**SUBMISSION OF THE**

**AIR LINE PILOTS ASSOCIATION**

**TO THE**

**NATIONAL TRANSPORTATION SAFETY BOARD**

**REGARDING THE ACCIDENT INVOLVING**

# Pinnacle Airlines Flight 3701
## CRJ-200

**Jefferson City, MO**
**October 14, 2004**

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## Executive Summary

On October 14, 2004, at 10:13 pm central daylight time (October 15, 2004, 03:15 Universal Coordinated Time), a Bombardier Canadair Regional Jet (CRJ-200), operated by Pinnacle Airlines crashed into a residential area in Jefferson City, Missouri, after declaring an emergency due to engine problems. The airplane was destroyed. The only occupants on board the airplane were the two pilots, and both were fatally injured. There were no injuries to persons on the ground.

This accident was the result of a series of latent failures on the parts of the airline, the airplane and engine manufacturers, and the certificating agencies, and active failures of flight crew. This flight crew made mistakes, but other, systemic failures enabled what should have been a recoverable event to become a fatal accident.

The positioning flight departed from Little Rock, Arkansas, for Minneapolis, Minnesota. Although the flight plan altitude was FL 330, the crew opted to climb to FL 410, the airplane's maximum certificated operating altitude. During the last several thousand feet of the climb to FL 410, the airplane was operated in a constant vertical speed ('rate') mode which resulted in a continuous airspeed decay. At FL 410 level-off, the airplane continued its deceleration, and the crew requested a lower altitude from ATC. Before ATC was able to clear the flight to descend, the stick shaker and pusher activated. The airplane entered a series of diverging pitch oscillations and departed controlled flight. The oscillations and departure from controlled flight caused both engines to flame out. At approximately FL 340 the crew re-established controlled flight, but they were never able to restart either engine. The crew did not decide to divert to an alternate airport in a timely manner. Once the decision to divert was made, the moonless night and 4400'ceiling contributed to the crew's difficulty in locating either the diversion airport or a satisfactory off-airport landing site.

This investigation revealed that an engine characteristic referred to as 'core lock' contributed to this accident. As revealed by this accident, core lock can preclude a timely in-flight restart, yet there is no evidence to indicate that those who need this information the most, the CRJ operators and flight crews, knew anything about this phenomenon. Furthermore, the airframe manufacturer and the certificating agencies failed to ensure that the operators and flight crews were provided with clear and effective emergency procedures that would prevent a CRJ from experiencing this phenomenon.

The safety issues identified during this investigation include CF-34 engine core lock, Pinnacle flight crew training deficiencies, design of the CRJ dual engine failure checklist, and CRJ simulator fidelity.

**1.0 Sequence of Events**

On October 15, 2004, 03:15 Universal Coordinated Time[1] (UTC) [October 14, 2004, 10:13 pm central daylight time], a Bombardier Canadair Regional Jet (CRJ-200), registration number N8396A, operating as Pinnacle Airlines flight 3701, crashed into a residential area in Jefferson City, Missouri, after declaring an emergency due to engine problems. The airplane was destroyed. The only occupants on board the airplane were the two pilots, and both were fatally injured. There were no injuries to persons on the ground.

The accident flight was a non-revenue positioning flight from Little Rock, AR (LIT) to Minneapolis-St. Paul, MN (MSP) to return the airplane to revenue service subsequent to maintenance on the right engine fire detection system earlier that day. The two flight crew members were notified at about 22:00 on October 14 to deadhead from their base in Detroit to LIT to retrieve the airplane.

On departure from LIT, the crew performed some non-standard maneuvers during the takeoff and in the climb. Although the flight plan altitude was FL 330[2], the crew requested and was cleared by Air Traffic Control (ATC) to FL 410, the airplane's maximum certificated operating altitude. However, the crew did not advise dispatch (System Operations Control (SOC)) as required by the Pinnacle Flight Operations Manual (FOM). Cockpit voice recorder (CVR) and flight data recorder (FDR) information is consistent with the two crew members exchanging seats between 02:24:18 - 02:26:43, beginning after the airplane had climbed through 7,700.'

The factual information indicates that from FL 365 to FL 410, the airplane was operated in a constant vertical speed ('rate') mode instead of the constant airspeed ('speed') mode. Climbing in the rate mode resulted in a slow but continuous airspeed decay, and at some point the airplane got slower than the lowest recommended climb speed. At level-off, the airplane had insufficient thrust to accelerate, and it continued to decelerate. The crew noted this continuing speed decay and requested a lower altitude from ATC. Their discussions and actions indicate that neither pilot was alarmed by the situation. Before ATC was able to clear the flight to descend, both the stick shaker and pusher activated. The airplane entered a series of diverging pitch oscillations and departed controlled flight. Just subsequent to this, both engines failed, probably as a result of the inlet flow disruptions.

Loss of both engines caused the airplane to rely on the battery and the air driven generator (ADG) for power. The CVR remained operative, as did the ATC transponder. However, by design, the FDR did not remain powered. Analysis of ATC radar data indicates that following about 25 seconds of uncontrolled flight, the airplane returned to controlled flight at approximately FL 340. Once the crew regained airplane control, they began the auxiliary power unit (APU) start process, and the APU was operating by FL 290. At this point the FDR came back on line, leaving a period of just over four minutes without any FDR data.

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[1] Unless otherwise noted, all times are UTC.
[2] Unless otherwise noted, all altitudes are MSL below 18000, and Flight Levels at and above 18000.

Initially the crew did not clearly advise ATC of the dual-engine-out nature of their emergency, implying that only one engine was inoperative. It was not until 03:09:06, when they were at an altitude of approximately 10,000', that the crew explicitly notified ATC that they had a dual engine failure.

There are three air-start modes for an engine on the CRJ; windmilling, APU-assisted, and cross-bleed. If neither engine is operating, the cross-bleed mode is not available. The windmill start envelope is FL210 and below, while the auxiliary power unit (APU)-assisted start envelope is 13,000' and below. The airspeeds associated with these two methods are also different. The minimum windmill speed is 300 knots, while the APU-assisted start range is from 0 to 300 knots.

After the upset, once the APU was running, the crew began to perform the windmill start checklist. At approximately FL 230 and 5 ½ minutes after regaining controlled flight, the crew began pitching over to accelerate to 300 knots for the windmill start. However, they aborted this attempt at about 240 knots. CVR information indicates that the Captain had consulted the appropriate checklist and, considering the extremely rapid descent and lack of any N2, decided to perform the APU-assisted start once they reached the top of that start envelope (13,000'). FDR data shows that at 235 knots, the descent rate was about 4,000 fpm, while at 170 knots, the descent rate was approximately 2,000 fpm. From the altitude of 29,000 ft, the 170 knot speed provides 14.5 minutes aloft, compared to only 7 minutes at 240 knots. The crew configured the airplane properly for an APU-assisted start, and performed several start attempts, but were unable to restart either engine.

The flight plan route from LIT to MSP was essentially due north; upon recovering from the upset, the crew continued in a northerly direction. There was no significant weather to prompt any changes to the flight route or altitude, and turbulence does not appear to have been a factor in the initial upset. It was a moonless night, and there was a cloud ceiling of 4,400' (AGL) in the area of the diversion airport. The crew made a belated decision to divert, and the dark night and low cloud cover contributed to their difficulty in locating the diversion airport (Jefferson City, MO, 'JEF'). JEF is a towered airport, but the tower was closed at the time. The lights for the main runway (12/30) are pilot controlled (activated by repeated microphone keying), and include a medium intensity approach lighting system with runway alignment indictor lights.

Very late in the descent, the crew realized that they would not be able to make JEF, and began an abbreviated search for a satisfactory off-airport landing site. They attempted to steer the airplane towards a road, but did not deploy flaps or landing gear. The airplane was destroyed when it struck trees, terrain and auxiliary buildings in a suburban neighborhood.

## 2.0 CF-34 Engine Core Lock

The GE CF-34-3B1 engines installed on the accident airplane were introduced in 1995. The design employs two independent compressor and turbine sections, known as a 'dual spool' configuration. The first compressor section (at the front of the engine) includes the high bypass fan and is connected to and driven by the second turbine section (the rearmost part of the engine); together these are known as the 'low pressure spool.' The second compressor section is connected to and driven by the first turbine section; collectively these are known as the 'high pressure spool' or 'core.' 'N2' is rotational speed designation (in percent of a nominal maximum rotation speed) for the engine core section.

The engine components are manufactured to certain specifications, and the engine is then built up. Rotating seals are affixed to the core, and abrade into the engine case honeycomb material to prevent combustion gases from bypassing the turbine blades. The actual case-to-core seal clearances are not measured. The manufacturing process includes a break-in procedure whereby each new engine is run in a test cell to establish an operational fit for the seals.

Core lock is a temporary occurrence that may be experienced in an engine that has shut down and where the core has stopped rotating. When a turbine engine shuts down in flight (assuming it has not failed mechanically), the spools will generally continue to rotate, albeit at a lower RPM than if the engine is operating, due to airflow through the engine. This condition is known as 'windmilling'. However, in a multi-spool engine such as the CF-34, if there is insufficient airspeed and airflow, the inner spool (core) may cease to rotate. The diminished airflow through the core causes differential cooling between the core and engine case, which results in differential contraction of the case and core. In some engines, the differential contraction causes the core's seal components to physically bind against the engine case, and the engine core is temporarily 'locked' or prevented from rotating. Not all CF-34 engines are equally susceptible to core lock, meaning that not every engine exposed to the same conditions will experience core lock, or will experience it to the same degree. Therefore, the susceptibility of any single CF-34 engine to core lock is not predictable. However, in this accident, both engines were subjected to the same conditions, and both experienced core lock. This indicates that CF-34 engines are more prone to core lock than has been asserted by the manufacturer (GE).

A core locked engine cannot be restarted until the core is able to rotate again. This can be accomplished in two ways- either applying sufficient torque to overcome the internal binding, or allowing the component temperatures to reach some equilibrium value, which in turn reduces or eliminates the internal binding. Torque can be applied by airspeed (to induce windmilling) or the air turbine starter, which uses bleed air from the APU or an operating engine. Tests have shown that the time required for the case and core to reach temperature equilibrium can exceed 30 minutes, so in the case of a dual engine flameout, expecting a flight crew to wait for equilibrium temperatures is not an option.

Since CF-34 seal clearances, differential cooling and differential contraction are not known or modeled to the point that the core lock phenomenon can be accurately predicted (and therefore avoided by design), the only way that core lock can positively be avoided in a non-operating engine is to ensure that the rotating parts continue to rotate (i.e. that N2 remains at some non-zero value). Clearly then, N2 is the critical parameter for preventing core lock. Airspeed is a useful reference value, but N2 is the critical parameter that must be monitored and controlled. In other words, maintaining a specific airspeed will not necessarily prevent core lock, but maintaining some positive N2 definitely will prevent core lock.

Evidence indicates that the engines of Pinnacle 3701 ceased operation due to inlet airflow disturbances caused by the pitch oscillations and subsequent uncontrolled flight. There is nothing inherent in this type of failure that would preclude the engines from being re-started and developing full thrust. FDR data shows that an overtemperature condition was experienced in the right engine during one of the start attempts, and post accident examination revealed that some turbine blades of the right engine were damaged from high temperature conditions. Analysis indicates that this damage would have prevented the engine from producing full thrust, however, it would not have prevented the engine from being started. Post accident investigation did not reveal any damage that would have prevented the left engine from being started.

The post-upset controlled descent was within the normal flight envelope and the published engine start envelope. However, the engines' N2 never increased from 0 during any of the multiple start attempts.

The two air start procedures available to this crew were the windmilling and APU-assisted methods, both of which are contained in the dual engine failure (DEF) checklist. The DEF checklist did not indicate the necessity to maintain a positive N2; instead it specified a "target airspeed." This airspeed is intended to keep N2 non-zero, but the checklist does not contain any guidance about how quickly to establish the target airspeed.

Absent knowledge regarding core lock, the captain's decision to fly at 170-190 knots to wait until the airplane entered the APU-assisted start envelope was entirely reasonable, since the slower speed yielded a reduced descent rate.

Core-lock is a transient phenomenon, and will normally not leave any physical evidence or artifacts. Until this accident, the 'core lock' phenomenon was known only to a small segment of the industry, but not to any pilots or airlines operating the CRJ. As seen in this accident, core lock can prohibit the timely in-flight restart of the engine. While it may be both understandable and even acceptable that CF-34 engines can be susceptible to core lock, what is unacceptable is the lack of appropriate knowledge and defenses for this condition to be known to the end-users, the pilots.

### 2.1 Manufacturers' Activity Related to Engine Core Lock

In the mid 1980's, GE and Bombardier encountered core lock in early versions of the CF-34 engines during the test flights of the Challenger business jet, the predecessor to the CRJ. The two manufacturers report that they cannot ensure that any CF-34 engine will be immune to core lock until it is flight-tested. The manufacturers jointly developed pre-delivery flight test procedures (FTPs) for identifying engines susceptible to core lock, and follow-up procedures to supposedly eliminate that potential. However, these FTPs are only applied to engines already installed on airplane. New or overhauled engines that are delivered from GE or Strothers (the engine overhaul facility) directly to an operator are not subjected to the FTP, and consequently are at unknown risk for developing core lock. The left engine of the accident airplane had been through the FTP, but the right engine had not.

The FTP does not replicate the actual conditions that would be encountered during an inflight failure or inadvertent shutdown. The FTP employs a five minute idle cooling period before shut down. NTSB public hearing testimony indicated that the turbine section could be damaged if the engine was shutdown in flight without this idle cool down period. In contrast, data from FAA Service Difficulty Reports (SDR) show that there are many cases where engines have been abruptly shut down without damage.

While ALPA understands the manufacturer's need to prevent damage to new engines caused by an FTP, it is nevertheless mandatory that the FTP still provides a reliable indication of an engine's core lock susceptibility. Based on the results of this investigation, the FTP clearly failed in this regard.

