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I. EXECUTIVE SUMMARY

A. History Of Flight

At 0607 Eastern Daylight Time (EDT) on August 27, 2006, a Canadair RJ (CL65-2B19), N431CA, operated by Comair Airlines (CMR) Flight 5191, crashed on takeoff from Bluegrass Airport, Lexington, Kentucky (LEX). The flight was destined for Atlanta, Georgia. There were 3 crew members and 47 passengers on board. Forty nine of the 50 souls onboard received fatal injuries and one received serious injuries.

Ongoing construction at LEX left airport signage inconsistent with airport diagrams in place at the time of the accident. In addition, because of the construction, various taxiway and runway lights were out of service at this time. A number of these inconsistencies were not present on current airport Notices to Airmen (NOTAMs), the accident crew's company dispatch release information or the Automated Terminal Information System (ATIS) broadcasts in effect.

This was the first flight of the day for the crew and at the time of the accident, it was still dark at the airport. Prior to the accident aircraft's departure that morning, there had been two air carrier aircraft that had departed the airport. The FAA Air Traffic Control Tower was operating, with one air traffic controller on duty performing clearance delivery, ground control, local control, and departure control duties. The preflight and engine start were uneventful. The flight was instructed by the controller to taxi to runway 22. The taxi from the ramp to the runway was approximately 4 minutes in duration. Indications are that the crew was not rushed and all preflight checklists and briefings were conducted. Approximately 3 minutes after their initial taxi clearance, Comair 5191 was cleared for takeoff without mention of the intended runway by the controller. After a brief exchange with the Eagle flight, the controller turned his back on the departing aircraft and proceeded to execute his administrative duties. The captain taxied the aircraft onto runway 26 and transferred the flight controls to the first officer for takeoff. Approximately 43 seconds after receiving their takeoff clearance, Comair 5191 began their takeoff roll on Runway 26.

The initial portion of the takeoff roll proceeded normally. Although approximately 12 seconds into the takeoff roll, the first officer made a comment "*...is weird with no lights*." Eight seconds later, the captain made the required one hundred knot airspeed callout, followed by a normal first officer response. Seven seconds later, the captain called V-one rotate at a speed slightly less than calculated for the aircraft weight. He then made an exclamatory "*whoa*".

Calculations indicate that the aircraft was just reaching the end of the runway at this time and almost immediately began to traverse the grass beyond the runway end. Wheel tracks indicate the landing gear hitting an earthen berm approximately 300 feet beyond the end of the runway. The aircraft briefly became airborne before striking trees. The aircraft then began to descend and again struck more trees. The aircraft came to rest less than 2,000 feet past the runway end. A significant post-impact fire ensued. The air traffic controller "*heard a noise and saw fire west of the airport*" and called for the airport's fire trucks to respond. The airport's public safety officers responded to the scene within 5 minutes, and were able to extricate the first officer from the aircraft. The ARFF vehicles arrived within 8 minutes of their notification. The first officer was the only survivor.

During the course of this investigation, numerous system and safety deficiencies were identified as well as a significant number of human performance issues on the part of both the flight crew and the controller on duty at the time; all of which played a major role in this accident. What follows is ALPA's analysis of the NTSB's factual record related to this accident.

B. Overview

As a party to this investigation, the Air Line Pilots Association, International (ALPA) has identified numerous safety concerns which will be addressed in this document. Some of the areas of concern are as follows: First, numerous changes to the airport's layout were not accurately presented to the crew. Second, some of the Notices to Airman (NOTAM) reflecting the changes to the airport were not made known to the accident crew. Third, ALPA has identified several human factor concerns relating to situational awareness including fatigue and workload management. Fourth, our investigation has identified areas of concern regarding air traffic control policy and procedures which led to inadequate staffing, fatigue, and lack of controller vigilance. Finally, poor coordination between the air traffic controller and the airport crash and rescue personnel delayed the first responders. Additionally, lack of proper emergency locator equipment caused further delay when personnel were not immediately able to accurately locate the wreckage location.

