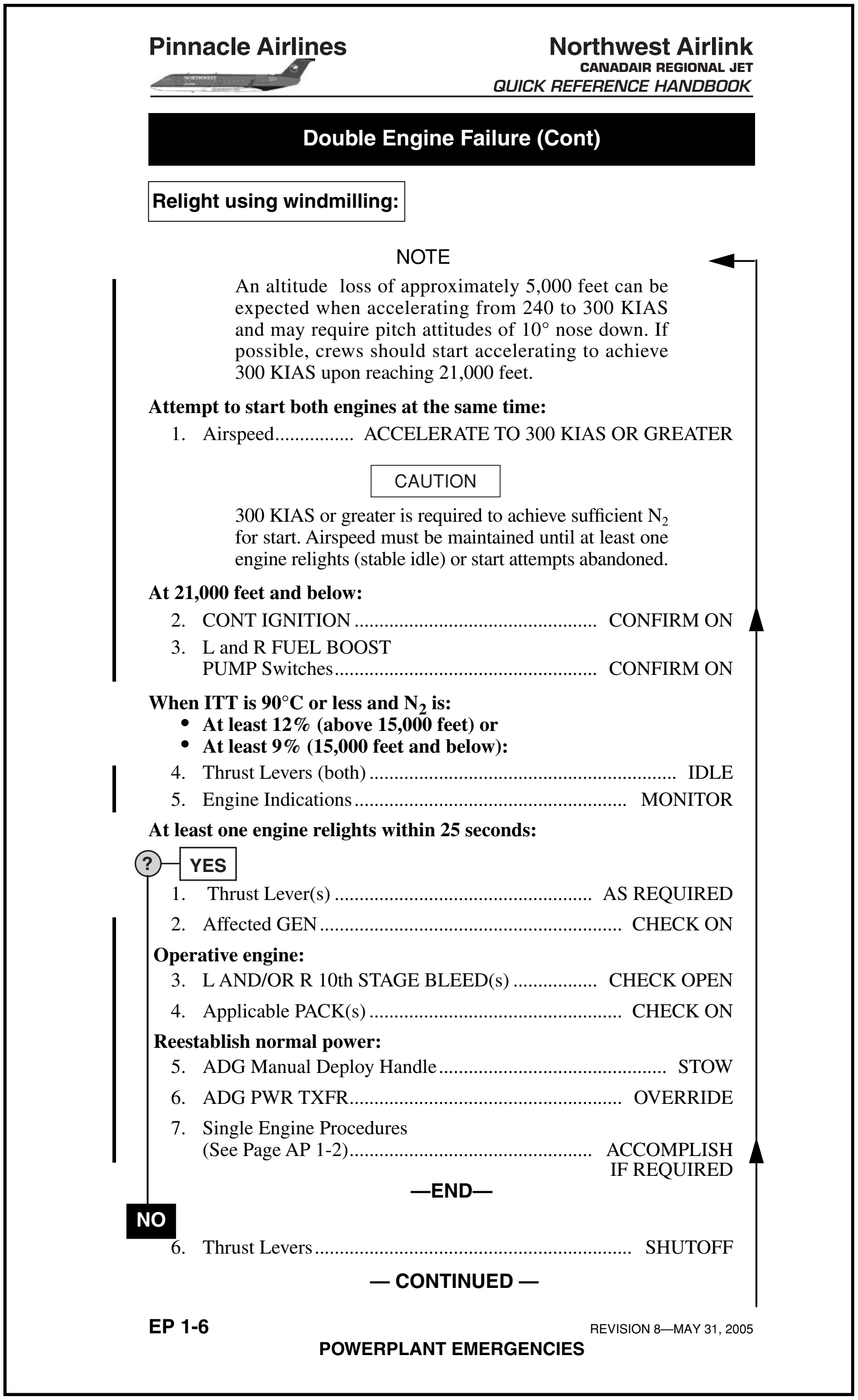
Maintain between 190 KIAS (51,000 pounds) and 170 KIAS (36,000 pounds).

— CONTINUED —

REVISION 8—MAY 31, 2005

EP 1-5

POWERPLANT EMERGENCIES



Pinnacle Airlines

Northwest Airlink
CANADAIR REGIONAL JET
QUICK REFERENCE HANDBOOK

Double Engine Failure (Cont)

Relight using windmilling:

NOTE

An altitude loss of approximately 5,000 feet can be expected when accelerating from 240 to 300 KIAS and may require pitch attitudes of 10° nose down. If possible, crews should start accelerating to achieve 300 KIAS upon reaching 21,000 feet.

Attempt to start both engines at the same time:

1. Airspeed................ ACCELERATE TO 300 KIAS OR GREATER

CAUTION

300 KIAS or greater is required to achieve sufficient N_2 for start. Airspeed must be maintained until at least one engine relights (stable idle) or start attempts abandoned.