### 2.2 FAA Activity Related to Engine Core Lock

Investigation evidence indicates that neither the FAA or Transport Canada were explicitly aware of the core lock phenomenon on the CRJ-200, and granted the CRJ-200 airworthiness certificates without unusual or special limitations regarding engine restart. The fact that both the engine and airframe manufacturers (GE and Bombardier, respectively) were well acquainted with this phenomenon, but apparently did not inform the certificating agencies, is indicative that the certification standards and procedures are not robust enough to ensure adequate hazard detection and mitigation.

Subsequent to the CRJ-200 certification, the FAA obtained information that CF-34 high bypass engines have some unique air-start issues, but the FAA has yet to change the regulations or certification procedures and guidance. On May 31, 2000, the FAA published Issue Paper AT1388NY-T regarding the Bombardier CRJ- 700, which uses CF-34 engines. This paper states that "the current engine restart criteria in § 25.903(e) are inadequate with respect to unassisted inflight engine restart following an all engine flameout." The issue paper also states that for airplanes lacking APU-assisted air start capability "reduced engine restart capabilities could result in an unsafe condition following an all-engine flame out event at mid to low altitudes." Despite this, the FAA's Master Minimum Equipment List (MMEL) for the Bombardier CRJ-200 still allows the airplane to be dispatched with the APU inoperative, which then exposes the CRJ-200 to the "unsafe condition" cited in the FAA Issue Paper.

On June 2, 2005, the FAA issued Special Aviation Information Bulletin (SAIB) NM-05-55. This SAIB advised operators that Bombardier had issued a revised DEF checklist (on 5/16/2005) for the CRJ, and that this "new AFM procedure clarifies the steps necessary to improve the chances for a successful airstart in case of a dual engine failure emergency."

## 3.0 Organizational Issues

### 3.1 Pinnacle Airlines Corporate Culture

In every organization, high-level management decisions strongly influence that organization's culture, processes and practices. This investigation has revealed that at the time leading up to the accident, Pinnacle did not have a robust safety culture, and the lack of such a culture permitted this accident to occur.

Senior level management in the aviation industry faces the challenge of having to address both company production and protection goals. 'Production' refers to the provision of goods and services for a profit. 'Protection' refers to the prevention of damage or loss of both human resources and hard assets. Production activities are a well-understood business endeavor, and are easy to identify, measure and manage. Protection activities are the lesser understood of these two aspects, and are more difficult to identify, measure and manage.

The economic upheaval experienced by many of the legacy airlines has also adversely impacted the regional airlines, particularly those owned by or code sharing with major airlines. Frequently, the success of the regional airlines is highly dependent on the success of the major airlines. In spite of or because of this, some regional airlines have expanded, and even prospered. But the competition is intense, and growth and economic pressures can adversely affect the resources allocated by management for 'protection.' Care must be taken to not let economic expansion override the need to establish and maintain robust safety processes and controls.

In view of the economic hardships and mergers in the industry today, it is critical for senior airline managers to determine and implement is sufficient levels of protection. Airline operations are governed by federal regulations, but these regulations do not specifically address all of the hazards that an airline might face. These regulations are minimalist in nature, and require each airline to develop policies and procedures that define how their operation will be conducted. These policies and procedures are then promulgated through programs and operating manuals.

It is impossible for the FAA to provide complete oversight of an airline operation to ensure compliance with the regulations. Ultimately, however, and by US Federal law (USC44702), it is the airline, not the FAA, that is responsible for determining and providing the appropriate level of protection to its operation. A robust safety culture, which includes a safety risk management process, is the best means to ensure an appropriate level of protection. It is a virtual certainty that any airline without a robust safety culture and effective risk management processes will eventually experience a major fatal accident on its property.

Management decisions can have an adverse impact on safety by creating the pre-existing conditions that enable active errors by operational ('front-line') personnel. Such pre-existing conditions are referred to as 'latent failures' or 'latent errors.' Examinations of certain organizational elements, issues and their influence on Pinnacle safety are discussed below, and provide the substantiation for our assessment of the Pinnacle safety culture.

### 3.2 Pinnacle Airlines Growth

Pinnacle Airlines is a regional airline and a code-sharing partner of Northwest Airlines. Pinnacle was formerly Express Airlines I, which was founded in 1985, and at that time was a code sharing partner of Republic Airlines. At the high point of its period with Republic, Express I operated 27 turboprop airplane in 32 markets. In 1986, Northwest Airlines acquired Republic, and Express I became a Northwest code-sharing ('Northwest Airlink') partner. In April 1997, Express I became a wholly-owned subsidiary of Northwest Airlines. Sometime later Express I transferred its headquarters to Memphis, TN.

Delivery of CRJs to Express I began in April 2000, and the inaugural revenue flight occurred in June 2001. In May 2002, Express I changed its name to Pinnacle Airlines, and in November 2003 became a publicly held company. The following table provides some specific information regarding the rapid expansion of Pinnacle.

| Year* | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|
| **Turboprop** | 30 | 31 | 30 | 29 | 0 | 0 | 0 |
| **Turbine** | 0 | 0 | 8 | 30 | 75 | 114 | 139 |
| **Total A/C** | 30 | 31 | 38 | 59 | 75 | 114 | 139 |
| **ASMs** (x1000)** | 535.2 | 687.1 | 899.1 | 1714 | 2678.0 | 4219.0 | 5,732.8 |
| **First Year Pilots** | n/a | 53 | 91 | 125 | 60 | 108 | 307 |
| **Total Pilots** | n/a | 212 | 258 | 407 | 500 | 622 | 887 |

*Numbers valid for beginning of each year
** 'ASM' = Available Seat-Miles

This rapid expansion of the airline's fleet and route structure resulted in a large growth of the pilot ranks, but without commensurate growth of its safety infrastructure. While Pinnacle met the minimum safety requirements of the FARs, this investigation has identified deficiencies in the safety infrastructure stemming from senior level management decisions. Deficient areas include the pilot training program, the Chief Pilot's office, the line standardization program, and System Operations Control (SOC). All these areas are the responsibility of the Vice President (VP) of Operations. In addition, the overall safety risk management efforts, which are the responsibility of the VP of Safety, were also below industry standards. While Pinnacle was working to improve some of these programs, Pinnacle did not devote the resources required to fully implement them. As a result, Pinnacle lacked the processes and information necessary to ensure the highest level of safety within its operation.

It is evident that the senior management was focused more on 'production' than 'protection' goals. Had these safety deficiencies been identified and corrected in concert with Pinnacles rapid growth, it is highly likely that this accident would have been prevented.

### 3.3 Vice President of Operations

The VP of Operations at the time of the accident was hired by Pinnacle in 1998, and was responsible for many elements, including the Corporate Education Center (CEC), the Chief Pilot, the Pinnacle pilots, and the financial aspects of Pinnacle operations. His previous experience provided him with knowledge of the administrative and safety controls required to deal with potential risks. He had been Manager of Flight Operations and Quality Assurance for NWA from June 1997 to August 1998, had been in charge of NWA's Internal Audit Program for about seven years, and was very familiar with airline training and flight operations departments. While employed with American and American Eagle, he developed the training specifications for regional air carriers. He also had experience performing Code Share Audits for American and NWA.

In his NTSB testimony, it was clear that the VP of Operations was well-acquainted with the tools and controls necessary to maintain operational safety at the airline. He accurately pointed out that Pinnacle needed a Quality Assurance Manual and a system safety program before the airline "could do meaningful work". He also noted that Pinnacle needed to complete its Internal Evaluation Program (IEP) and establish the relevant duties and responsibilities. However, even eight months after the accident, Pinnacle still did not have these tools or methods fully implemented.

The VP of Operations openly admitted in the interview that, "…in order to effectively manage the operation, they [Pinnacle] have to know the truth about what is happening within its operational activities." He recognized the need for feedback mechanisms. In ALPA's view, Pinnacle management was not getting the necessary operational feedback because the proper reporting mechanisms were not in place.

The unannounced FAA inspection of Pinnacle in December 2002 showed that Pinnacle had some deficiencies in its pilot training requirements; the program did not meet the intent of Part 121, Appendix E. This forced Pinnacle to rewrite most of its flight crew training manual, its flight crew instructor guide, and the FCOM.

While it is clear that while the VP of Operations had identified and had in place a number of safety controls, the programs lagged in implementation due to significant resource constraints. ALPA believes that the airline's rapid expansion prevented Pinnacle from fully implementing these safety and administrative controls. ALPA considers this a latent failure attributable to Pinnacle senior management.

### 3.4 Pinnacle Corporate Education Center

The Corporate Education Center (CEC) is the division of the airline responsible for all the education and training at Pinnacle, including flight crew, maintenance and flight attendant training. As a consequence of management's decision to expand its operation, beginning in 2004 the CEC had to deal with a large influx of new pilots. Shortly thereafter, due to limited instructors and the demand to train more new captains, the company reduced the training hours for captain upgrades, reducing training programs from 25 hours to 15 hours. The end result was a significant increase in the failure rate of upgrading captains, from under 10% to over 20%.

The NTSB interview with the Director of the CEC indicated that he was not well qualified for the position. For example, in NTSB testimony, he was not able to provide any detail on regulatory training requirements and company procedures. The Director of the CEC stated that he relied on the CRJ Program Manager to ensure an adequate level of safety, and compliance with the training regulations. The CRJ Program Manager was hired by Pinnacle in June 2001, and was a lead instructor for a short period. He had flown previously for a Part 135 operator and had been a captain for a short period with Comair.

However, the CRJ Program Manager was relatively inexperienced, and the CEC Director's reliance in him was inappropriate. For example, in NTSB testimony, the CRJ Program Manager provided an erroneous interpretation of FAA stall training recovery criteria. He cited the ATP Practical Test Standard (PTS) as Pinnacle's reference, but this PTS is used primarily for Part 61 checking. Since about 1996, the FAA has not considered the PTS to be a Part 121 checking standard; instead the applicable standard is contained in Part 121, Appendix F, which does not provide any specific stall recovery criteria.

The investigation identified that the training provided to Pinnacle pilots in high altitude operations is inadequate. The CRJ Program Manager admitted that Pinnacle's training on high altitude operations was weak, and that the Pinnacle philosophy is to rely on pilot expertise when problems arise. This presents an obvious problem, since most Pinnacle pilots had relatively little in the way of applicable experience. The corporate executives and organizations responsible for ensuring the safety of Pinnacle operations downwardly delegated these responsibilities to the point where the airline relied on its front line personnel (the pilots) to make up for guidance and training shortcomings, and provide an adequate margin of safety.

ALPA discussions with Pinnacle line pilots indicate that prior to the accident, the Pinnacle training program officials were not receptive to suggestions to incorporate additional material into the training programs. This suggests the need for formalized information gathering and sharing mechanisms in order to improve coordination between the CEC, the check airmen, and the line pilots.

### 3.5 Chief Pilot

Per FAR Part 119, Chief Pilot (CP) is a required position at each airline. The CP can play a critical role in developing and supporting a healthy safety culture at an airline. In most ways, the CP is the company's representative to the pilots, and vice versa. As such, a CP can either be a facilitator or inhibitor of information flow and ideas. This in turn will positively or negatively affect the safety culture of the airline.

The Pinnacle CP had been in this position since January 1999, and has been with the airline or its predecessors for 20 years. When he started as CP there were less than 300 pilots at Pinnacle. Management did not provide the CP with adequate support to oversee the growing pilot group. At the time of the accident, Pinnacle had one CP (and no assistant CPs) in charge of 1,200 pilots at three domiciles (Minneapolis, Memphis, and Detroit). Physically and geographically, this is a huge span of control for one individual.

The CP's office is in Memphis, but according to his Public Hearing testimony he spends "a lot of time" at all three bases, and he usually travels every week to either Minneapolis or Detroit to confer with the pilots and exchange ideas and information. To accomplish this, the CP uses monthly pilot meetings and forums at each base. In addition, the CP indicated that he has "an open door policy" with regard to receiving or discussing safety concerns of the pilots.

Internal (primarily administrative) company oversight of the pilots is accomplished through base managers and assistant base managers, but only some are pilots. In an NTSB interview, the CP stated that he wished all base managers were pilots. Pinnacle also uses flight standardization personnel and check airmen to assist in providing oversight.

In interviews and testimony, the Chief Pilot stated that he was not aware of any differences between how Pinnacle operated their Part 91 and Part 121 flights, which conflicts with the Pinnacle FCOM. This is one indication that the CP is unfamiliar with the disparity between published guidance and actual line operations. He acknowledged that Pinnacle was looking for ways to make improvements, and noted that Pinnacle has added additional personnel to the SOC.

Pinnacle's relatively low level of support for its CP is a telling indication of the airline's approach to and prioritization of safety matters, and another manifestation of the company emphasizing production over protection.

### 3.6 System Operations Control (SOC)

The investigation disclosed that Pinnacle System Operations Control (SOC, or 'dispatch') was under-staffed, and was therefore sometimes unable to provide adequate flight following support in accordance with company policy. In particular, SOC staff shortages resulted in the SOC focusing more on passenger revenue flights than on positioning flights, but this support was unevenly available.

The dispatcher on duty at the time of the accident was working a 10 hour shift. He indicated that that day was a normal workload, and that he was responsible for 40 to 45 flights over the course of his shift. The dispatcher for the accident flight recalled that he spoke with the crew approximately 10 to 15 minutes prior to their departure, but that was no discussion regarding operations at FL 410. Subsequent to departure, the accident crew had no contact with SOC, nor were any contact attempts initiated either by the crew or by SOC. The dispatcher was not aware of the accident until he was notified by the Pinnacle Airlines CEO.