C. Lexington Airport

At the time of the accident, Lexington Blue Grass Airport had been under a major construction project. Throughout most of this project, construction progressed on schedule and changes were properly updated and distributed to the aviation community. However, in April 2006 a new Airport District Office (ADO) Project Coordinator was appointed to oversee the construction. Shortly thereafter, in order to maintain accuracy of the FAA's Airport Facility Directory (AFD), the ADO notified the airport that its construction timeline was unacceptable. While the AFD was published with accurate data and the change sent to Jeppesen, due to a software error it was not implemented. Therefore the Jeppesen charts provided to the crew inaccurately depicted the actual conditions.

D. Notices To Airman (NOTAMS)

During the investigation of the accident, ALPA uncovered numerous discrepancies inherent in the NOTAM system. Numerous critical NOTAMs in effect at the time were not made available to the crew. These NOTAMs included information related to taxiway closures, available runway lengths, and the status of runway 26. Additionally, NOTAMs are difficult to decipher and extract the pertinent information required for each segment of the flight. There are only two normal methods by which a flight crew can receive these critical NOTAMs: The ATIS and the crew's flight release produced by the airline's dispatcher. For the accident crew, the only NOTAM that was broadcast on the ATIS dealt with construction on the air carrier ramp. Numerous other NOTAMs regarding the airport environment were not made available to the crew.

E. Human Performance Considerations

It is important to understand that people make decisions and choose courses of action based on their current perception of reality. The crew of Comair 5191 taxied out to and took off of what they believed was runway 22. Maintaining an accurate situational awareness requires correct perception, comprehension and projection into the future. Any failure in any of these three functions due to absent, misperceived or erroneous information will disconnect our situational awareness from reality. When navigating on the surface of an airport, pilots rely on information from previous experience, correct charts, correct signage and NOTAMS to ensure that they have sufficient understanding of their environment. If these sources of information, in addition to flight crew procedures, are correctly provided, they add multiple layers of redundancy and safety to an aviation system. The crew of Comair 5191 was provided inaccurate charts, inaccurate signage and incomplete NOTAMs. Human behavioral phenomena such as confirmation bias and plan continuation may prevent the human operator from recognizing such disconnects. Without these multiple layers of safety to ensure a robust safety system, procedures alone will not be able to prevent a tragedy.

F. Air Traffic Control

During the investigation of the accident it was found that due to budget and personnel constraints, the air traffic control tower was operating at less than required staffing levels. This caused workload issues directing the controller's attention away from their primary task of controlling traffic. Scheduling rotations directly impacted the controller's ability to maintain adequate rest, resulting in his being fatigued on the morning of the accident. It was also found that the procedures in place at the time of the accident regarding takeoff clearances were not sufficient to ensure the level of safety required for air carrier operations.

G. Survival Factors

The accident revealed deficiencies in both guidance for rescuers and safety areas. Airport Rescue and Fire Fighting (ARFF) personnel were not provided the advantage of locating the accident in the most efficient means possible. The Air Traffic Controller, while in the best position to see the crash, did not offer assistance to the responders in locating the scene. This lack of input on the part of the controller resulted in a longer than necessary response time and a lack of a direct routing to the accident scene.

The ARRF vehicles were also slowed in their response to the scene by the delayed remote opening of a security gate, something that been previously addressed by NTSB Recommendations. There are also several technological advancements that could have provided a more efficient means to not only navigate to the scene but also help with documentation of the scene upon arrival.

The runway safety area for this particular runway was 300 feet; significantly less than the 1000 feet required for air carrier aircraft. As the aircraft exited the runway, it immediately impacted an earthen berm located approximately 300 feet from the runway end. Subsequently, the aircraft impacted trees located approximately 900 feet from the runway end. Had this runway been maintained in compliance with its particular runway safety area requirement, the aircraft's initial impact with the berm would not have occurred. Had the runway safety area been required to be maintained to a standard air carrier runway safety area, less aircraft damage may have occurred.

H. Technological Advances

There are many advances in technology that would have helped with not only improving situational awareness but also improving safety margins. One of the advances is in the Runway Advisory Alerting System (RAAS). This system would have audibly alerted the crew that they were approaching runway 26. If they would have still continued to attempt a takeoff on runway 26 it would have audibly alerted them to the amount of distance remaining. Another advancement is the Electronic Flight Bag (EFB) with airport electronic display. An EFB with appropriate software can display own-ship position on an airport electronic display. This would significantly improve crew situational awareness using specific airport information.