At 21,000 feet and below:

2. CONT IGNITION .... CONFIRM ON
3. L and R FUEL BOOST
   PUMP Switches.. CONFIRM ON

When ITT is 90°C or less and N_2 is:

- **At least 12% (above 15,000 feet) or**
- **At least 9% (15,000 feet and below):**

4. Thrust Levers (both) .... IDLE
5. Engine Indications.. MONITOR

At least one engine relights within 25 seconds:

? **YES**

1. Thrust Lever(s) .... AS REQUIRED
2. Affected GEN... CHECK ON

Operative engine:

3. L AND/OR R 10th STAGE BLEED(s) .... CHECK OPEN
4. Applicable PACK(s) .... CHECK ON

Reestablish normal power:

5. ADG Manual Deploy Handle... STOW
6. ADG PWR TXFR.. OVERRIDE
7. Single Engine Procedures
   (See Page AP 1-2).. ACCOMPLISH IF REQUIRED

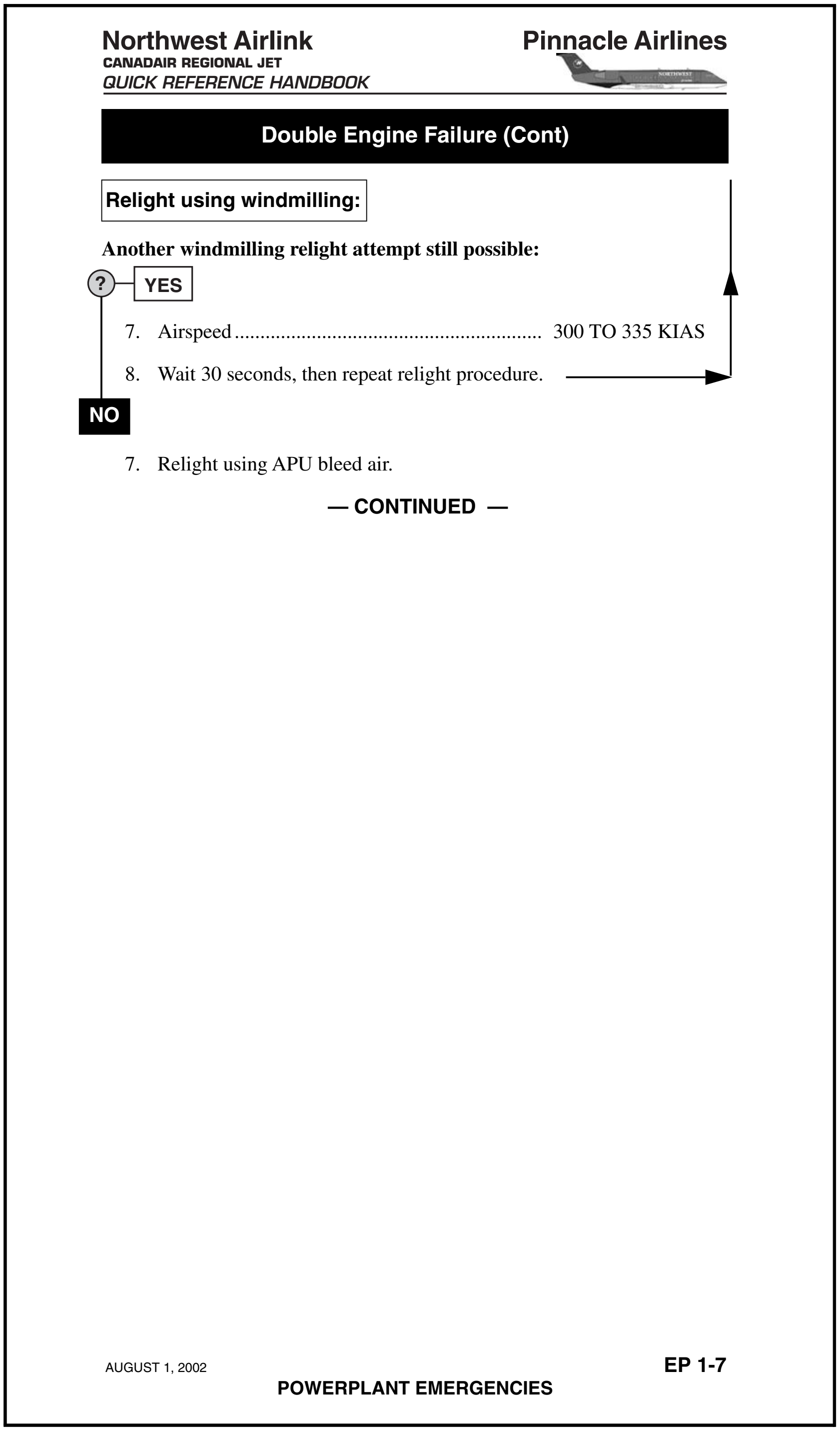
—END—

NO

6. Thrust Levers... SHUTOFF

— CONTINUED —

EP 1-6 REVISION 8—MAY 31, 2005
POWERPLANT EMERGENCIES



Northwest Airlink **Pinnacle Airlines**

CANADAIR REGIONAL JET

QUICK REFERENCE HANDBOOK

Double Engine Failure (Cont)

Relight using windmilling:

Another windmilling relight attempt still possible:

? — **YES**

7. Airspeed .... 300 TO 335 KIAS
8. Wait 30 seconds, then repeat relight procedure.

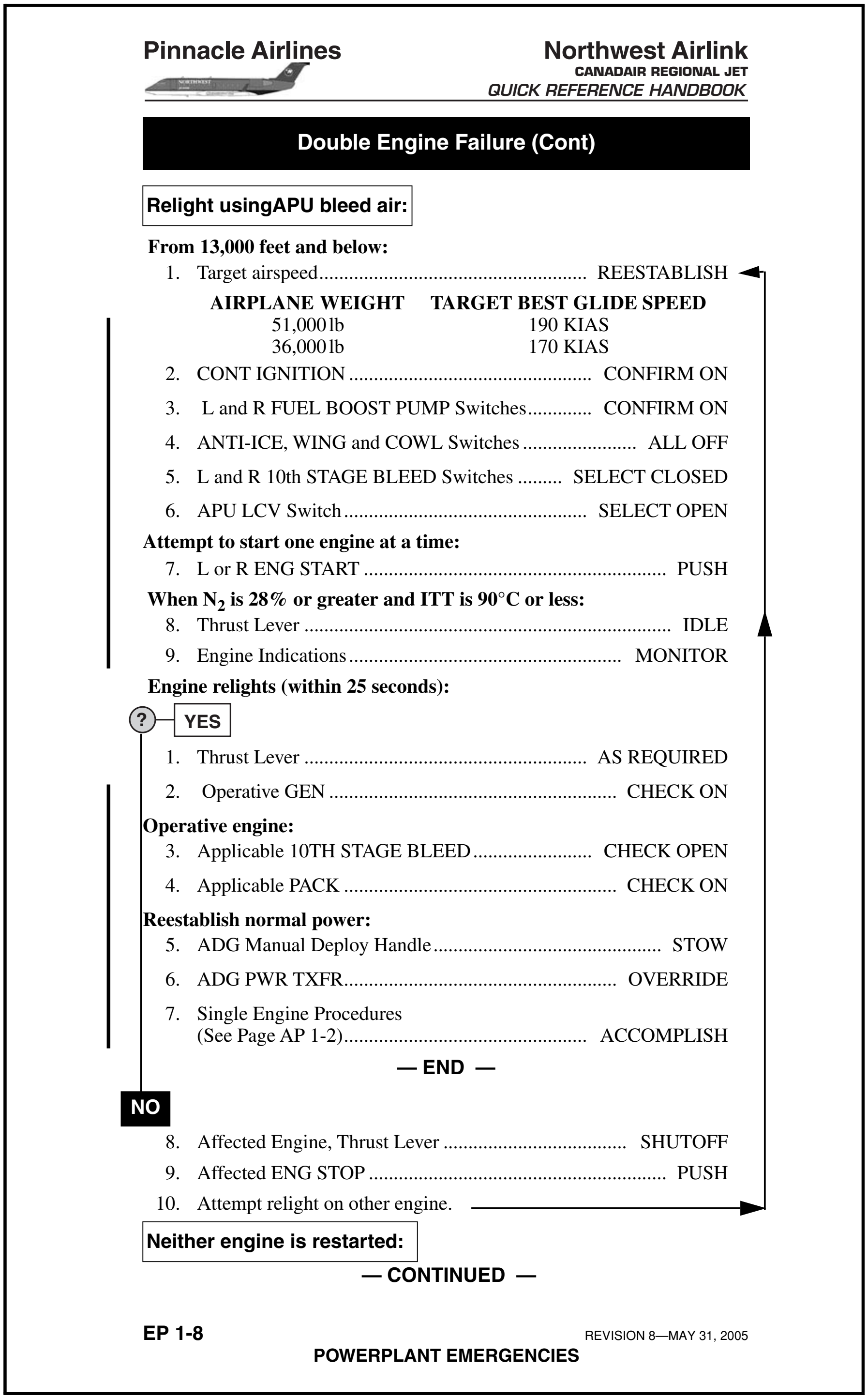
NO

7. Relight using APU bleed air.

— CONTINUED —

AUGUST 1, 2002 EP 1-7

POWERPLANT EMERGENCIES



Pinnacle Airlines **Northwest Airlink**

CANADAIR REGIONAL JET

QUICK REFERENCE HANDBOOK

Double Engine Failure (Cont)

Relight usingAPU bleed air:

From 13,000 feet and below:

1. Target airspeed ...... REESTABLISH

AIRPLANE WEIGHT	TARGET BEST GLIDE SPEED
51,000 lb	190 KIAS
36,000 lb	170 KIAS

2. CONT IGNITION ...... CONFIRM ON
3. L and R FUEL BOOST PUMP Switches ...... CONFIRM ON
4. ANTI-ICE, WING and COWL Switches ...... ALL OFF
5. L and R 10th STAGE BLEED Switches ...... SELECT CLOSED
6. APU LCV Switch ...... SELECT OPEN

Attempt to start one engine at a time:

7. L or R ENG START ...... PUSH

When N_2 is 28% or greater and ITT is 90°C or less:

8. Thrust Lever ...... IDLE
9. Engine Indications ...... MONITOR

Engine relights (within 25 seconds):

? **YES**

1. Thrust Lever ...... AS REQUIRED
2. Operative GEN ...... CHECK ON

Operative engine:

3. Applicable 10TH STAGE BLEED ...... CHECK OPEN
4. Applicable PACK ...... CHECK ON

Reestablish normal power:

5. ADG Manual Deploy Handle ...... STOW
6. ADG PWR TXFR ...... OVERRIDE
7. Single Engine Procedures
   (See Page AP 1-2) ...... ACCOMPLISH