One function of SOC is to provide flight following services. Legally, Pinnacle positioning flights are Part 91 flights, but Pinnacle has the option of conducting them in accordance with its normal Part 121 procedures. Although Pinnacle repeatedly reported in NTSB interviews that positioning flights were to be conducted in accordance with Part 121 procedures, the investigation determined that this is not accomplished in practice. The Pinnacle FOM states that SOC does not have to provide a release, but it will provide flight following for all Part 91 operations (such as the accident flight).

This indicates that while Pinnacle does have the option of conducting all its flights in accordance with Part 121 standards, the airline has made some conscious decisions not to do so. Given the repeated standardization challenges in Pinnacle's Part 121 operations, it is reasonable to conclude that Part 91 flights were beset with at least the same challenges, and probably more. The lack of a strong standardization program for Part 91 flights provides an opportunity for flight crews to begin to ignore SOPs and best practices.

The information and decision-making assistance provided by SOC adds an important layer of redundancy to an airline's operational safety. Pinnacle's decisions and SOC's consequent inability to uniformly support Part 91 flight operations represents a latent failure that is another indication that Pinnacle management emphasized production over protection.

### 3.7 Vice President of Safety, Security and Regulatory Compliance

The VP of Safety was hired in 1998 and was previously a career FAA employee. He was hired at Pinnacle before the growth period. In NTSB testimony, the VP of Safety stated that the Pinnacle CEO considered the VP of Safety the only other person besides the CEO who could shut the airline down. This clearly placed him in a very responsible and authoritative position at Pinnacle.

However, some of the important programs that the VP of Safety was responsible for were not fully implemented. Prior to the accident, the Pinnacle Internal Evaluation Program (IEP) and safety risk management activities were not fully operational. The VP of Safety reported that the IEP was still under development, and that the Pinnacle risk analysis process was embedded in the IEP. Therefore, Pinnacle was not equipped to adequately assess the performance of its departments, programs and processes. Furthermore, participation in the IEP was voluntary on a department-by-department basis within the company. This lack of a requirement for a fundamental risk-management tool is another manifestation of senior management's casual approach to safety.

The investigation revealed that Pinnacle did have a program and database for capturing and tracking operational and safety deficiencies. Pinnacle called this the Aviation Safety Information System (ASIS). NTSB testimony of the VP of Safety indicated that ASIS was being operated informally, and that his department was not regularly entering or acting on any of the 'suspense dates' for problems and deficiencies. 'Suspense dates' is the Pinnacle ASIS term for the due dates for specified corrective actions on each issue or deficiency. This indicates that Pinnacle was ineffective in tracking, following up on, or correcting potential safety problems. In other words, Pinnacle did not or could not use ASIS to gauge any risks or track progress regarding its operational activities.

The investigation revealed additional evidence of inadequate incident and accident prevention efforts. Pinnacle and NWA used to conduct quarterly safety meetings to identify and address safety concerns, but this activity ceased sometime prior to the accident, and was not supplanted by any other programs or mechanisms. After the accident, they reinitiated these quarterly safety meetings.

Pinnacle did not have FAA-compliant FOQA or ASAP programs[3] in place at the time of the accident. These are two key safety programs that have gained wide acceptance throughout the industry. NTSB testimony indicates that prior to the accident, the VP of Safety considered the typical ASAP program to be a resource intensive program, and he did not push for a budget to implement one.

### 3.8 Safety Information Collection and Reporting Systems

Pinnacle did not employ at least two key safety programs that have gained wide acceptance throughout the industry; Flight Operations Quality Assurance (FOQA) and Aviation Safety Action Program (ASAP). FOQA (see FAA Advisory Circular 120-82) is a program for the routine collection and analysis of digital flight data (typically from the FDR or QAR) from normal line operations. FOQA can identify accident precursors, and can improve safety by significantly enhancing training effectiveness and operational procedures. A viable FOQA program requires both initial and sustaining equipment and personnel investments, but virtually all operators with FOQA programs report that these programs are cost effective.

Prior to the accident, Pinnacle had a flight monitoring program which Pinnacle referred to as a 'FOQA program', but it was actually a pilot standardization program under the control of the VP of Operations. It was not the standard, industry-accepted FOQA program described above. The central function of Pinnacle's 'FOQA office' was to manage the check airman program. The check airmen were not directed to review specific areas or items; instead they were used to observe line operations and detect problems. Their observations were not systematically collected or analyzed for use in developing or improving flight crew training.

Absent such a system there will be no significant fleet-wide changes; there may be correction or discipline of a single pilot or crew, but there will be no trending of common weaknesses, no matter how they are observed. With such deviations being relatively rare, and often not being explicitly considered so, it is too easy for an overburdened CP's office to "classify" them as one-time aberrations when reviewing the occasional report.

In the June 2005 Public Hearing, the Pinnacle 'FOQA' manager noted that his office intended to conduct safety audits involving the SOC and the Corporate Education Center (CEC), and implied that these audits would be done shortly. As of April 2006, ALPA is unable to determine whether these audits have been accomplished. Reportedly, Pinnacle initiated an FAA compliant FOQA program in Spring 2006.

The complementary program to FOQA is the Aviation Safety Action Program (ASAP). ASAP (see AC120-66B) is a cooperative program between the company, the pilots and the FAA. It is a non-punitive reporting program whereby employees report safety deficiencies, issues and concerns. One primary feature of ASAP is the de-identification of the report, to protect reporters from retribution. This non-punitive aspect stimulates reporting where none would otherwise be

[3] See next section for detailed discussion

forthcoming. Reportedly, Pinnacle will implement an FAA compliant ASAP program in late Spring 2006.

Prior to the accident, Pinnacle did have a toll free telephone number for employees to report problems and suggestions. Callers were required to leave their names, with no assurance of anonymity. ALPA did not support this program because it lacked provisions to protect the reporters. Furthermore, this program was not actively promoted by Pinnacle, to the point where, at the June 2005 Public Hearing, the Pinnacle VP of Safety admitted that they had not received any calls or reports via this program.

Any airline which does not have a FOQA, ASAP or any other monitoring or non-punitive reporting programs in place will be ill-equipped to detect safety deficiencies and institute timely and viable corrective actions. While such programs do require initial and recurring investments, all indications are that these programs are economically beneficial in the long run; witness their existence at many air carriers. The fact that Pinnacle is just beginning to implement such programs is another indication of its emphasis of ‘production’ over ‘protection.’

It appears that Pinnacle’s implementation of FOQA and ASAP programs is in response to the accident. These tools are essential to Pinnacle’s ability to properly manage its growth and consequent safety risks.

These shortcomings in Pinnacle's safety programs significantly hampered its ability to manage safety risks, and is another latent failure that helped set the stage for this accident. These program are extremely important to the safety health of the airline. While the company may have had the best of intentions, Pinnacle chose to avoid devoting the resources to fully implement them. As a result, Pinnacle lacked adequate knowledge of its operations. Had these latent failures been corrected before Pinnacle began its rapid growth, it is highly likely that this accident would have been prevented.

### 3.9 FAA Oversight

Changes to an airline’s fleet composition, or increases in an airline’s size, route structure and pilot ranks complicate the task of providing satisfactory FAA oversight. During and after the period when Pinnacle transitioned from turboprops to turbojets and greatly expanded its fleet, route structure and pilot ranks, there were several different Principal Operations Inspectors (POI) assigned to Pinnacle, further exacerbating the oversight difficulties.

A new POI, qualified only on turbo-prop airplane, was assigned to Pinnacle in 1996. Although he later tried to get qualified in the CRJ, he was unable to do so. When Pinnacle began planning to acquire CRJ, the Certificate Management Unit (CMU) supervisor realized that the POI’s lack of turbojet qualifications would inhibit the POI’s ability to provide adequate oversight, and particularly his ability to evaluate the adequacy of training programs for the new turbine airplane. Therefore, in August 1998, the CMU assigned an Aircrew Program Manager (APM) to assist the POI. During the period when Pinnacle transitioned from turboprop airplane to turbojet airplane, the same (previous) POI remained assigned to Pinnacle.

The FAA removed the POI from his position in February 2003 for a variety of reasons; He did not have an air carrier background, he was not type-rated in the CRJ, and he did not, in the FAA's opinion, provide the proper guidance to Pinnacle in developing an acceptable CRJ training program. The POI's removal resulted in the FAA providing three different temporary POIs, until a permanent one was assigned in July 2004. Additionally, there was a change in the CMU supervisors responsible for Pinnacle. These FAA management changes had a negative impact on the FAA oversight, particularly on the development and implementation of Pinnacle's training and checking programs.

For example, in December 2002, the FAA determined that Pinnacle training and pilot standardization methods and controls were deficient, and the POI nearly had to shut the airline down until the training program was revised. These deficiencies occurred despite the fact that the Pinnacle training program had been written by a former FAA inspector, and that it had been approved by the then-current Pinnacle POI. This raises questions about the performance of the previous POI, and the performance of the APM designated to assist that POI. The APM at the time of the accident was assigned to Pinnacle in August 2001. He had a general aviation background, but was a POI for about twenty Part 135 operators. He was the only Pinnacle APM until the FAA had hired two assistants in late 2004.

In order to evaluate the adequacy of an airline's pilot training program, FAA inspectors can use the FAA Aircraft Evaluation Group and the Flight Standardization Board (FSB) report for assistance. The purpose of the FSB report is to specify master training, checking and currency requirements for flight crews on a particular airplane type used by the air carrier. While use of the FSB report is not mandatory, it has always been a primary reference document for the FAA inspectors and air carriers for developing training and checking programs.

With the exception of variant requirements, the December 2002 FSB report does not specify any unique provisions or requirements for the CRJ. However, it does specify some areas of emphasis for Special Event Training, including use of the flight mode control panel, use of engine mode annunciations, FMS operation, dual hydraulic system malfunctions, and air driven generator (ADG) deployment. Many of these are items that would be encountered in a dual engine failure scenario.

In NTSB testimony, when asked about use of the FSB report, the current APM stated that he was not familiar with the document. Furthermore, when asked why certain FSB training recommendations were not part of Pinnacle's training program, he stated that, "Yeah, we all missed it; that's all I can tell you."

What is missing from the December 2002 CRJ FSB report is any emphasis on the engine flameout and restart procedures. This is alarming, since the FAA issue paper on that topic was issued approximately 2½ years prior. The FSB report should have included the issue paper's finding as an area of emphasis. Although the cause for this omission is unknown, it appears that there was a breakdown in communication and coordination within the FAA.

The investigation revealed that the FAA was unable to effectively manage the Pinnacle certificate when Pinnacle expanded its operations and transitioned to an all turbojet fleet. The December 2002 inspection results and subsequent corrective actions should have been identified and accomplished previously. Clearly, the CMU was in a reactionary mode (with respect to Pinnacle expansion) while concurrently dealing with its own personnel changes. The CMU was also confronted with resource constraints that restricted its activities and effectiveness. While there was evidence and justification to temporarily shut down Pinnacle Airlines, and apparently the manager of the FSDO threatened to do so, the CMU chose to cooperate and allow Pinnacle senior management time to correct the noted deficiencies.

While budget and resource constraints had a negative impact on the CMU's management capabilities, it is unknown whether this was the result of internal FAA decisions or the result of wider Congressional budget constraints on the FAA. Nevertheless, US law holds the air carrier responsible for providing "…the highest possible degree of safety in the public interests…" In this case Pinnacle fell short of this responsibility for providing adequate protection over its operations.

Even after the December 2002 'wake up call,' Pinnacle failed to quickly and thoroughly implement satisfactory safety control programs, and the FAA failed to take sufficient action to ensure that Pinnacle quickly and effectively corrected their noted deficiencies. ALPA considers these latent failures on the part of FAA and the airline.

## 4.0 Human Performance Considerations

In an attempt to explain and understand the flight crew's actions and this accident, an analysis of the flight crew's performance is contained in the two following subsections. The first subsection covers the generic considerations. The second subsection focuses on certain specific actions and events in the accident sequence.

The three generic considerations discussed in this submission can influence individual behavior, and are some of the underlying or latent factors which affect flight crew performance.

### 4.1 Behavioral Prioritization Scheme - Skin, Tin, Ticket (STT)

There is an aviation human factors maxim known as "skin, tin, ticket" (STT). This denotes the priority scheme that should be respected in the interest of minimizing risks and losses when unexpected or unforeseen events occur. The words "skin, tin, ticket" respectively refer to human life, the airplane and other hardware, and the licenses and certificates of the involved individuals or organizations. In basic terms, under the STT scheme, all actions and guidance are designed to ensure that the potential for exposure to personal safety risks is significantly lower than the potential for exposure to administrative risks.

By definition, STT prioritization challenges and non-compliance typically only arise during unusual or unforeseen circumstances, and they ultimately require a decision between personal risk and ‘administrative’ (e.g. sanction) risk. The most common manifestation of non-compliance with the STT scheme is when the flight crew ends up more concerned about enforcement action (‘Ticket’) than personal safety (‘Skin’).

Strict compliance with the STT priority scheme could require extreme decisions and actions in order to minimize risk. Another way to view this scheme is to consider the prioritizations from a ‘conservative’ versus a ‘non-conservative’ perspective. The most conservative approach would be to always presume a worst-case situation and act accordingly. Another way to consider this is that ‘worst-case’ presumes failure instead of success. This scheme can sometimes conflict with normal human nature, as well as with efficient business operations, and exceedingly conservative approaches to minimizing risk can cause significant disruptions to daily operations.

### 4.1.1 Generic Factors Influencing Deviations from the STT Scheme

In an ideal airline with a robust, non-punitive safety culture, there would never be any reason or pressure for any pilot or other airline employee to ever violate the STT scheme. All risks are continually identified and evaluated, and procedures and guidance implemented to ensure safe operations. This would preclude FAR or other violations from occurring. However, due to the real-world need to maintain an effective business operation, pilots and other airline personnel are sometimes put in the position of having to weigh the risk of physical harm against the risk of FAA or company sanctions, and their solutions are not always congruent with the STT scheme. Sometimes, for reasons completely unrelated to maintaining an effective business operation, pilots and other airline personnel may deviate, intentionally or otherwise, from the STT scheme.