II. THE ACCIDENT AIRCRAFT'S TAXI ROUTE

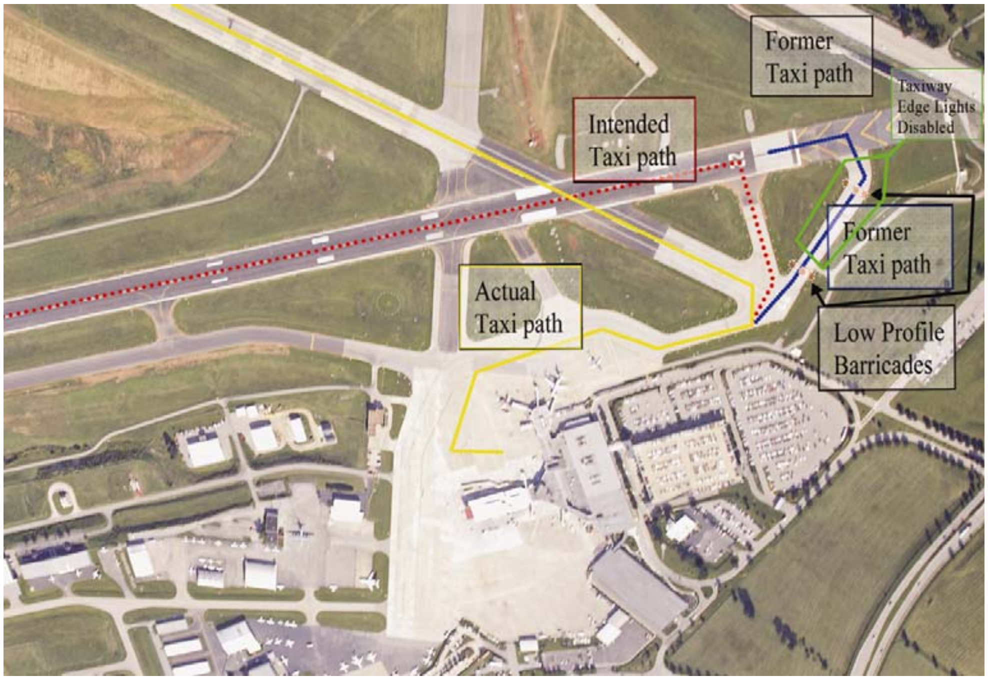

Photo 1: Accident Aircraft's Taxi Route

III. LEXINGTON AIRPORT

A. Construction

The tragic events on the morning of August 27, 2006 happened near the end of a major safety improvement project at LEX. Completion of the project would bring the Runway 4/22 nonstandard 100 foot runway safety areas into compliance with the 1000 foot recommendation identified in FAA AC 150/5300-13 and as required by FAA Order 5200.8. Throughout the five-year project, the parties involved faced many significant challenges, from coordination with many different FAA departments, to physically moving Cave Creek and the road south of Runway 4. As the project unfolded, these, and the many other challenges were met according to schedule, within federally established safety guidelines for such a project. In fact, the airport had three 14CFR139 compliance inspections during this period without a single violation related to any aspect of the construction project. Additionally, the airport met all of the schedule milestones requested by the FAA. Keeping the project on schedule helped the FAA ensure accuracy of the airport diagram and navigation charts as the airport layout changed, minimizing the need for NOTAMs.

1. June 2006: Changes to Airport Construction Plan

The project required LEX to move the runway 22 threshold from its original position to a point 325 feet to the southwest. The plan was that they would not make this movement until taxiway “A7” was constructed, some 30-45 days after the repaving of runway 4-22 which took place on August 18-20, 2006. This would allow the runway 22 taxi operations to remain unchanged. This plan had been clearly stated, and FAA approved, in the safety plan construction documents. Furthermore, there had been ongoing discussions and coordination meetings with FAA representatives during the previous three years of work on the project. In April 2006, the FAA’s Airport District Office (ADO) project coordinator was replaced by a new individual. Two months later the ADO informed Blue Grass Airport Authority that their plan was unacceptable. The ADO’s focus was on maintaining accuracy of information in the Airport Facilities Directory (AFD)[1]. Maintaining this accuracy required movement of the runway 22 threshold earlier than planned in the construction sequence.