— END —

NO

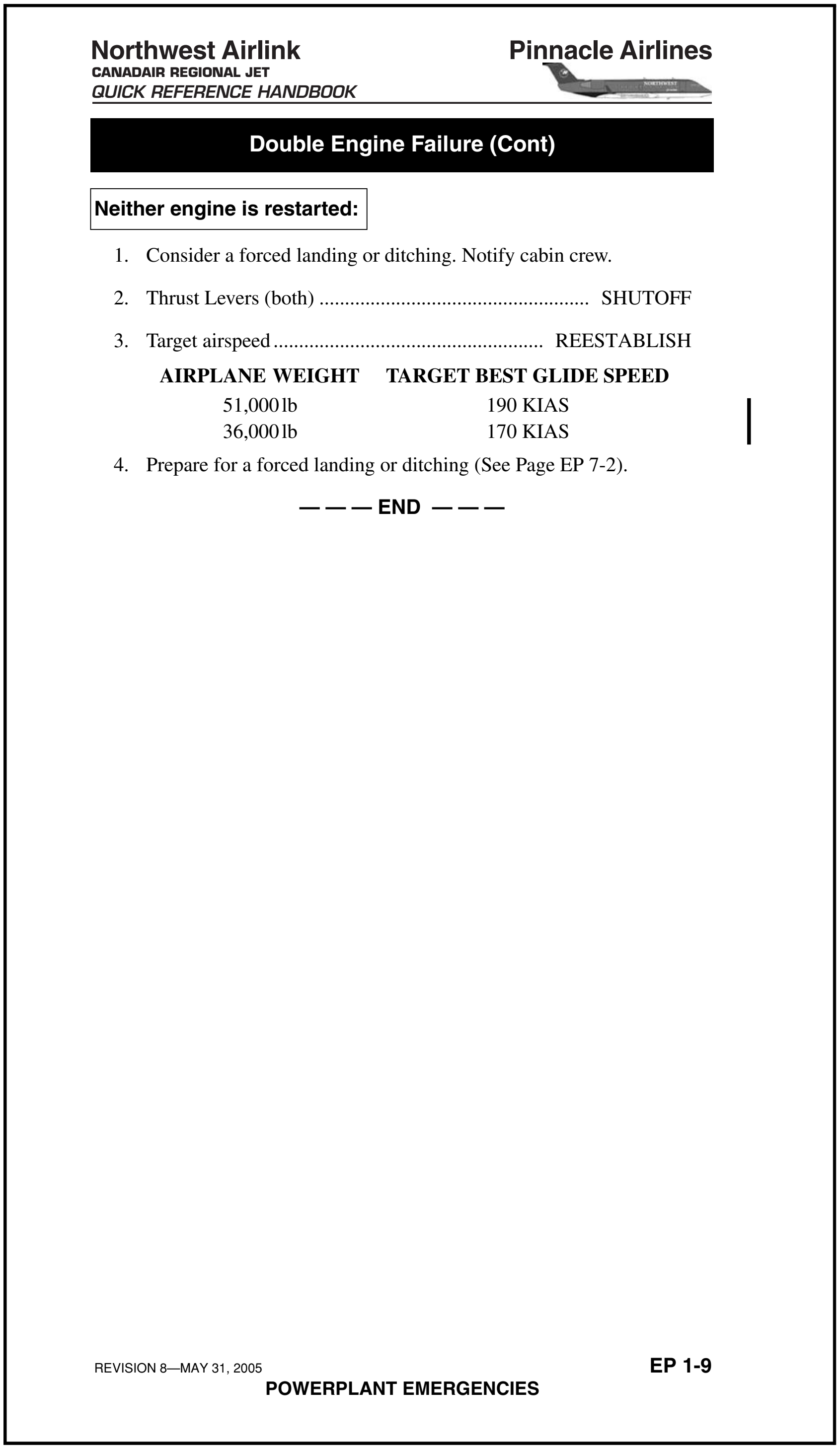
8. Affected Engine, Thrust Lever ...... SHUTOFF
9. Affected ENG STOP ...... PUSH
10. Attempt relight on other engine.

Neither engine is restarted:

— CONTINUED —

EP 1-8 REVISION 8—MAY 31, 2005

POWERPLANT EMERGENCIES



Northwest Airlink **Pinnacle Airlines**
CANADAIR REGIONAL JET
QUICK REFERENCE HANDBOOK

Double Engine Failure (Cont)

Neither engine is restarted:

1. Consider a forced landing or ditching. Notify cabin crew.
2. Thrust Levers (both) .... SHUTOFF
3. Target airspeed .... REESTABLISH

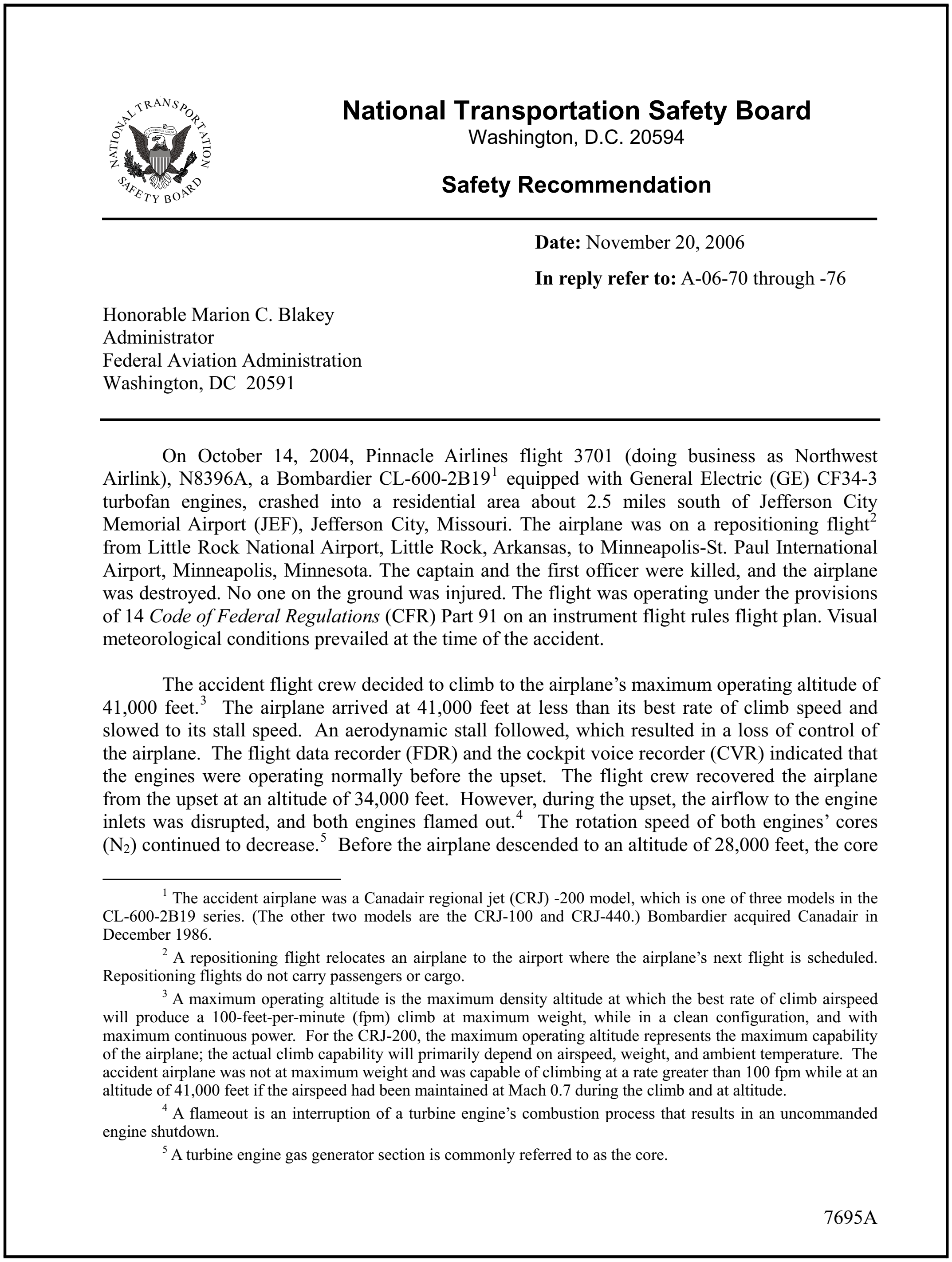
AIRPLANE WEIGHT	TARGET BEST GLIDE SPEED
51,000 lb	190 KIAS
36,000 lb	170 KIAS