An individual’s perception of the likelihood of physical harm, or FAA and/or Company sanctions, consciously and subconsciously affects that individual’s behavior. Individuals’ perceptions vary, and can be strongly objective or strongly subjective. The perceived likelihood of physical harm from a given action is a function of that individual’s experience, training, knowledge, skill and awareness. The perceived likelihood of a sanction for a given action is also a function of several factors, including the individual’s previous experiences, the timing, duration and location of their particular action, the magnitude of their deviation, and their familiarity with the context within which they are operating. Peer pressure and group dynamics can exert additional influence on the involved individual(s), causing them to act differently than they would if they were alone.

Needless to say, the actual likelihood of physical or administrative risks may be significantly different from their perceived likelihood. Unfortunately, the biases and information shortfalls that cause these differences are often not apparent to the decision-makers in real time. In contrast, retrospective analysis of any given situation is always more accurate, for two primary reasons. First, there is more information available to the analyst than was available to the subject decision-maker. Second, the outcome of each decision is known to the analyst. Together, these put the analyst in a position nearing omniscience.  One goal of accident investigation is to learn from previous mistakes and decisions, in order to provide decision-makers (such as pilots) with the information that will prevent them from making similar mistakes or decisions.

Under the STT scheme, the accident crew, company guidance and corporate culture should have prioritized first on saving lives, then on saving the airplane, and finally on avoiding any certificate actions or Company penalties. However, examination of this accident reveals several instances where actions or guidance deviated from this priority scheme.

#### 4.1.2 Flight Crew Actions in the Context of STT

One example of a deviation from the STT scheme can be seen in the crew's actions at FL 410. As the airplane continued to decelerate, the crew requested a lower altitude from ATC, but had not been cleared for lower prior to experiencing the shaker and pusher. On the macro level, this crew was confronted with having to make a choice between remaining at FL 410 (and possibly stalling the airplane), or deviating from their assigned altitude (and possibly incurring an FAA enforcement action). The most conservative approach would have been to descend immediately, thereby positively assuring continued safe flight, but risking FAA enforcement action. However, real-world decisions are rarely so clear-cut, and this one was no different. Real-world decisions are primarily influenced by qualitative assessments of the potential outcomes, particularly with respect to the timing and likelihood of the accompanying risks. But these factors can be very subjective, and are influenced by such aspects as training, experience levels, previous exposure to similar circumstances, etc.

As another example, the crew's first post-upset actions (recovering controlled flight and deploying the Air Driven Generator (ADG)) were in accordance with the STT scheme, but the crew then quickly deviated from that prioritization. If this crew had adhered to the STT scheme and assumed a worst-case situation, they would have predicated their subsequent actions on the premise that they would not be able to re-start either engine. Instead of being evasive with ATC and failing to immediately divert to a suitable airfield, they would have informed ATC as to the nature of their emergency, and initiated a diversion, even though in the end it might not have been necessary.

The specific rationale for their actions and inactions are discussed in detail later in this report, but it is clear that this crew was convinced that they would be able to re-start at least one engine. Given this conviction, some of the crew's actions appear to be motivated in part by fear of FAA or Company punishment.

#### 4.1.3 Checklist Design in the Context of STT

Another example of deviation from the STT scheme can be seen in the design of the CRJ Dual Engine Failure (DEF) checklist. If designed in the most conservative form, this checklist would presume the worst-case situation (where neither engine could be restarted), and the first two items would be to divert to a suitable landing site and to establish an appropriate airspeed (e.g. best glide, core lock avoidance, etc). In contrast, the actual CRJ DEF checklist does not take the most conservative approach; it is structured to presume success in restarting at least one engine. This checklist lists 'diversion' as the last item if the start attempts are unsuccessful. The airspeed guidance is complex and ambiguous, and the checklist never mentions core lock, or the need to maintain some non-zero N2. It also does not mention the need to don oxygen masks.

Checklist design is governed just as much by varying industry philosophies as they are by technical requirements. Checklist design issues include the overall format and wording, failure scenarios, flight crew responses, memory items, consistency with other flight crew documents, and the implications of human performance capabilities and limitations. The challenges associated with checklist design and use is the subject of the Emergency and Abnormal Situations Study initiated by the Human Factors Research and Technology Division at NASA Ames Research Center. This study is still active, but is expected to produce further improvements in the design and use of checklists.

### 4.1.4 Pinnacle Corporate Culture in the Context of STT

At the time of the accident, the corporate culture of Pinnacle tended to induce flight crews to deviate from the STT scheme when non-standard situations arose, causing them to prioritize job protection over safety. Subsequent to the accident, Pinnacle culture appears to have become worse in this regard. Prior to the accident, marginal performance by a flight crew member during a Proficiency Check (PC) would result in a passing grade; today similar performance will likely result in the employee being dismissed from the company.

Since the accident, the company has been aggressively firing crews for any failure to perform per standards. One obvious outcome of such a strategy is the potential for flight crews' increased emphasis on preserving their jobs and concealing poor performance.

While it is not ALPA's intent to prohibit discipline up to and including dismissal, it is well established that a punitive culture results in more safety hazards than it reduces. In an airline with a robust safety culture, personnel can readily adhere to the STT scheme, and management would obtain the information that it needs to improve the safety of the organization.

## 4.2 Fatigue

Interviews about the accident crew with other pilots, check airmen and family members reveal two properly trained, certified and competent individuals. Yet the investigation of this accident has uncovered numerous flight crew errors in procedures, judgment and airmanship. While there is no doubt that Pinnacle flight crew training deficiencies were a significant factor in this crew's performance, fatigue may explain some of their behaviors in this accident sequence. However, more evidence[4] is needed to better understand what, if any, contribution fatigue made to the accident sequence.

[4] See Appendix 2 for a more detailed discussion on fatigue evidence required.

### 4.3 High Altitude Physiology and Hypoxia

While remote, the possibility of mild hypoxia as a contributor to some of the crew's behaviors in this accident sequence cannot be eliminated.[5]

## 5.0 Unsafe Acts

An unsafe act is defined as an intended or unintended action, on the part of front line personnel, in the presence of a hazard, that could lead to adverse consequences. Several points are worth noting:

- The 'unsafe acts' identified and discussed in this analysis do not necessarily lead to an incident or accident.
- An 'unsafe act' does not necessarily significantly increase the risk of a given situation.
- All aviation front line personnel (flight crews, mechanics, etc) regularly commit unsafe acts, but the error-tolerant design of the system normally prevents these acts from becoming links in incident or accident chains.
- The majority of these unsafe acts were due to deficiencies in the accident flight crew's training, guidance, experience or knowledge.
- Although this analysis identifies specific unsafe acts on the part of this flight crew, several of these could and probably have been made by other Pinnacle and CRJ crews as well[6], but none with fatal results or loss of an airplane.

### 5.1 Overview of Hazard Events

In this submission, a 'hazard event' is a natural grouping of related unsafe act within the same segment of flight. ALPA identified twelve key hazard events. Four of these had no direct bearing on the accident sequence of events, but they are indicative of Pinnacle training or safety culture problems/deficiencies. The remaining eight hazard events were direct links in this particular accident chain, and it is highly likely that had any one of these links not been present, this accident would not have occurred. Therefore, these links individually & collectively represent opportunities for corrective action.

Each identified hazard event was analyzed by examining the possible or probable motivations, risks, and defenses (risk mitigation controls) associated with those acts. When applicable, an examination of the pertinent organizational latent conditions or failures is also included. In simple terms, the analysis attempted to answer the following questions for each hazard event:

<u>Motivations</u>: "What factors prompted the crew to take these actions?"
<u>Risks</u>: "What were the perceived and actual risks associated with these actions, and if they differ, how and why do they differ?"

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[5] See Appendix 3 for a more detailed discussion on hypoxia
[6] See Appendix 4 for a list of recent ARSR reports regarding aircraft getting "too slow" at altitude.

Defenses: "What systems, procedures, and other factors existed to mitigate the risk or to prevent the crew from taking these actions?"
Latent Failure: "What management decisions led to deficiencies or breakdowns in the company's culture, processes and practices that created the condition(s) for operator error and violations."

The table below summarizes these events.

| **FLIGHT SEGMENT** | **HAZARD EVENT** | | |
|---|---|---|---|
| | **#** | **Linked to Accident Chain** | **Not Linked to Accident Chain** |
| Takeoff and early climb | 1 | | Takeoff and Climb |
| | 2 | | Crew Seat Exchange |
| Climb to FL 410 | 3 | Climb to FL 410 | |
| | 4 | Climb Speed Schedule | |
| Events at and shortly after leaving FL 410 | 5 | | F/O Oxygen Mask |
| | 6 | Speed Decay | |
| | 7 | Stick Shaker/Pusher | |
| Descent | 8 | ATC Communications | |
| Engine restart attempts | 9 | | Crew Oxygen Masks |
| | 10 | Descent Airspeeds | |
| Diversion | 11 | Diversion | |
| | 12 | Forced Landing | |

The following evaluation of the identified hazard events and unsafe acts is intended to help understand the crew's performance errors, and how some of these errors led to the accident.

## 5.2 Hazard Events in the Accident Chain

### 5.2.1 Hazard Event 3 - Climb to FL 410

Event Summary: FL 330 was the dispatch cruise altitude, but the crew selected FL 410 as their final cruise altitude.

The CVR recording did not capture this crew's discussion regarding their decision to climb to FL 410, but some circumstantial evidence allows their motivation(s) to be explored. FL 410 is the maximum certificated operating altitude (MCOA) of the CRJ-200, and the airplane must be at a relatively light weight to achieve this altitude. Given the typical short legs and passenger loads of this airplane, CRJ revenue flights rarely, if ever, use this altitude.

NTSB interviews and Public Hearing testimony revealed that other flight crews had attempted flight at FL 410. These sources also mentioned the existence of an unofficial "four-one-oh club", where membership was predicated on having flown the CRJ to FL 410. Apparently, this represented something of a unique or elite status within the Pinnacle pilot ranks. Since it is human nature (generally more so in the pilot community) to be competitive, the potential for seeking membership in such a ‘club’ certainly would be an incentive for flight crews to attempt this altitude when circumstances permit. In the case of this accident crew, this night positioning flight seemed to provide the opportunity to do so.

Operating any airplane at its MCOA is not inherently dangerous, provided that the flight crew is properly trained, and adheres to all applicable procedures, conditions and limitations. However, a turbine-powered swept wing airplane at its MCOA has some significant characteristics that are very different from those of straight-wing, propeller-driven airplane. Proper training is essential to maintain adequate margins of safety. The Pinnacle training in high altitude climb procedures and operations was very limited, and the guidance and training tended to underemphasize the necessary information and associated hazards.

Since the bulk of these two pilots’ experience was in propeller-driven, straight-wing airplane, which routinely and more easily operate at their MCOA, it is likely that these pilots simply presumed that turbojets were no different. It is reasonable to assume that an underlying tenet of these pilots’ mindset was that the airline would provide all necessary information and training, particularly with respect to issues associated with safety of flight.

Interviews with some Pinnacle CRJ pilots who tried to reach FL 410 revealed that they were frequently surprised at the deteriorating performance and sometimes abandoned the effort. Some were surprised when they could not maintain altitude during a turn. None of those pilots seemed to be aware of the limitations or hazards before they encountered them, which reinforces that this accident crew was not the only Pinnacle crew who was unfamiliar with actual CRJ performance at FL 410.

Prior to the accident, Pinnacle flight crew training inadequately addressed flight to and at this altitude. Other than brief mention of the CRJ MCOA, high altitude operations were not discussed or demonstrated during any ground or flight simulator training. Generally, high altitude operations were only discussed in the jet-upset module during initial training. Simulator instructors who were familiar with the details of high altitude operations admitted that they did not teach it in detail, nor did they teach it on a regular basis.

With regard to the informal training that occurs during normal line flying, the pilots at Pinnacle and other regional jet operators are at a great disadvantage compared to the pilots who have flown for the legacy carriers. In these legacy carriers, the transition through the ranks to Captain could take 10 years or more, which provided a period of ‘seasoning’ for junior pilots to observe and learn from the highly experienced senior pilots. In this era of regional jets, the pilots have very little access to senior guidance or expertise, and are therefore significantly more reliant upon viable and thorough training programs. However, the economic environment tends to discourage or even prevent carriers from investing heavily in training programs; instead these training programs more frequently only tend to meet the minimum FAA standards.

Certainly this accident crew was aware that they were not the first Pinnacle or CRJ flight crew to climb to FL 410. This knowledge would suggest the perceived risk was small, since the pilots would think that if the others did it, so could they. However, without more training and experience in airplane operation at high altitudes, this operation was clearly hazardous.

Within a few weeks of this accident, Pinnacle responded by limiting the CRJ from operating above FL 370. While this defense will partially mitigate the hazard, it has not been eliminated. A departure from controlled flight could just as easily be experienced by a CRJ at FL 350 if the aircraft weight and ambient temperature are not appropriate. Certainly, this artificial altitude limitation is no substitute for a robust high-altitude training curriculum. As of April 2006, this altitude limitation is still in effect at Pinnacle.

### 5.2.2 Hazard Event 4- Climb Speed Schedule

Event Summary: FDR data indicates that the crew selected, and the airplane flew, a 500 fpm climb up to FL 410. This resulted in a continuous airspeed decay. At level-off, the airplane could not accelerate, and instead, continued to slowly decelerate.

During the climb from FL 365 to FL 410, the airplane was operated using the autopilot in a constant vertical speed (‘rate’) mode instead of the constant airspeed (‘speed’) mode. Pinnacle SOP calls for crews to climb at optimum rates consistent with the operating characteristics of the airplane to 1,000 feet above or below the assigned altitude, and then at a rate of at least 500 fpm until the assigned altitude is reached. Pilots are taught that if at any time a climb or descent rate of at least 500 fpm cannot be maintained, they are to advise ATC.