Extending from the approach side of the runway threshold is an Obstacle Free Zone (OFZ)[2]. Movement of the threshold would cause infringement on the OFZ during use of taxiway “A” between runways 26 and 22. Due to this change, the entire plan for the runway 4/22 taxi operations needed to be redeveloped. More than the actual change in plan, it was the timing by which this information became known that was critical. The need for the change was identified on June 20, 2006. The last minute change in

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[1] The ADO was responsible for AFD publication information and release of FAA grant money for the construction project.

[2] AC 150/5300-13 Chapter 3 par. 306; defines the OFZ as extending 200 feet beyond each end of the runway and 400 feet each side of the extended runway centerline.

requirements resulted in inadequate time for the parties involved[3] to develop a new plan before the National Flight Data Center (NFDC) charting deadline the next day, June 21, 2006. Therefore it was decided to submit charting information which would depict the final airport configuration, and communicate any actual differences by NOTAM.

During the investigation, it became evident that changes to the construction project were discussed with several stakeholder groups including Air Traffic Control, Airport Management and Airlines. However, discussions with pilots operating air carrier aircraft at LEX never took place. FAA is currently considering implementing Safety Management Systems (SMS) at FAR part 139 airports. Use of an effective SMS would include full stakeholder involvement in safety risk analyses of airport construction projects, particularly those with potential operational safety impact. An example of this stakeholder involvement exists today in the Airport Liaison Representative program in operation at over 200 US and Canadian airports by ALPA. Therefore, ALPA recommends that FAA aggressively pursue implementation of SMS for airports.

2. Jeppesen Chart Production Software Malfunction

The beginning of August 2006 again brought unexpected changes regarding operations at the north end of LEX. The AFD came out with information submitted the previous June, however the Jeppesen chart remained unchanged. This left the Airport Authority in a position of trying to use the NOTAM system to correct conflicting information on two inaccurate charts.

Jeppesen normally receives information concerning changes to the National Airspace System from the NFDC. This information is then electronically logged into Jeppesen's document control system. The system triggers a daily report of the new source documents which are sent to an analyst for evaluation. After the close of business on Friday, June 23, 2006, the LEX NFDC chart information arrived in the Jeppesen document control system. Unknown to Jeppesen, their system had only been programmed to generate reports for information received during business hours Monday through Friday and not on the weekends. Due to this programming limitation, no report was generated, and the information sat in the document control system for over two months. Jeppesen only discovered the missing information after research, prompted by the Comair 5191 accident, into why their chart was different from the AFD.

Jeppesen publishes a page 10-8 detailing airport construction projects. These are commonly referred to as "yellow sheets," and contain temporary chart information printed on yellow paper. They are used to alert pilots of airport construction, temporary approach procedures, and special events. When major runway construction is scheduled in pre-announced phases, a yellow sheet may be issued, but are not mandatory. The determination to publish a yellow sheet is usually made by the Jeppesen Revision

[3] From the Blue Grass Airport: Director of Operations, Director of Planning & Development, and the Contract Project Manager. From the FAA: the ADO, Air Traffic Control Tower manager, and Lexington Facilities manager. In addition there were four (4) other sub contractor engineers

Preparation and Planning team. This team evaluates all aeronautical source changes for chart revision activity. The decision to publish a yellow sheet is a completely internal Jeppesen decision and is dependent on how organized and lengthy a construction project is. As there was no information about construction stages and dates available in the information received from the NFDC, the changes at Blue Grass Airport "would not have met the yellow sheet criteria"[4].

3. Charting and Signage Discrepancies

The preceding events resulted in several charting and signage discrepancies following the repaving during the weekend of August 20, 2006. The AFD presented an accurate representation of the airport, except north of runway 26 (see Figure 1). In this area the AFD depicted a single "A7" taxiway leading to the runway 22 threshold. In actuality, there were two taxiways north of runway 26; neither of which were "A7". When sitting on taxiway "A" at the hold short line south of runway 26, the view was as follows: Directly across runway 26 was the closed portion of taxiway "A". At approximately a 70 degree angle to the left across runway 26 was the re-designated taxiway "A". This was the taxi route leading to runway 22.