4. Prepare for a forced landing or ditching (See Page EP 7-2).

— — — END — — —

REVISION 8—MAY 31, 2005 EP 1-9
POWERPLANT EMERGENCIES

Appendix E
Core Lock Safety Recommendation Letter



National Transportation Safety Board
Washington, D.C. 20594

Safety Recommendation

Date: November 20, 2006

In reply refer to: A-06-70 through -76

Honorable Marion C. Blakey
Administrator
Federal Aviation Administration
Washington, DC 20591

On October 14, 2004, Pinnacle Airlines flight 3701 (doing business as Northwest Airlink), N8396A, a Bombardier CL-600-2B19[1] equipped with General Electric (GE) CF34-3 turbofan engines, crashed into a residential area about 2.5 miles south of Jefferson City Memorial Airport (JEF), Jefferson City, Missouri. The airplane was on a repositioning flight[2] from Little Rock National Airport, Little Rock, Arkansas, to Minneapolis-St. Paul International Airport, Minneapolis, Minnesota. The captain and the first officer were killed, and the airplane was destroyed. No one on the ground was injured. The flight was operating under the provisions of 14 *Code of Federal Regulations* (CFR) Part 91 on an instrument flight rules flight plan. Visual meteorological conditions prevailed at the time of the accident.

The accident flight crew decided to climb to the airplane's maximum operating altitude of 41,000 feet.[3] The airplane arrived at 41,000 feet at less than its best rate of climb speed and slowed to its stall speed. An aerodynamic stall followed, which resulted in a loss of control of the airplane. The flight data recorder (FDR) and the cockpit voice recorder (CVR) indicated that the engines were operating normally before the upset. The flight crew recovered the airplane from the upset at an altitude of 34,000 feet. However, during the upset, the airflow to the engine inlets was disrupted, and both engines flamed out.[4] The rotation speed of both engines' cores (N_2) continued to decrease.[5] Before the airplane descended to an altitude of 28,000 feet, the core

---

[1] The accident airplane was a Canadair regional jet (CRJ) -200 model, which is one of three models in the CL-600-2B19 series. (The other two models are the CRJ-100 and CRJ-440.) Bombardier acquired Canadair in December 1986.

[2] A repositioning flight relocates an airplane to the airport where the airplane's next flight is scheduled. Repositioning flights do not carry passengers or cargo.

[3] A maximum operating altitude is the maximum density altitude at which the best rate of climb airspeed will produce a 100-feet-per-minute (fpm) climb at maximum weight, while in a clean configuration, and with maximum continuous power. For the CRJ-200, the maximum operating altitude represents the maximum capability of the airplane; the actual climb capability will primarily depend on airspeed, weight, and ambient temperature. The accident airplane was not at maximum weight and was capable of climbing at a rate greater than 100 fpm while at an altitude of 41,000 feet if the airspeed had been maintained at Mach 0.7 during the climb and at altitude.

[4] A flameout is an interruption of a turbine engine's combustion process that results in an uncommanded engine shutdown.

[5] A turbine engine gas generator section is commonly referred to as the core.

rotation speed of both engines had reached 0 indicated rpm. The flight crew attempted to restart the engines several times but was unable to do so. The flight crew then attempted to make an emergency landing at JEF, but the airplane crashed before reaching the airport.[6]

This accident is still under investigation, and the National Transportation Safety Board has not yet determined the probable cause of the accident. Nonetheless, the investigation has revealed a safety issue regarding a condition that can preclude pilots from restarting an engine after a double engine failure.