CRJ climb performance deteriorates with altitude, but rarely does it become a limiting factor in normal operations. As cited previously, FL 410 is an unusual altitude for this airplane. Without the appropriate guidance, training and experience, crews have no basis to climb to the higher altitudes any differently than they do to the lower, more common altitudes.

In determining the crew’s possible motivations for conducting the climb in this fashion, it is important to consider two primary factors: Pinnacle pilots’ normal mode of climbing, and Pinnacle pilots’ awareness of the airplane performance capabilities and limitations in the upper region of the CRJ altitude envelope. Since the CRJ has an autopilot but does not have autothrottles, flight crews prefer to climb the airplane in the ‘rate’ (constant rate of climb) mode rather than the ‘speed’ (constant airspeed/Mach) mode. The autopilot ‘speed’ mode causes the airplane to ‘hunt’ for a pitch attitude to maintain the selected airspeed and results in an uncomfortable ride. Additionally, the Aeronautical Information Manual (AIM) states: “If at anytime the pilot is unable to climb or descend at a rate of at least 500 fpm, advise ATC.” Therefore, due to these equipment and ATC constraints, climbs are almost never conducted in the ‘speed’ mode, and the lowest climb rate normally used by Pinnacle CRJ crews is 500 fpm.

The CVR recording begins shortly before the airplane was climbing through FL 370, so it does not contain any flight crew discussions about their method to climb to FL 410. The conversations that the CVR did capture do not reveal any doubt or concern about reaching FL 410 safely, even though the flight crew did remark about the speed decay.

CRJ performance data indicates that the airplane was limited to a maximum climb rate of 300 fpm for the estimated airplane weight during its climb to FL 410. At the accident aircraft's weight, any attempt to climb at a rate greater that 300 fpm would result in an airspeed deterioration, which did occur, and which the crew did notice. The crew did not appear to understand how to manage the energy state of the airplane. It can be concluded that aside from the need to maintain the required stall margin, the crew did not perceive any other risk as a result of this airspeed loss.

Ideally, the two primary defenses against unsafe climb procedures would be adequate training, and clear guidance in the form of operating procedures and performance data. Secondary defenses would include flight crew awareness of this issue obtained via other means, normally as a function of experience on the CRJ or other turbine airplane. Based on their actions and comments, it is clear that this crew did not possess the requisite knowledge or experience.

NTSB interviews show that there was a lack of knowledge and standardization among Pinnacle pilots, instructors, and check airmen. Some instructors and check airman knew the techniques for high altitude flight and cruise climb but did not discuss them with students. There were no SOPs for climbing at a constant speed versus at a constant rate. Pinnacle had no specific guidance in their FCOM or FOM on how to perform climbs. There is no simulator training on autopilot modes for climbs or energy state concerns. These results indicate shortcomings in standardization and training.

Pinnacle guidance on climb procedures is very limited; it is less than one page in the FCOM. The FCOM provides three climb speed schedules, but it is not very helpful in explaining why these schedules are different. By way of explanation, the FCOM states "the speed selected is determined by operational requirements." "Operational requirements" is not further defined. Another FCOM paragraph entitled "Climb Speed Determination" addresses only the departure phase, and simply states if "there are no altitude or airspeed restrictions, accelerate to the desired climb-speed schedule." This suggests that there is no performance limit that might become a factor in the climb. FCOM performance charts are discussed as a part of training.

It appears that the crew believed that the airplane would accelerate once it reached its assigned altitude, and this was likely based on their previous experience in propeller airplane. The Pinnacle training program should have provided flight crews with the information and procedures necessary to enable them to safely climb to these altitudes, but it did not.

## Hazard Event 6 – Speed Decay

Event Summary: In climb and after leveling at FL 410, the airspeed exhibited a continuing decay. Although the crew observed and discussed the speed decay. they did not display a sense of urgency in their consideration of any corrective action.

Shortly after reaching FL 410, the crew also made comments regarding the "ball" being "off." This is a reference to the slip/skid indicator on the primary flight display, and "off" suggests that the airplane was in uncoordinated flight. The crew comments indicate that while they did notice this fact, they appeared to be unconcerned by it, and that they did not seek to diagnose or correct the situation. The lack of discernible crew concern, or any efforts to diagnose or correct the apparent uncoordinated flight, are indicative of a lack of flight crew knowledge or understanding of the potential implications of sustained uncoordinated flight, particularly at very high altitudes where the performance margins are extremely narrow.

One of the first verbalizations of their slowing airspeed occurred when climbing through approximately 38,100' at an airspeed of 195 knots, when the Captain noted "We're riding the green line there. " The 'green line' is an FAA- mandated airspeed display notation which is advisory in nature. The Captain's remark does not indicate any sense of urgency or concern, although he further noted incorrectly that it indicates 1.2 times the stall speed. The F/O corrected the Captain's observation, noting that the green line indicates 1.27 times the stall speed, which provided more margin and possible reinforcement that there was no need for urgent corrective action. Pinnacle guidance does not include any procedures regarding the green line, and Pinnacle crews are not provided with any procedural training regarding the green line.

While this crew was aware that they were close to the stall speed, they did not appear to be appropriately concerned. ALPA believes that they did not perceive the speed decay as a high-risk situation, primarily because they lacked an adequate understanding of the performance limitations and implications. Their comments and actions suggest that they may have thought they that they could halt or possibly reverse the speed decay. The fact that the Captain left the cockpit just after level-off suggests that he was convinced there was no problem, and this likely sent a strong message to the F/O that there was no immediate hazard.

The crew's previous experience in propeller airplane and the CRJ simulator may have resulted in their false perception that the airplane would easily accelerate to cruise speed after reaching FL 410. It is true that at lower altitudes, the CRJ has sufficient thrust to accelerate from airspeeds near the stall speed. This would certainly have been true for the majority of altitudes and weights that these crew members had flown in the training and operational environment.

The performance degradation at level-off seemed to take the crew by surprise, as exemplified by the Captain stating "yeah, that's funny, we got up here, it won't stay up here." This clearly demonstrates either the Captain's lack of understanding of, or familiarity with, the actual performance limitations of the airplane. The Captain finally realized that they would not be able to maintain either their airspeed or altitude, but the F/O had very little verbal reaction to the Captain's annunciation of this situation.

Level D simulators are intended to enable flight crews to develop their initial familiarity with the airplane performance and handling characteristics, and it follows that inaccurate simulator modeling can introduce the potential for incorrect training or negative reinforcement. In post accident evaluations by the FAA, the CRJ simulator was shown to have poor low speed fidelity at high altitudes, and the FAA reported that the simulator "appeared to have less drag at FL 410 than the airplane." The FAA report noted that at "165 knots, the Pinnacle accident FDR shows that with a 94% N1 setting, the airplane was decelerating in level flight. In the simulator, at 94% N1, the airplane was accelerating and would not decelerate until an N1 of approximately 87.5% was set." An independent and informal ALPA evaluation of a third party Level D CRJ simulator indicated that, when configured to the accident airplane weight/CG and the ambient temperature, the simulator performed similar to that behavior identified by the FAA. The simulator was significantly overpowered, and would not exhibit any airspeed decay until the power was reduced to 85% N1.

The FAA Advisory Circular on simulator standards (AC 120-40B) specifies only a very limited number of test conditions for the purposes of simulator fidelity evaluation. ALPA firmly believes that all simulators used for Part 121 pilot training should accurately model actual airplane performance throughout the entire flight regime.

### 5.2.4 Hazard Event 7 – Stick Shaker and Pusher

Event Summary: The airplane continued to decelerate at FL 410, and prior to receiving a clearance from ATC to descend as requested, the stick shaker and then stick pusher activated. The crew appears to have attempted to modulate the pusher inputs in an effort to simultaneously preclude significant altitude loss yet still avoid stalling the airplane. The resulting divergent pitch oscillations caused the airplane to depart from controlled flight and the engines to flame out.

Based on the radio communications by the Captain, and the fact that he was also the crew member to temporarily leave the cockpit, it appears that the F/O was the pilot flying (PF) at level off. It can never be known with absolute certainty who manipulated the flight controls prior to and into the upset, or why they responded as they did. According to investigative evidence, both crew members had only been exposed to normal Pinnacle stall training, which is conducted in the simulator at a 10,000’ altitude and at average airplane weights. This training emphasizes minimal altitude loss, using power and pitch for recovery. In the simulator exercises, the airplane responds readily to the inputs, and pilots have little or no difficulty meeting the performance criteria.

At FL 410, the CRJ performs far differently than it does at 10,000’. Given the flight crew’s stall training experience and their lack of familiarity with high altitude operations, it is highly likely that this crew fully expected the airplane to perform and recover at FL 410 just as it did at 10,000’. Review of the FDR data shows that the crew did attempt to recover to their previous pitch attitude, but this soon became a divergent oscillation. Like the vast majority of their fellow Pinnacle pilots, neither one had ever been exposed to stalls at high altitudes, particularly at FL 410. Neither the CVR nor FDR reveal any indication that the crew applied maximum thrust, but since the climb and FL 410 cruise thrust values are virtually identical, it is possible that this accounts for the crew’s apparent failure to add power, instead relying solely on pitch inputs to maintain altitude and avoid stalling.

On November 30, 2004, the FAA New York Aircraft Certification Office (responsible for the Bi-lateral type certification of the CRJ), recommended that Transport Canada require the modification of “...the airspeed tape display software to accurately depict the top of the Low Speed Awareness ...” speed because the FAA had determined that “...the [Pinnacle] stick shaker had activated 10 knots above...” this speed. Pinnacle crews are taught that the top of the Low Speed Awareness Band (‘red band’) indicates the airspeed at which the stick shaker will initially activate. In other words, the shaker (and likely the pusher as well) clearly caught this Pinnacle crew by surprise because it erroneously activated at least 10 knots higher (and hence sooner) than the crew's instrumentation indicated that it would or should have.

ALPA has not been able to determine the results of this FAA recommendation, or whether the recommended modifications have been made to CRJ software. Furthermore, ALPA has not been able to obtain any confirmation that Bombardier, Transport Canada or the FAA has made CRJ operators and flight crews aware of this erroneous flight software.

The functioning and 'startle factor' of the stick pusher must also be addressed. Pinnacle flight training rarely exposed crews to stick pusher activation, and there was no guidance or instruction anywhere in the training regimen on how a pilot is to respond to a stick pusher activation. There is no evidence to indicate that either of the accident crew members were ever exposed to the CRJ stick pusher. Stick pusher activation and release occur fully and without any explicit or dedicated warning to the pilot. The stick pusher actuates with a force of 80 pounds at the control wheel, and when it releases, the column is backdriven by elevator airloads to its approximate previous position. According to Bombardier, this system is highly damped, and there is very little overshoot when the pusher releases and the column returns to its trimmed position.

When the pusher activated, it would have been a reflexive reaction for one or both pilots to reach out and grab the control wheel in an attempt to modulate the column and airplane motion. The CVR indicates that it is likely that the F/O was the crew member who was initially on the controls, since he stated "I got it" three seconds after the first pusher activation. Evidence suggests that while one or both of the pilots were resisting the column's forward motion in an attempt to control the pitch attitude, the pusher deactivated, and the crew's approximate 80 lb pull was no longer opposed by the pusher. This apparently caused the column to move aft past neutral. This column motion, in combination with the airplane trim and speed, resulted in another pitch-up, which in turn activated the pusher again. This cycle repeated several more times, and eventually the airplane stalled.

The behavior of the airplane when it experienced the stick pusher on takeoff was far different from the behavior at FL 410. At takeoff, the pusher activated, the crew responded by pulling the column to resume the climb attitude, and the climb continued uneventfully. This may have provided the crew with the impression that the pusher could be responded to similarly at higher altitude. However, the flight crew was not exposed to stalls at high altitude, and when combined with the startle factor of premature shaker and pusher, they therefore responded inappropriately.

The NTSB has examined the issues of stall training and simulator fidelity in several other accidents. The FAA did not respond fully to the intent of the NTSB's recommendation from the 1998 Airborne Express DC-8 accident at Narrows, VA, although there have been a several initiatives to address the development of adequate stall training. One stemmed from efforts to address loss of control accidents. The second was an update to the 1998 industry- and government-developed Airplane Upset Recovery Training Aid.

Recently, ALPA participated in the FAA Aviation Rulemaking Committee (ARC) to review and recommend changes to Part 121 Subparts N and O, which address training and checking. The

ARC recommended significant changes to Part 121 training and checking requirements, and the NPRM with these changes is expected by the end of 2006.

### 5.2.5 Hazard Event 8 - ATC Communications

Event Summary: Although the crew definitely knew that they had a dual engine failure (DEF), their communications with ATC about the nature of their problem were elusive. They did not notify ATC that they had a DEF until 14 minutes after the upset, which was less than 6 minutes before impact.

Immediately following the upset and recovery, the Captain was the pilot communicating with ATC. His transmissions indicate that he was reticent to clearly admit the dual engine failure to ATC. However, instead of using simple and clear terminology, the Captain used convoluted and ambiguous sentences that appear to have been an attempt to intentionally mislead ATC, suggesting to ATC that the situation was under control when it actually was not.

Since no-one else but the flight crew flight crew contributed to or participated in the decision and method regarding the climb to FL 410, and the DEF was a result of their mishandling of the airplane instead of any externally induced (and therefore unavoidable) factors, it is highly likely that the Captain was well aware of his responsibility for this predicament, and that he therefore wanted to minimize the negative consequences. If the DEF had been caused by some unavoidable event such as hail ingestion or clear air turbulence, it is more likely that both crew members would have perceived themselves as ‘victims’, and would have been much more willing to openly admit their predicament to ATC. Instead, this DEF was essentially a self-induced problem, and therefore the crew members were probably seeking (possibly subconsciously) to minimize blame and/or punishment.