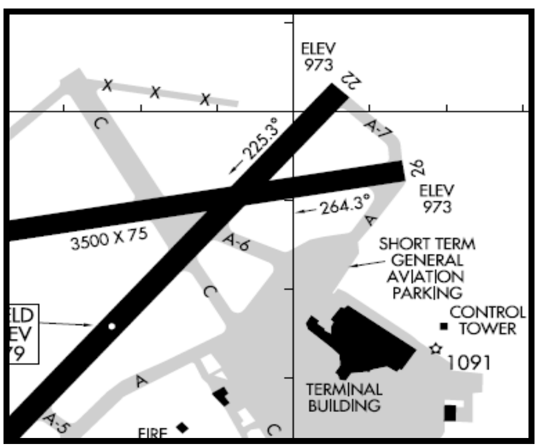

Figure 1- AFD portrayal

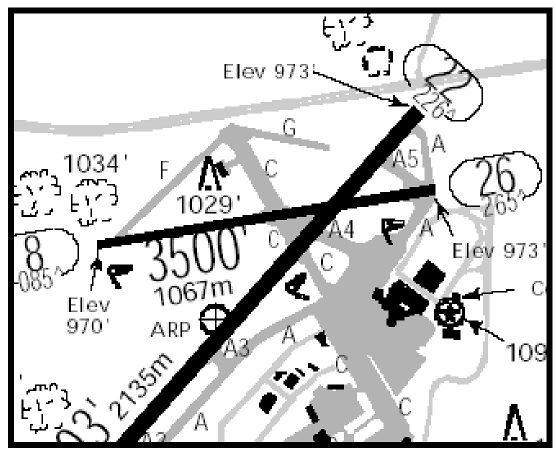

Figure 2: Jeppesen Portrayal

The Jeppesen airport diagram (10-9 chart) presented an accurate representation of only two taxiways along Comair 5191's taxi route (see Figure 2): Taxiway "C" slightly to the south while exiting the air carrier ramp, and taxiway "A" up to the runway 26 hold short line. Three taxiways were depicted inaccurately. First, taxiway "A4" south of runway 26 was signed as "A6"; Second, taxiway "A5" was depicted as north of runway 26 and was signed as taxiway "A"; and Third, taxiway "A" north of runway 26 was depicted but was actually barricaded closed. On the Jeppesen chart, which the crew had, taxiway "A" north or runway 26 was depicted as an operational taxiway leading to runway 22.

[4] Section 6.2, Pg 26, paragraph 3, Survival Factors Group Chairman's Factual Report dated December 21, 2006

The Jeppesen chart also did not incorporate 2 NOTAMs in effect since 2001. One designating runway 8-26 as unusable for landing or taxiing of aircraft over 12,000 lbs GWT (gross weight) and the other designating runway 8-26 as daytime VMC (visual meteorological conditions) use only.

So, as outlined above, both the AFD chart and Jeppesen chart were inaccurate in different ways. The NOTAMs in effect at the time more accurately corrected the AFD chart than the Jeppesen chart. Because the Comair 5191 flight crew had the Jeppesen chart, they were faced with the more confusing configuration. This confusion was compounded by the fact that the NOTAMs issued to correct the chart inaccuracies were not available to the Comair 5191 crew.[5]

4. Positional Uncertainty

Several other crews, in addition to the Comair 5191 crew, experienced confusion during the taxi to runway 22, especially during hours of darkness. Interviews of pilots noted this change had caused confusion. An interview with a veteran Captain with over 18,000 hours who routinely flew in and out of LEX during the month of August explained; *"…most of the takeoffs had been in the dark.* Before the airport repaved runway 4/22, she had no confusion at LEX because she had been doing it for so long and it was the same for so long. After they repaved the runway, she said that whenever you were taxiing out for runway 22, the ATIS would tell you that taxiway Alpha was closed north of runway 26. She said that in the morning, the controller just instructed you to taxi to runway 22 and they did not give you any specific instructions. You had to turn slightly onto runway 26 to get onto taxiway A5 that was now taxiway Alpha. However, according to the Jeppesen charts, the taxiway had not changed and still said taxiway A5. The first time she took off from the repaved runway it was morning, with a low overcast, was dark, was not raining, and it was her first experience to go to a paved runway 22 with taxiway alpha closed like that. When they taxied out, they were looking around and had to take their time because it looked different. You had to stop, think about what you were doing, and get used to it, because you were not used to things looking like that."[6]