Restart Attempts for Accident Engines

Pinnacle Airlines' double engine failure checklist at the time of the accident indicated that pilots were to maintain a target airspeed of 240 knots.[7] The purpose of maintaining this airspeed was to keep the engine cores rotating at an appropriate speed for either a windmill restart[8] or an auxiliary power unit (APU)-assisted restart.[9] FDR data and the CVR recording showed that the flight crew did not accelerate the airplane after the upset and that the engine core rotation slowed to 0 indicated rpm. FDR data also showed that the crew did not achieve the 240-knot airspeed before or after attempting to restart the engines.

The flight crew first attempted to restart the engines using the windmill restart procedure. A windmill restart requires accelerating the airplane to an airspeed of at least 300 knots to increase the core rotation speed before the attempted restart. FDR data showed that the crew did not achieve the 300-knot airspeed (the maximum airspeed recorded by the FDR was 236 knots) and that the engine cores remained at 0 indicated rpm during the restart attempt. The CVR recording indicated that the flight crewmembers then elected to descend to an altitude of 13,000 feet so that they could attempt to restart the engines using the APU-assisted restart procedure, which requires slowing the airplane to 170 or 190 knots (depending on the airplane's weight) before initiating the restart. Once the airplane descended to an altitude of 13,000 feet, the flight crew attempted four APU-assisted engine restarts (two attempts per engine), but FDR data showed that the engine cores still remained at 0 indicated rpm.

The accident airplane's APU and start system components were found mostly intact at the accident scene. Examination and testing of these components found nothing that would have prevented adequate torque from being delivered to the engines for the restart attempts. Engine disassembly inspections found no mechanical failures or evidence of any condition that would have prevented engine core rotation. Although the inspections disclosed thermal damage in the No. 2 engine that would have impeded the engine's ability to produce thrust, this damage would not have prevented core rotation during an attempted restart.[10]

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[6] For more information about this accident, see DCA05MA003 at the Safety Board's Web site at <http://www.ntsb.gov>.

[7] All airspeeds cited in this letter are knots indicated airspeed.

[8] A windmill restart is an emergency in-flight procedure in which the effect of ram airflow passing through the engine as the airplane moves through the air provides rotational energy to turn the core.

[9] Pinnacle Airlines' double engine failure checklist indicated that the windmill restart procedure was to be used at altitudes from 21,000 to 13,000 feet and that the APU-assisted restart procedure was to be used at altitudes of 13,000 feet and below.

[10] The inspections found no preimpact damage to the No. 1 engine.

Manufacturer's Core Lock Screening Procedure

During the accident investigation, the Safety Board learned that GE CF34-1 and CF34-3 engines[11] had a history of failing to rotate during in-flight restart attempts on airplanes undergoing production acceptance flight testing at Bombardier. The manufacturers referred to this condition as "core lock." Bombardier first identified this problem in 1983 during Challenger certification tests, and GE attributed the problem to interference contact at a high pressure turbine (HPT) air seal.

The CF34 HPT air seals are designed to control cooling and balance airflow. The seals include teeth on the rotating components that grind operating grooves into abradable surfaces on the stationary components. The efficiency of these seals significantly affects engine performance, so the seals are designed to operate with minimal clearances.

Bombardier added a procedure to the production acceptance flight tests for its CF34-1- and CF34-3-powered airplanes to screen engines for the potential to experience core lock. At the time of the accident, this screening procedure was as follows:

1. Climb to flight level 310.
2. Retard the test engine throttle to idle and stabilize for 5 minutes.
3. Shut down the test engine.
4. Descend at 190 knots.
5. Slow the aircraft until N_2 is reduced to 0 percent.
6. At 8 1/2 minutes from shutdown, push over to 320 knots.
7. If N_2 is 0 rpm at flight level 210, the engine is declared to be core locked.

Engines that are found to be core locked are reworked using an in-flight "grind-in" procedure that was designed to remove seal material at the interference location.[12] Engines that undergo grind-in rework are then rescreened for core lock. The grind-in procedure, which includes a cross-bleed start for the core locked engine, is as follows:

1. Air turbine starter cross-bleed start.
2. Ascend to flight level 310.
3. Repeat core lock screening procedure but descend at an airspeed of about 240 knots to establish 4 percent N_2.
4. Maintain 4 percent N_2 for at least 8 1/2 minutes.
5. Confirm that no core lock exists by repeating screening procedure.

As testimony during the Safety Board's June 2005 public hearing on the Pinnacle Airlines accident indicated, neither Bombardier nor GE considered core lock to be a safety-of-flight issue. The manufacturers claimed that engines that passed the screening procedure, with or without grind-in rework, would not core lock as long as the 240-knot airspeed was maintained.

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[11] Bombardier airplanes that are powered by either GE CF34-1 or CF34-3 engine models are the Challenger 601, Challenger 604, CRJ-100, CRJ-200, and CRJ-440.

[12] Newly manufactured engines undergo a test cell seal grind-in before delivery.

Turbine Engine Shutdowns

The operating temperatures in parts of the HPT reach more than 2,000° Fahrenheit. After a turbine engine has been operating, its rotating and stationary components have expanded to their normal operating dimensions and clearances. When an engine is shut down, its rotating and stationary components do not contract at the same rates because of differences in their material properties and their exposure to cooling air. Temporary losses of clearance between the rotating and stationary components and misalignment between the rotating teeth and stationary grooves of the air seal occur until the temperatures of the components reach equilibrium. Because of this characteristic, turbine engine shutdown procedures include operation for several minutes at a lower power setting to permit internal temperatures and clearances to stabilize. Engines that flame out suddenly in flight experience more severe thermal changes that may result in losses of clearance so that the rotating and stationary components rub or bind.