Furthermore, since it is highly likely that the crew knew the engines had failed due to the airplane’s dynamics, and that there was likely no permanent problem with the engines or airplane, they had the legitimate expectation that the engines could easily be restarted. This presumption relegated the issue of a successful restart to a question of “when”, not “if”, it would permit the flight to continue on to destination. This satisfied the ‘skin’ and ‘tin’ elements of the STT scheme, and the crew’s remaining challenge was to preserve their ‘tickets’. This mindset clearly influenced the nature of the crew’s communications with ATC.

However, as the investigation revealed, engine core lock invalidated the crew’s presumption that the flight was not in any significant physical danger. At the time of the accident, core lock was a latent hazard unknown to CRJ flight crews and operators, and was therefore not considered by the accident flight crew as they prioritized their tasks. As it became more evident to the crew members that a successful engine start might not be accomplished, their risk perceptions and reactions began to change, and this is apparent in their later ATC communications.

The risk associated with the loss of all engines in flight varies as a function two primary factors; airplane altitude, and the reason for the engine failure. Altitude decreases risk by providing time to restart the engines, or to glide to a successful landing. Even after stall recovery, the airplane had sufficient altitude for several engine start attempts. Undetermined or irreversible engine failure modes (e.g., fuel exhaustion, hardware failure, etc.) present significantly higher risks than do temporary or reversible events such as turbulence or inadvertent shutdown. The engine failure mode (upset-induced) was known, and presumed by the crew to be a temporary condition.

These two primary factors influencing risk were both strong indicators for a successful restart, and the Captain based his communications with ATC on this premise. Regardless of the level of presumed risk, the most conservative approach to coping with a DEF is to divert to a suitable landing site and to establish an appropriate airspeed (such as best glide). Advising ATC of such a situation can reduce flight crew workload by using ATC to assist with any diversion decisions and activities.

The following sequence of events shows that the crew's perception of the risk did change over time. The stall occurred at approximately 02:55:00, and approximately six seconds later Pinnacle 3701 declared an emergency. At 02:55:32, ATC called Pinnacle 3701, and the crew responded eight seconds later with "stand by." The airplane regained controlled flight at approximately 02:55:55. The crew then took more than four minutes from their "stand by" to return their call to ATC, responding at 02:59:46 with a request for 13,000' (the top of the APU-assisted start envelope).

The crew was still conducting the DEF checklist when the next ATC communication (asking whether Pinnacle 3701 could accept a frequency change) was received at 22:00:57, and Pinnacle 3701 replied with another "stand by". Pinnacle 3701 accepted the frequency change two minutes later, and then ATC inquired as to the nature of the emergency. This was eight minutes after the upset, and the airplane was now at 19,500'. Over the course of the next minute, the crew avoided answering the ATC query clearly, and did not correct ATC when ATC said that they understood that Pinnacle was in controlled flight with one engine operating. Finally, fourteen minutes after the upset, at 22:09:06, at the command of the Captain (apparently prompted by the failure of the APU-assisted start) the F/O informed ATC that they had a dual engine failure. Shortly thereafter, at the suggestion of ATC, they requested the closest airport.

Had the crew properly prioritized their actions in accordance with the STT scheme, it is highly likely that the accident would not have occurred. The pre- and post- accident DEF checklists are clearly not in accordance with the STT scheme. They presume success, and only contain diversion as the last item, which would only be reached if all restart attempts fail. This checklist should contain diversion as one of the most immediate actions, in order to prompt the flight crew into enlisting the assistance of ATC.

### 5.2.6 Hazard Event 10 - Descent Airspeeds

Event Summary: The investigation revealed the criticality of achieving these speeds. In contrast, the checklist did not convey the necessity of achieving these speeds, and the crew consequently failed to achieve these required speeds.

Compliance with checklist procedures is necessary to ensure safe operations. Compliance with abnormal or emergency checklist procedures is even more critical, for several reasons. First, the fact that the checklist is being conducted indicates that there is a problem that must be addressed. Second, by their very nature, abnormal or emergency procedures are not activities that flight crews conduct very frequently, and flight crews will lack intimate familiarity with those procedures unless they have been thoroughly trained in them. Finally, some abnormal procedures can be complex and lengthy, and deviations from them can lead to unsuccessful outcomes.

The DEF checklist procedures contained two separate airspeed reference for different portions of the procedure. The 240 knots target is intended (but not guaranteed) to prevent N2 from going to zero, while the 300 knots value is intended to provide sufficient N2 for the windmill start.

With this background and the accident scenario in mind, it can safely be concluded that this flight crew was highly motivated to conduct the DEF accurately and effectively. However, this crew did not or could not execute the windmill start procedures in accordance with the checklist designer's intent. Inability to properly execute portions or all of a checklist can be due to a number of factors, including deficient training, poor checklist design, task saturation, distractions and physiological limitations.

The checklist called for maintaining a speed between 170 and 190 knots for the APU-assisted start. The Captain quickly determined that it was better to fly at this slower airspeed than at the higher airspeed, probably because he was aware of this speed on the checklist and since the descent rate was significantly higher at 240 knots (4,000 ft/min vs. 2,000 ft/min). Flight at 170-190 knots would double the time the airplane could remain aloft.

Shortly after the upset, it is likely that, to the flight crew, the overall risk to the flight appeared low. The airplane was still fully controllable, there was emergency power, and they had a checklist for their specific anomaly. These factors probably helped reduce the crew's immediate sense of risk.

The DEF checklist could have provided a false sense that flying slower than 240 knots was a low risk situation. The checklist's use of the word "target" for airspeed is vague and unusual, and different from "minimum" or "maximum," which clearly communicate the requirement. Additionally, the other conditional words modifying the checklist speeds add more uncertainty to any need to adhere to the stated speed. Some of these checklist speeds seemed more recommended than mandatory.

The 240 knots descent was probably perceived by the crew as a very high risk maneuver, since it yields a high descent rate. When the Captain observed that this speed was not achieving any positive N2, he aborted the windmill start procedure and began preparing for the APU-assisted engine start. In contrast, the APU-assisted start procedure presented a lower perceived risk since it resulted in a significantly reduced descent rate.

The crew had never been exposed to the 300 knots descent for windmill start in training. The checklist provided no information regarding how long it would take to accelerate, how much altitude would be lost, and what pitch attitude was required to achieve 300 knots. It is not surprising that the crew approached this speed incrementally. Achieving 300 knots results in an abnormal nose down attitude and a very high descent rate, both of which can be disconcerting to a flight crew. In comparison, the APU engine start procedure results in a much lower-risk descent.

The DEF checklist did not state a specific reason for the 240 knot speed. The investigation has made it clear that the checklist should state that N2 is the critical parameter. The checklist should also state that 240 knots is the minimum airspeed likely to maintain positive N2, and that allowing N2 to decrease to zero may prevent a successful restart.

### 5.2.7 Hazard Event 11 – Diversion

Event Summary: The flight crew did not discuss diverting to any alternate airport until the Captain commanded the F/O to request ATC assistance in guiding them to the "closest airport," and the F/O responded immediately. This request was made approximately fourteen minutes after the initial upset, when the airplane was at an altitude of approximately 9600' (~8600' AGL).

It is apparent that shortly after the upset recovery, this crew had a high expectation that they would successfully restart both engines. Based on the information and guidance available to the flight crew at the time, this expectation was justified. Furthermore, it is reasonable to presume that any other CRJ flight crew would have had similar expectations in these circumstances.

As the airplane descended and the crew attempted to restart the engines, their perception of the probability of a successful start began to diminish. As the likelihood of an unsuccessful start increased, it is likely that one or both crew members began to consider the necessity for an alternate airport or even an off-airport landing. This was not discussed between them until the Captain unilaterally decided that ATC should be asked for the closest airport.

'Diversion' is the last item on the DEF checklist. There are several compelling reasons for a DEF checklist to include 'diversion' as one of the first items. First, people do not always think clearly in stressful, task-focused, high workload, or unfamiliar situations such as a DEF. Conditions such as high stress, distraction or task saturation can often mask obvious solutions or impede robust decision-making. 'Diversion' as the last step of a checklist deprives a crew of the 'parallel processing' opportunity to concurrently proceed towards a safe landing site while performing restart procedures. Finally, the sooner a diversion is made, the higher the diversion altitude will be, and the more likely it is that a suitable landing field will be within gliding distance if the restart attempts are unsuccessful.

Crews are trained to execute checklists methodically, which conveys the implicit message that the checklist is the ultimate guidance and that it should be executed as written. Without 'divert' at or very near the top of the DEF checklist, the checklist presents the perspective to the crew that they will not need to consider an alternate or off-airport landing. Until the APU-assisted engine starts attempts failed, the crew's actions and discussions indicate that they considered a successful engine start the only outcome, instead of only one of several possible outcomes. The flight crew’s lack of exposure to the DEF scenario in simulator training added to the unfamiliarity and stress, and perhaps focused their thinking too much on the step-by-step items in the checklist, instead of causing them to evaluate the overall situation.

Although they had difficulty accomplishing the windmill start checklist procedures and saw that their altitude was rapidly decreasing, the crew was probably reassured by the prospect of an APU-assisted start, due to the fact that it was a familiar, often-used and successful procedure. This probably caused them to believe that an engine start was still possible and that, although they would restart the engines at a much lower altitude than they had originally expected, there was still no need for an alternate- or off-airport landing.

Based on what was known by CRJ operators and pilots at the time of the accident, this confidence in the APU-assisted start was reasonable. After the windmill start attempts but before the APU-assisted attempts, the crew’s discussions and actions indicate that they still perceived the need for a diversion as low or non-existent. After abandoning the windmill start and two unsuccessful APU-assisted start attempts, the Captain instructed the F/O to report the DEF to and request the nearest airport from ATC.

An examination of another dual engine failure accident may provide some additional insight into the Pinnacle crew’s behavior. On March 20, 1994, a Canadair CL-601 (the predecessor to the CRJ) operating on a night positioning flight experienced a dual engine flameout (NTSB event CHI94FA116) during cruise flight between FL 370 and FL 410. Based on several pre-takeoff and in-flight events, this crew had good reason to suspect that their engines would not start again after they flamed out at FL 410. As the airplane descended through approximately FL 370, the crew reported the loss of both engines and requested ATC vectors to the nearest airport. This airplane landed gear up in a field.

This CL-601 accident has several similarities to the Pinnacle accident, but also some significant differences. Unlike the Pinnacle crew, the CL-601 crew was well aware of the potential for engine problems on this flight. Furthermore, it is likely that due to the nature of their engine problems, this CL601 crew immediately recognized that their chances for a successful restart were probably not very good, and that diverting to an alternate airport was best accomplished as soon as possible. Although it is impossible to assess whether or how much certain additional factors influenced the CL601 crew’s decision to divert, the two following items warrant consideration:

- Since the CL-601 crew had not directly induced the engine failures, they may have felt more like victims of circumstance, and thus would have been more willing to readily admit their predicament and seek ATC assistance.
- Since the CL-601 was flying over a sparsely populated area of the US, this CL-601 crew might have had a heightened awareness of the relative paucity of available airports, and therefore may have been more inclined to begin the divert process as soon as any indication of a serious problem arose.

This information reinforces the need to ensure that ‘diversion’ procedures are included near the top of DEF checklists.

### 5.2.8 Hazard Event 12 – Forced Landing

Event Summary: The crew did not begin to discuss an off-airport landing until forty-nine seconds before impact.

Approximately four minutes elapsed between the time the airplane broke out of the overcast and ground impact. The first two minutes of this period, the crew was simultaneously conducting engine restart procedures and searching for the airport. Approximately two minutes before impact, when the airplane was about 2,500' AGL, the crew's focus turned solely to locating the airport and runway, and the F/O announced that he had the JEF airport beacon in sight. Eight seconds later, the landing gear warning horn sounded. Thirty seven seconds after the gear horn, the Captain stated that they were not going to make the field, and the F/O echoed that sentiment twenty-one seconds later. Two seconds later, the Captain suggested finding a road to land on. One minute after the gear horn, and only twenty seconds before initial impact, the Captain stated that he wanted to keep the gear up to avoid going "into houses here." Five seconds later, the F/O spotted a road and began guiding the Captain towards it.

The Pinnacle training program does not include forced landing or ditching in either the initial or recurrent segments. The Pinnacle 'forced landing' procedures in the QRH call for configuring and slowing the aircraft by approximately 2000'AGL but Pinnacle does not provide any guidance or training regarding the glide ratio of the airplane.

The evidence suggests that the crew's fixation with reaching JEF prevented them from considering an off-airport landing until they were very low. Training flight crews in forced landing procedures, and providing them with the necessary glide performance information would greatly enhance their performance in such situations. Amending the DEF checklist by moving 'diversion' towards the top of the checklist would provide an additional defense against an incident or accident.

## 5.3 Non Links in the Accident Chain

### 5.3.1 Hazard Event 1 – Takeoff and Climb

Event Summary: The airplane lifted off, leveled off just above the runway, accelerated and then was pulled up aggressively, triggering a momentary stick shaker. Also, there were several points in the climb that the crew assertively maneuvered the airplane.

The takeoff maneuver was apparently intentional on the part of the flight crew. It is likely that the captain was demonstrating a high performance takeoff maneuver for the F/O. Such a takeoff can be exciting, and is an opportunity for the crew to become more proficient in handling the airplane. It is highly likely that the stick shaker was an unintended consequence of the takeoff maneuver. Momentary stall warnings on takeoff are extremely rare, but the crew responded promptly and correctly by lowering the nose.

As executed, the pitch and roll maneuvers in climb also presented little or no additional physical risks. If it were common at Pinnacle for crews to abandon their normal standards of performance in non-revenue flights, this would have further reduced the crew's perception of the risk. The crew certainly knew that the airplane was capable of being flown far more aggressively than it is in normal revenue operations. Therefore, the crew members' perception of physical risk of these maneuvers was also likely very low or non-existent.