More importantly, flameouts at high power and high altitude conditions produce even greater thermal distress because internal temperatures are the hottest at high power settings and the air is colder at high altitudes. The increased thermal shock exacerbates the loss of component clearance and alignment. Because the accident engines flamed out under these conditions, axial misalignment caused the seal teeth, which were positioned aft of their normal grooves, to contact stationary abradable material when radial seal clearances closed down. Once core rotation stopped, binding prevented core rotation from resuming during the windmill or APU-assisted restart attempts. Thus, the lack of core rotation on the accident airplane engines could be explained by the core lock phenomenon.

Potential for Core Lock in CF34-1 and CF34-3 Engines

Bombardier's core lock screening procedure requires a cool-down period before engine shutdown to stabilize internal temperatures and clearances.[13] However, as previously discussed, this procedure does not produce the more severe thermal distress associated with the high power, high altitude flameouts that occurred during the accident flight. Thus, the successful demonstration of Bombardier's production flight test procedure may not ensure that an engine will not experience core lock if the core is allowed to stop rotating after a high power, high altitude flameout. In fact, the Safety Board notes that the No. 1 accident engine had successfully passed the screening procedure during initial production acceptance testing.[14] Also, the successful demonstration of Bombardier's production flight test procedure may not ensure that slowing the airplane to an airspeed of 170 to 190 knots is sufficient to maintain core rotation during an attempted APU-assisted restart.

During the public hearing for the Pinnacle Airlines accident, a GE manager testified, "As long as core rotation is maintained, you will not have core lock … we have a body of data

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[13] After the accident, Transport Canada mandated that Bombardier change the engine stabilization time from 5 to 2 minutes.

[14] The No. 2 accident engine was installed new as a spare engine and was not subject to the the core lock screening procedure because it applies only to engines that are installed in Bombardier's production airplanes.

that shows that 240 knots maintains core rotation."[15] This testimony suggests that the most effective way to mitigate the safety risk of core lock during in-flight restarts is to use an operational procedure to keep an engine's core rotating until a restart can be attempted. The Safety Board is unaware of flight test data that demonstrate that 240 knots is sufficient to keep the core rotating after the more severe thermal distress associated with a high power, high altitude flameout. Thus, the Board is concerned that sufficient testing and engineering analysis have not been performed to demonstrate whether the 240-knot airspeed is effective in maintaining core rotation and preventing core lock after high power, high altitude flameouts.

The Safety Board concludes that it is critical to identify the airspeed needed to maintain core rotation in CF34-1 and CF34-3 engines after high power, high altitude flameouts and to ensure that restart procedures can be accomplished under such conditions. Therefore, the Safety Board believes that, for airplanes equipped with CF34-1 or CF34-3 engines, the Federal Aviation Administration (FAA) should require manufacturers to perform high power, high altitude sudden engine shutdowns; determine the minimum airspeed required to maintain sufficient core rotation; and demonstrate that all methods of in-flight restart can be accomplished when this airspeed is maintained.[16]

The importance of maintaining a minimum airspeed to keep the engine cores rotating was not communicated to pilots in airplane flight manuals (AFM). For example, at the time of the accident, Bombardier's and Pinnacle Airlines' double engine failure checklists stated that 240 knots was the "target" airspeed for the procedure but did not indicate that this airspeed was essential to the success of the restart procedure. As a result of the accident, Bombardier and Pinnacle Airlines revised their double engine failure checklists to indicate that 240 knots was the "minimum" airspeed and that the failure to maintain positive core rotation might prevent a successful restart.

The Safety Board concludes that it is important for pilots to be aware of the possibility of core lock and the specific actions that are needed to preclude this condition. Therefore, the Safety Board believes that the FAA should ensure that AFMs of airplanes equipped with CF34-1 or CF34-3 engines clearly state the minimum airspeed required for engine core rotation and that, if this airspeed is not maintained after a high power, high altitude sudden engine shutdown, a loss of in-flight restart capability as a result of core lock may occur.

Performance Penalties for CRJ-100, -200 and -440 Airplanes

The 240-knot airspeed included in Bombardier's and Pinnacle Airlines' double engine failure checklists is 70 knots greater than the airplane's best glide speed[17] (at an airplane weight of 36,000 pounds) of 170 knots. To maintain the 240-knot airspeed with no engine power and

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[15] The GE manager further testified that the 240-knot airspeed also served to maintain a minimal hydraulic pressure.

[16] The Safety Board notes that Bombardier Aerospace and Transport Canada have performed high altitude, high power engine shutdowns to verify the 240-knot target airspeed included in Bombardier's double engine failure checklist. The APU-assisted in-flight restart process has not yet been verified.

[17] An airplane's best glide speed provides the airplane with the most distance forward for a given loss of altitude.

transition to a 300-knot airspeed for a windmill restart, a flight crew must significantly increase the airplane's descent rate, thereby reducing the range of available landing locations if a forced (emergency) landing were to become necessary as a result of a failure to restart at least one engine. Because of the effect that this loss of glide range could have on a flight crew's ability to find a viable emergency landing site, the Safety Board concludes that CRJ-100, -200, and -440 pilots must be fully aware of the performance penalties that can be incurred while maintaining core rotation and attempting a windmill restart. Therefore, the Safety Board believes that the FAA should require that operators of CRJ-100, -200, and -440 airplanes include in AFMs the significant performance penalties, such as loss of glide distance and increased descent rate, that can be incurred from maintaining the minimum airspeed required for core rotation and windmill restart attempts.