Given that it was night and that there were no other persons on board the airplane, it is likely that the flight crew believed that there would be few, if any, witnesses to observe or report this takeoff. Also, since Pinnacle did not have any flight data monitoring program in place, the risk of detection of these events by the company was further reduced. The crew likely perceived the risk of any resultant administrative action as extremely low or non-existent.

There is insufficient factual information to determine whether these actions were behaviors isolated to this Captain, only to these two crew members, or whether this was a typical habit pattern for Part 91 operations at Pinnacle. There did not appear to be a specific policy against aircraft maneuvering on repositioning flights. Flight crews are expected to be confident operators of their equipment, which may include need for aggressive maneuvering. Crews benefit from having an opportunity to safely experience airplane handling in such an environment.

### 5.3.2 Hazard Event 2 - Crew Seat Exchange

Event Summary: Analysis of the CVR and FDR information indicates that the Captain and F/O switched seats sometime during the climb, so that the F/O moved to the left seat and the Captain occupied the right seat.

In normal and most abnormal operations, the CRJ is easily operated in flight from either crew seat. Camaraderie between the Captain and F/O probably led to the Captain offering to exchange seats with the F/O. The captain was very familiar with the right seat, and the F/O was also generally familiar with the left seat. Since there were no other persons on board the airplane, there was negligible risk that the seat exchange would be detected by the company, especially if the crew members had planned to re-exchange seats prior to landing, making the administrative risk minimal.

Analysis indicates that the crew members returned to their assigned seats at approximately 22:09:06 when the airplane was at approximately 10,000 ft during the descent.

Seven months after the accident, Pinnacle issued Revision 25 to its FOM, apprising flight crews of the required crew complement and duty stations. The fact that the company had to address this fundamental rule at all is indicative of standardization problems with Pinnacle's flight operations.

### 5.3.3 Hazard Event 5 – F/O Oxygen Mask

Event Summary: FAR 91.211(b)(2) requires that, at altitudes at and above FL 350, one pilot must wear his oxygen mask any time the other pilot leaves the flight deck. Once the airplane leveled at FL 410, the Captain got up and went aft to the galley, and the F/O should have, but did not, don his oxygen mask.

There are a number of reasons that either singly or in combination could have precluded the F/O from donning his mask in the Captain's absence from the flight deck. Given the short stage lengths of most Pinnacle CRJ flights, and the strict cockpit security measures in place after 9/11, the new-hire F/O might have had limited or no exposure to being left alone on the flight deck above FL 350, and simply was not habituated into this reaction.

The Pinnacle CRJ galley is located directly behind the cockpit. The F/O likely expected that the Captain would only be gone for a very brief time (per the CVR, the Captain was out of his seat for approximately one minute), that the Captain would be no more than a few feet away from the cockpit, and that the cockpit door would remain open the entire time. While the F/O's failure to don his oxygen mask was a violation of FAR 91.211(b)(2), it could have been intentional or unintentional.

### 5.3.4 Hazard Event 9 –Crew Oxygen Masks

Event Summary: As the cabin altitude rose above 10,000' the Crew Alerting System (CAS) sounded a 'Cabin Pressure' alarm. The F/O perceived the hazard that the crew was not on oxygen, and announced his concerns to the Captain. The Captain was slow to react and don his mask.

Most likely because he was task saturated and focused on the DEF checklist, the Captain was agreeing with the F/O but not donning his mask, or instructing the F/O to don his mask. Certainly, restarting the engines was this crew's highest priority, and due to the critical need to get one or more engines running, the Captain was obviously intent on adhering to the DEF emergency checklist procedures and likely not paying attention to other events or concerns.

When flight crews attempt conduct checklists that they are unfamiliar with or have not been trained on, it is reasonable to expect that they will be slower and more methodical in their actions, and will tend to ignore other priorities or inputs. Although the F/O correctly identified and verbalized the risk (not donning O2 masks), the captain was unable to process or act on this input. The Captain likely thought that foregoing his O2 mask was not a significant risk, or that donning it was a much lower priority task than completing the DEF checklist successfully.

An amendment of the DEF checklist and training to include reminders to don oxygen masks (if appropriate) would assist crews in executing this task. All emergency and abnormal checklists should be evaluated in detail to ensure that they are well designed and provide appropriate guidance to enable the crew to successfully cope with the emergency. Crew members who are subjected to sensory overload or task saturation in emergency situations will load shed mental and physical tasks in order to focus on those having the highest priority.

## FINDINGS

1) The Captain and the First Officer were properly certificated and qualified in accordance with Federal Aviation Regulations. The flight crew members possessed valid and current medical certificates appropriate for 14 Code of Federal Regulations Part 121 flight operations.

2) The Captain and First officer were trained in accordance with Pinnacle Airlines training programs and policies.

3) The Pinnacle Airlines training program met the minimum requirements of the applicable FARs and FAA guidance.

4) Prior to being employed by Pinnacle Airlines, neither crew member had any previous experience operating turbojet aircraft, or operating above FL 250.

5) Pinnacle Airlines expanded rapidly in the few years preceding the accident, and neither Pinnacle nor the FAA was able to adequately manage operational control.

6) Prior to the accident, Pinnacle System Operations Control ('dispatch) was understaffed.

7) Prior to the accident, Pinnacle airlines did not have any functional safety information collection and analysis programs.

8) Pinnacle Airlines did not have any formalized mechanisms to provide feedback and coordination between the training organization, the check airmen, and the line pilots.

9) The Captain and First Officer performed several unusual pitch, roll and yaw maneuvers during the takeoff and climb.

10) No unusual airplane maneuvers were performed between FL 290 and the level off at FL 410.

11) The crew climbed the airplane to FL 410 using a climb rate of 500 fpm, instead of adhering to a climb speed schedule.

12) Prior to the accident, there was no Pinnacle guidance available to crew members regarding minimum climb speeds.

13) Prior to the accident, Pinnacle training and guidance regarding high altitude operations was minimal.

14) During the climb and after level-off at FL 410, the aircraft speed continuously decayed.

15) CRJ simulators do not accurately replicate aircraft performance at FL410; independent tests on two separate simulators erroneously exhibit thrust/drag performance far superior to the actual aircraft.

16) The crew recognized that the aircraft could not remain at FL 410, but before ATC could clear them for lower, the stick shaker and pusher activated.

17) Prior to the accident, Pinnacle training and guidance did not contain any information regarding aircraft stalls at FL 410.

18) According to the FAA, the stick shaker erroneously activated at a speed at least 10 knots higher (and hence sooner) than the crew's instrumentation indicated that it would or should have.

19) Prior to the accident, Pinnacle did not provide training or guidance regarding stick pusher procedures.

20) The crew response to the multiple stick shaker and pusher activations at FL410 precipitated the departure from controlled flight and dual engine flame out.

21) Prior to the accident, Pinnacle did not provide training on dual engine failure procedures.

22) Prior to the accident, the CRJ dual engine failure checklist was difficult to use and incomplete:
   - The checklist did not contain any reference to N2, the critical parameter necessary to avoid core lock.
   - The referenced airspeeds appeared to be discretionary rather than mandatory.
   - 'Diversion' information was not provided until the end of the checklist, instead of near the top/beginning.
   - The need for supplemental oxygen is not noted on the checklist.

23) Subsequent to the accident, the CRJ dual engine failure checklist was modified, but 'diversion' information still is not provided near the beginning of the checklist.

24) Although the crew properly configured the airplane for an APU-assisted start and made multiple restart attempts, they were unsuccessful.

25) The engines failed to restart due to a phenomenon known as 'core lock'.

26) Although core lock was known to the airplane and engine manufacturers, CRJ certificating agencies, operators and pilots were unaware of this hazard until after this accident.

27) Fatigue and mild hypoxia can degrade crew performance, but there is insufficient evidence to determine whether these factors affected this crew's performance.

## SAFETY RECOMMENDATIONS

The Air Line Pilots Association offers the following safety recommendations to the FAA:

1) Complete and publish, by December 2006, the Notice of Proposed Rulemaking (NPRM) on amendments to 14 CFR Part 121, Subparts N and O, and related Parts. This NPRM should include, to the maximum extent possible, the ARC recommendations that were developed to improve critical safety areas in training, checking and qualification standards for flight and cabin crew, and dispatchers.
2) Conduct (using experienced air carrier inspector resources) an assessment of regional air carrier training and proficiency checking programs of present and future turbojet operators to determine the adequacy of those programs, and to include consideration of the recommendations of the pertinent Flight Standardization Board (FSB) reports.
3) Require air carrier inspectors to review existing ground training programs of their turbojet certificate holders to ensure that these programs include significant information that is peculiar to the operation of turbojet airplane.
4) Require Level C and D simulators to accurately replicate aircraft performance and handling characteristics in all flight regimes.
5) Require air carrier inspectors to review existing flight training and proficiency checking programs of their turbojet certificate holders to ensure that they require Level C and D simulator demonstrations of flight conditions at or below minimum drag airspeeds, stall warning systems (stick shaker/pusher), and high altitude stall recovery techniques.
6) Require operators of the CRJ airplane to include, in their flight crew ground training programs, information on the CF-34 core lock phenomena and the emergency procedures needed to handle a dual engine failure.
7) Require operators of the CRJ airplane to include, in their Level C and D simulator flight training programs, demonstrations of the dual engine failure emergency procedures for both the windmill and APU restart.
8) Encourage the Airline Transport Association (ATA) members to share information on the industry's best practices in pilot training, proficiency, checking and safety risk management programs with their regional air carrier code sharing partners.
9) Require air carrier inspectors to review the FCOMs of their certificate holders to ensure that flight crews have ready access to airplane performance information for normal flight regimes, including but not limited to climb and cruise profiles.
10) Encourage the ATA, RAA and air carrier operators to voluntarily adopt the Advisory Circular on Safety Management System (SMS). This AC was developed to promote robust safety cultures and safety risk management processes within a quality management system framework that consolidates and enhances internal evaluation and monitoring type programs.
11) Ensure that qualified and experienced Part 121 inspectors are assigned to manage regional air carrier certificate holders.

12) Assess FAA air carrier inspector orientation and training courses, and revise as necessary, to ensure that inspectors have the knowledge, skills and abilities to effectively evaluate, assess and validate air carrier administration and safety programs and systems.

13) Require air carrier inspectors to thoroughly assess and validate air carrier training program reduction proposals prior to granting approval.

14) Ensure that the necessary resources are allocated to meet the FAA's 2007 air carrier ATOS program transition goals.

15) Recommend to Transport Canada to require revision the CRJ dual engine emergency procedure checklist to include guidance on forced landing and supplemental oxygen near the top of the checklist.

16) Revise the CRJ Master Minimum Equipment List by deleting the exception that allows dispatch with an inoperative APU.

17) Support and complete the Emergency and Abnormal Situations Study initiated by the Human Factors Research and Technology Division of the NASA Ames Research Center in order to further enhance methods and criteria used in checklist development.

18) Utilize human factor specialists in the design and development of airplane normal, abnormal and emergency checklists to ensure they are designed to achieve the correct flight crew response, give consideration to interruptions, distractions and unplanned events and take into account human capabilities and limitations since these form a basis for crew member training and proficiency.

## APPENDIX 1

## TIMELINE of SIGNIFICANT EVENTS

| Time UTC | EVENT | ALTITUDE (Ft MSL) |
|---|---|---|
| 02:54:48 | Onset of stick shaker/pusher | FL 410 (40,800) |
| 02:54:49 | First indication of engine failure | 40,700 |
| 02:55:06 | Crew radios “Declaring emergency” | 39,390 |
| 02:55:20 | Last FDR data prior to blackout | 38,800 |
| 02:55:21 | Return to controlled flight | No data |
| 02:55:23 | Captain notes “Don’t have any engines” | No data |
| 02:55:38 | ADG deployed | 33,500 |
| ~ 02:59:15 | APU on line | 29,000 |
| 02:59:20 | FDR returns to operation | 28,900 |
| 03:01:30 to 03:02:15 | Windmill start attempts | 23,300 to 20,200 |
| 03:07:38 to 03:08:35 | APU start attempts | 12,100 to 10,900 |
| 03:09:06 | Dual engine failure reported to ATC | 10,000 |
| 03:09:21 | Diversion to KJEF initiated | 9,600 |
| 03:10:09 | F/O notes JEF “right in front, 15 miles” | 7,800 |
| 03:11:45 | Aircraft breaks out of overcast | 5,400 (4400 AGL) |
| 03:15:01 | Impact | 1,000 |

## APPENDIX 2

# FATIGUE

Fatigue poses a serious threat to aviation safety due to its insidious impairment to alertness and performance. Fatigue can be caused by many factors, including sleep loss, shift work, and long duty hours. Although the extent, degree and symptoms of fatigue vary from person to person, some of the most common effects are inattentiveness, fixation, carelessness, decreased vigilance, decreased memory recall, and impaired judgment. In the cockpit, these effects can result in a loss of situational awareness and poor crew coordination.

The physiological and psychological impairment from fatigue is similar in many ways to alcohol intoxication. In fact, several researchers have been able to correlate the similarities in cognitive decrements of acute fatigue with blood alcohol concentration (BAC). One study demonstrated cognitive impairment equivalent in subjects who have been awake for 17 hours to a BAC of 0.05%. One study. specifically demonstrated that the decrement in reaction time was greater for the fatigue group than the alcohol group.

Research concerning the cumulative effect of fatigue and altitude on complex task performance has demonstrated that relatively lesser amounts of fatigue, in combination with lower levels of hypoxia, may in fact produce some degree of cognitive impairment.

Individuals have no control over an acute episode of fatigue, and no amount of determination, training or "professionalism" can overcome its detrimental effects. Several recent air carrier accidents involved flight crew fatigue of varying degrees. Although these were experienced and professional flight crews, their judgment and decision-making ability were severely affected by fatigue, and many were apathetic toward their deteriorating situation prior to the accident event.