Potential for Core Lock in Other Engine Models

Turbine-powered airplanes other than the Challenger 601 and 604 and the CRJ-100, -200, and -440 have turbine engine components with a similar physical design as those for the CF34-1 and CF34-3 engines. As a result, the Safety Board concludes that other turbine engines may also be susceptible to core lock after high power, high altitude flameouts. Therefore, the Safety Board believes that the FAA should review the design of turbine-powered engines (other than the CF34-1 and CF34-3, which are addressed in Safety Recommendation A-06-70) to determine whether they are susceptible to core lock and, for those engines so identified, require manufacturers of airplanes equipped with these engines to perform high power, high altitude sudden engine shutdowns and determine the minimum airspeed to maintain sufficient core rotation so that all methods of in-flight restart can be accomplished. Further, the Safety Board believes that, for those airplanes with engines that are found to be susceptible to core lock (other than the CF34-1 and CF34-3, which are addressed in Safety Recommendation A-06-71), the FAA should require airplane manufacturers to incorporate information into AFMs that clearly states the potential for core lock; the procedures, including the minimum airspeed required, to prevent this condition from occurring after a sudden engine shutdown; and the resulting loss of in-flight restart capability if this condition were to occur. In addition, the Safety Board believes that the FAA should require manufacturers to determine, as part of 14 CFR Part 25 certification tests, if restart capability exists from a core rotation speed of 0 indicated rpm after high power, high altitude sudden engine shutdowns. For those airplanes determined to be susceptible to core lock, the FAA should mitigate the hazard by providing design or operational means to ensure restart capability.

Windmill Restart Requirements

Airplane manufacturers rely on the windmill method as the primary means of restart after an all-engine flameout event. Consequently, the portion of the flight envelope in which a windmill restart is effective is critical to flight safety. However, increases in the bypass ratios of turbofan engines over the years have significantly reduced the windmill restart portion of the in-flight restart envelope. Specifically, the engines powering many current transport-category airplanes bypass between 80 and 90 percent of the airflow entering the inlet around the engine core, so as little as 10 percent of the inlet air enters the core during normal operation. Thus, the cores of high bypass ratio engines, such as the CF34,[18] require significantly higher airspeeds to achieve windmill restart than the cores of low bypass engines installed on older generation airplanes.

After an all-engine high power flameout, pilots need to sacrifice a substantial amount of altitude to achieve the higher airspeeds that are necessary for a windmill restart with high bypass engines. However, depending on the altitude where the shutdown occurred, a pilot may not have enough altitude available to use this restart option.

Certification requirements currently address the minimum airspeed needed to ensure windmill restart capability. However, there is no upper limit on the value of the minimum airspeed required for a windmill restart and no limit on the amount of altitude loss that can occur during a windmill restart. If the minimum airspeed value is too high, an excessive amount of altitude loss may be needed to accomplish a windmill restart. In September 1999, the FAA issued a notice of availability and request for comments on a proposed Propulsion Mega Advisory Circular,[19] which addressed this and other engine certification-related issues, but the FAA has taken no subsequent action.

The Safety Board concludes that, during design, airplane manufacturers must consider that a pilot's ability to restart high bypass turbine engines after an all-engine flameout might be compromised if an excessive airspeed or an excessive amount of altitude loss were needed for the restart. Therefore, the Safety Board believes that the FAA should establish certification requirements that would place upper limits on the value of the minimum airspeed required and the amount of altitude loss permitted for windmill restarts.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> For airplanes equipped with CF34-1 or CF34-3 engines, require manufacturers to perform high power, high altitude sudden engine shutdowns; determine the minimum airspeed required to maintain sufficient core rotation; and demonstrate that all methods of in-flight restart can be accomplished when this airspeed is maintained. (A-06-70)
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> Ensure that airplane flight manuals of airplanes equipped with CF34-1 or CF34-3 engines clearly state the minimum airspeed required for engine core rotation and that, if this airspeed is not maintained after a high power, high altitude sudden engine shutdown, a loss of in-flight restart capability as a result of core lock may occur. (A-06-71)
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> Require that operators of CRJ-100, -200, and -440 airplanes include in airplane flight manuals the significant performance penalties, such as loss of glide distance and increased descent rate, that can be incurred from maintaining the minimum airspeed required for core rotation and windmill restart attempts. (A-06-72)

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[18] The CF34 engine bypasses about 85 percent of inlet air past the core.

[19] For more information, see 64 *Federal Register* 52819, September 30, 1999.

Review the design of turbine-powered engines (other than the CF34-1 and CF34-3, which are addressed in Safety Recommendation A-06-70) to determine whether they are susceptible to core lock and, for those engines so identified, require manufacturers of airplanes equipped with these engines to perform high power, high altitude sudden engine shutdowns and determine the minimum airspeed to maintain sufficient core rotation so that all methods of in-flight restart can be accomplished. (A-06-73)

For those airplanes with engines that are found to be susceptible to core lock (other than the CF34-1 and CF34-3, which are addressed in Safety Recommendation A-06-71), require airplane manufacturers to incorporate information into airplane flight manuals that clearly states the potential for core lock; the procedures, including the minimum airspeed required, to prevent this condition from occurring after a sudden engine shutdown; and the resulting loss of in-flight restart capability if this condition were to occur. (A-06-74)

Require manufacturers to determine, as part of 14 *Code of Federal Regulations* Part 25 certification tests, if restart capability exists from a core rotation speed of 0 indicated rpm after high power, high altitude sudden engine shutdowns. For those airplanes determined to be susceptible to core lock, mitigate the hazard by providing design or operational means to ensure restart capability. (A-06-75)

Establish certification requirements that would place upper limits on the value of the minimum airspeed required and the amount of altitude loss permitted for windmill restarts. (A-06-76)

Chairman ROSENKER, Vice Chairman SUMWALT, and Members HERSMAN and HIGGINS concurred with these recommendations.

[*Original Signed*]

By: Mark V. Rosenker
Chairman