The determination of the presence of fatigue in an accident crew can be an in-depth and complicated process. It is important to understand that performance degradation due to fatigue takes place over time, not all at once. Factors affecting fatigue (and thus predictors of alertness and performance) include duration of prior wakefulness, time-on-task, consideration of circadian rhythm, total amount of sleep the previous three nights compared to the normal amount, quality of the sleep environment and the presence of any sleep disorders. A paper by Jana M. Price (NTSB) discusses several of these most common fatigue indicators. Most of these issues were not developed thoroughly in the human performance fact gathering portion of this investigation.

### Normal sleep history

The normal sleeping pattern for the captain was that he went to bed around 11:00 pm EDT and awoke around 7:45 am EDT. One can assume that this represents his normal sleep requirement. The Captain's actual wake up time the day of the accident was not reported, and there is no way to know whether the captain had received his required amount of sleep. According to Dr. Mark Rosekind, even one or two hours' less sleep than normal can result in some degree of cognitive impairment. In addition, the lack of the Captain's actual sleep time the three nights prior to the accident represents a missed opportunity to assess the possibility of a chronic fatigue situation.

Information for the first officer regarding normal sleep history and the three nights prior to the accident were not investigated.

**Time of wakefulness**
Since no actual wake up time was reported for the captain, the determination of his time awake is impossible. However, assuming that his "normal" wake up time was valid for the day of the accident, it can be assumed that he had been awake for at least 15 ½ hours at the time of the accident. This duration of wakefulness is near or in excess of the physiological limit for alertness and performance.

There was no information regarding the first officer's wake up time for the day of the accident. Because of this we have no ability to determine his time awake on the day of the accident.

**Circadian rhythm**
Humans are diurnal in nature; we are awake during the day and sleep at night. The average human requires about 8 hours of sleep a night to maintain peak mental and physical performance. However, during the 24 hour circadian cycle, there are several respective peaks and troughs of wakefulness and sleepiness. These peaks and troughs are approximate in time, and may be shifted several hours in either direction depending on numerous factors.

Maximum and lesser peaks for performance typically occur at 0900 - 1200 Hrs and 1900 - 2100 Hrs respectively. Maximum and lesser troughs for sleepiness typically occur at 0300 - 0500 Hrs and 1500 - 1700 Hrs respectively. The accident took place at 2215 CDT or 2315 EDT. Both crew members had been in Detroit (EDT) more than 24 hours prior to the accident so they were probably acclimated to an East Coast time zone (EDT). Since the accident occurred at 2315 EDT, they were both several hours past their peak performance circadian peak, and were approaching a lower point of the body's circadian rhythm cycle. An attempt to produce peak cognitive performance during a time of increasing sleepiness can result in numerous errors in judgment and ability.

**Quality of sleep**
An additional potential fatigue factor is the quality of sleep over at least three nights prior to the accident. The quality of sleep during the last sleep period prior to the accident is especially important for a fatigue assessment. The Captain's wife was seven months pregnant and they had two very young children at home. From a practical standpoint, obtaining adequate rest in this type of situation may be challenging at best. The Captain's quality of sleep for the last sleep period prior is unknown.

There was no quality of sleep history provided for the first officer, although he shared an apartment with several other pilots in Detroit. No other pertinent information regarding this aspect was obtained.

**Work history**
Work history, including number of days recently worked, hours of work each day, which time period the work was completed, the amount of time off in between work periods and time zones crossed are all important considerations for any fatigue investigation.

Recent work history was probably not relevant for the Captain since it was reported that he was off work the three days prior to the accident. However, many regional airline pilots have second jobs, and it is not clear if the Captain worked at another job during these three days. The day of the accident the Captain only had two flight legs, the deadhead segment and the accident flight.

The first officer was reported to be off October 8 –10, and working October 11 and 12. He was on reserve for the 13th and was apparently not used that day. Like the Captain, the F/O only had two flight legs on the day of the accident. No pertinent details of the previous trips were available.

**Time on task**
Both crew members departed on the first leg of the accident sequence (deadhead from DTW-LIT) at 22:19. It is assumed (but not known) that both crew members reported to the airport the customary one hour prior to departure. Since the accident occurred at 03:15, the accident crew's work day was approximately five hours, which is not a significant fatigue hazard.

**Sleep disorders**
Comments regarding both crew members medical history failed to mention any sleep disorder. However, it is unknown if the possibility of any sleep disorder was even investigated or asked of family members, AMEs, or any other treating physicians.

**Errors by the crew**
Interviews with other pilots, check airmen and family members reveal two properly trained, certified, and as reported by fellow airmen, competent pilots. Yet the investigation of this accident has uncovered numerous errors in procedures, judgment and airmanship.

However, the CVR transcript does suggest that the captain's alertness, time estimation, reaction time and cognitive abilities were not up to acceptable standards for a well trained crew member. The CVR shows that the captain never discussed or implemented a plan of action for more than the few minutes immediately ahead.

Prior to the loss of control the accident crew made several comments regarding the speed decay, but then delayed acting upon it. Increased reaction time is one behavior associated with fatigue. Apathy toward a developing dangerous situation has also been described in numerous NTSB accident reports as a behavior associated with fatigue. The observed delay in responding to the speed decay would not be expected from a properly trained and certificated professional flight crew, and suggests that other factors were adversely affecting their performance.

Cognitive learning and memory are also affected by fatigue. These pilots were never given specific simulator instruction for a dual engine failure or high altitude stall training. However, they had received in-flight engine restart and stall training that was significantly different from what they experienced on the accident flight. The accident crew had to cope by using a skill set learned in a situation that was dramatically different from the situation that they were faced with.

Fatigue will affect the ability to use previously acquired information or knowledge to formulate a plan of action to deal with an unknown situation. The workload and cognitive demands placed on this crew immediately after the loss of control were extremely high and would likely qualify as a sensory overload situation. This crew had no training for recovering from a dual engine failure.

According to Dr. Dan Peterson (2003), "the human being cannot help but err given a heavier workload than one has the capacity to handle". The workload can be physical, psychological or physiological, and 'capacity' refers to physical, physiological or psychological endowments, current state of mind, and current level of knowledge or skill for the task at hand. Additionally, factors such as drugs, alcohol, fatigue and hypoxia can temporarily reduce an individuals' 'normal' capacity.

The last minute prior to impact, the crew had very little effective communication between them. Preparing for an off airport landing would certainly be a time when extensive communication would be expected, yet this crew exhibited little or no interaction. With the exception of the last minute prior to impact, the captain appeared to be in denial that an off airport landing could possibly occur. At no point did he ever suggest or discuss with the first officer that an off-airport landing was a realistic possibility.

In fact, at 2205:33 he did just the opposite, and tried to reassure the first officer that everything would be OK. Both task fixation and the inability to plan have been associated with fatigue. Even after an off airport landing was inevitable, the Captain never slowed or configured the airplane for the impact.

There is no physiological test to determine if fatigue was present in an individual involved in an accident. The accepted technique to evaluate for the presence and role of fatigue is to review the above-discussed factors and make a reasonable determination.  Although there may be several explanations for the crew's behavior, fatigue and its impairment on higher cognitive functioning is one possibility. The above information suggests that fatigue may have affected this accident crew, and may explain some of the puzzling omissions and commissions demonstrated in this accident sequence. However, more evidence is needed better understand what, if any, contribution fatigue made to the accident sequence.

## APPENDIX 3

## HIGH ALTITUDE PHYSIOLOGY and HYPOXIA

At the time of the upset, the crew had been exposed to a cabin altitude of 8,000 ft for approximately nine minutes. While the FARs do not require supplemental oxygen for crew members until they have been exposed to a 12,500 ft-pressure altitude for more than 30 minutes, there are numerous reports and studies showing that cognitive performance can degrade at much lower altitudes. Frisby (1973), Crow (1971) and Green (1985) showed that for some test subjects, symptoms of hypoxia can occur at altitudes significantly lower than what is required by 14 CFR 91.211.

The time it takes for hypoxia symptoms to appear depends on the altitude, and can range from seconds to hours. Numerous factors can affect this time, including exposure to alcohol, medications, fatigue, and whether the individual is a smoker. A paper by Mertens (1986) showed that cognitive skills as measured by the commonly used Multiple Task Performance Battery (MTPB) degraded as altitude increased, and that this degradation is worse when the subject is fatigued.

Real world data regarding hypoxia shows that some pilots are being affected at altitudes similar to what the accident crew was experiencing. The Australian Army made a study of helicopter pilots (Smith, 2005) and found 60.9% of the pilots surveyed reported one or more symptoms of hypoxia below 10,000 ft. There were 17% who reported four or more symptoms consistent with hypoxia, the most common being difficulty with calculations (45%), but also noting delayed reaction time (38%) and mental confusion (36%). Of the reports having potentially significant operational symptoms, the average altitude was 8,462 ft. While we do not claim that the accident crew's actions during the takeoff and climb can be explained as cognitive impairment, this scenario may well explain the crew's lack of rapid response to the degrading airplane performance at the top of the climb, leading to the upset.

The crew did eventually don their oxygen masks, though this was amid numerous arrested attempts. It was only after the crew donned their oxygen masks that they communicated to ATC and admitted to having a dual engine failure and requested vectors direct to the nearest airport.

Many line pilots may not know what their symptoms are to hypoxia, and particularly are unlikely to have experienced it in an inflight scenario or simulated one. Mild hypoxia remains a controversial subject for when or where one is affected and how.

## APPENDIX 4

# Selected ASRS Reports

### Search Keywords: "Too Slow"

| | Ref. # | Date | Aircraft Model | Flight Level | Event Summary |
|---|---|---|---|---|---|
| 1 | 104201 | Feb-89 | Medium large transport turbojet | 350 | ATC report. Controller only controls from FL 350 and above. Aircraft descended because they indicated too slow. Additional report from pilot indicated charted performance would allow FL 350. Descended without clearance on perceiving light buffet. |
| 2 | 191785 | Nov-91 | DC-10 | 390 | Unable to climb in time allotted by ATC (FL 350 to 390 in 6 minutes). Had to descend and accelerate then climb at 100 – 300 fpm. Regretted not declaring emergency. |
| 3 | 316675 | Sep-95 | Comm'l fixed wing | 360 | Airspeed decayed in climb with turn, noted by FO, and acknowledged. Got stick shaker. Too much faith in electronics. |
| 4 | 331940 | Mar-96 | MD80 | 330 | Encountered turbulence and got airspeed and altitude fluctuations. Got too slow and lost 1,000 ft. |
| 5 | 363571 | Mar-97 | MD80 | 330 | ATC asked for 1,000 fpm from FL290 to 330. Airspeed bled off and crew advised ATC unable and descended to FL290. |
| 6 | 464100 | Feb-00 | SA226 | 170 | Light rime icing on wings. Center asked to slow to 150 knots, reduced power and increased but slowed further, began to descend. Descended to FL166 before accelerating enough to climb. |
| 7 | 475292 | Jun-00 | DC9 | 350 | Check airman with IOE FO. FO noted they were slow in climb and got yoke lateral oscillations at FL 330. Got stick shaker and descended to FL 310. Reportedly repeat problem for this check airman. |
| 8 | 478621 | Jul-00 | B737 | 350 | Unable to maintain altitude and airspeed, requested lower, denied. Declared emergency and descended. Computer indicated FL 350 was achievable. |
| 9 | 512016 | May-01 | Gulfstream G-IV | 430 | Stick pusher activated at M.80, and could not be overridden. Descended down to FL 330 before regaining control. Diverted to maintenance facility. Found AOA probes out of alignment by 120°. |
| 10 | 546215 | Apr-02 | B737 | 370 | Climbing for weather, moderate turbulence, slowing, added power to "chevrons", got "pitch limit indicator" on attitude indicator, descended to FL 350. |
| 11 | 552249 | Jun-02 | Falcon 2000 | 430 | Warmer than expected, would not accelerate after climb and decelerated. Request lower, told to stand by. Initiated descent, against ATC authorization. Should have declared emergency. |
| 12 | 553936 | Jul-02 | B757 | 400 | Airspeed was decreasing and encountered windshear and had to descend. Computed max altitude was FL 404. Declared emergency and descended. |

| | | | | | |
|---|---|---|---|---|---|
| 13 | 592623 | Sep-03 | MD80 | 350 | Climbing to avoid weather started at M.76 and slowed to M.64. FMS max altitude was FL 364. Declared emergency and descended. |
| 14 | 604812 | Jan-04 | CL60 | 390 | Performance charts indicated FL 390 was OK. Attempted to climb at 1,200 fpm. On reaching FL 390, airspeed would not stabilize and slowed. On reaching Green Line, requested lower to FL 350. ATC gave 4-minute delay and turns. Requested expedited descent and cleared. |
| 15 | 605597 | Jan-04 | CL60 | 350 | Cleared from FL 310 to 350 in 3 minutes (1,500 fpm). Reduced climb rate as airspeed decayed, then AP disconnected and got shaker. Got pusher while attempting to level, attempted to level again and got another pusher. |
| 16 | 606092 | Jan-04 | Gulfstream 200 | 410 | Accepted climb clearance from FL 390 with captain away from seat. Temperature increased from ISA –3 to ISA +5. Reached FL 410 but got buffet, descended 600 feet to recover. ATC was unable to give lower altitude. |
| 17 | 608654 | Feb-04 | B737 | 410 | FMC computed FL 410 would work, and computed time to climb. ATC asked for expedited climb, as computed, then (at FL 390) to maintain 1,000 fpm. Airspeed and climb rate decayed and AP initiated descent. ATC was unable to clear lower. Declared emergency and went to FL 370. |
| 18 | 632231 | Sep-04 | B757 | 410 | Level at FL 410 saw airspeed decay below 200 knots and got stall buffet. Disengaged autothrottles and advanced power and contacted ATC for descent. ATC said unable. Declared emergency and descended to FL 370. |