A First Officer who also regularly went in and out of LEX during August 2006 had this to say in his NTSB interview. "On Monday night, it was very confusing at the end of runway 26. Taxiway "A6" was closed. The special use data they had for runway 22 was for 6,600 feet versus 7,003 feet. That implied a departure on runway 22 at A5. There was a momentary confusion for both of the pilots as there was no clearance for an intersection takeoff. There were no NOTAMS indicating it was an intersection takeoff from A5. There was nothing other than the special use data from the company that showed it was a shorter takeoff distance, and the controller said nothing. Normally when you got an intersection departure, they told you to go to the intersection. When they used runway 22 on Monday, they were cleared to runway 22 and were totally surprised that taxiway Alpha was closed between runway 26 and runway 22. There was nothing written to

[5] See further discussion of the inadequacy of the NOTAM system in the next section.
[6] Operation Factors Group Chairman's Factual report dated December 17, 2006, Interview Summaries Pages 24-25

confirm it. He did not see taxiway A5 on Monday but A5 was listed on the chart he was using. He said it was an extremely tight area around runway 26 and runway 22 and the chart did not do it justice."[7]

The First Officer of the American Eagle Airlines Flight which took off only minutes before Comair 5191 stated, "*He was confused after he had done his duties and then looked up to try to figure out which was the right runway*. What originally confused him was he saw the captain starting to turn as they were going onto runway 26 and he then realized the captain was turning to go to runway 22. Part of what confused him was that they were not turning onto the runway when they crossed runway 26. He was confused for just a split second, but finally noticed the sign that said 22. There was not enough time for him to say anything before he saw the sign for runway 22. He never shared his concern with the captain as it was just a fraction of a second and he resolved his confusion a moment later when he saw the sign for 22. He did not recall seeing any flashing lights and saw no construction lights. As they were holding short of runway 22, they took a minute to do their checklist."[8]

According to current regulations, both the airport and the FAA inspections were in compliance with regulations. The airport had received awards from the FAA for the quality of their compliance. The factual record developed during this accident investigation demonstrates the inadequacy of the current regulations to provide adequate safety during airport construction.

The cover letter that accompanied FAA Advisory Circular (AC) 150/5340-1J - Standards for Airport Markings, issued in April 2005, required only the 73 largest airports in the US, as determined by 1.5 million enplanements in 2004, to comply with these enhanced markings. LEX is not one of those 73 airports. The enhanced markings for runways and taxiways described in this AC were developed through research involving government and industry, consistent with human factors understanding and subsequent validation testing at Green State Airport, Providence, RI. The AC provides for larger markings of hold lines, a centerline marking enhanced with dashes along each side to show a hold line is approaching, and a surface marking to indicate the specific runway being approached, having a red background and white lettering. This item is optional in the AC; however, it should be mandatory.

If LEX and other smaller Part 139 airports, were required to comply with this AC, there would have been additional painted markings on the surface hold short line. These markings provide additional visual cues to alert pilots of an upcoming runway holding position, identify the location as a runway holding position, and confirm the runway designation. Compliance with this AC could have been achieved for a cost estimated at less than $500 per intersection. Figure 3 shows the standard type of marking in use at

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[7] Operation Factors Group Chairman's Factual Report dated December 17, 2006 Interview Summaries Pages 28-29

[8] Operation Factors Group Chairman's Factual Report dated December 17, 2006 Interview Summaries Page 51

Blue Grass Airport. Figure 4 shows the enhanced marking with surface painted holding position signs, we recommend based on the current AC.

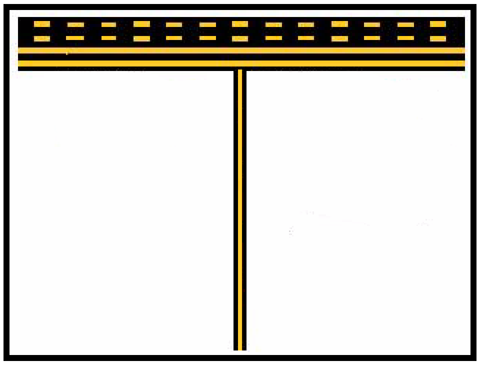

Figure 3: Standard Hold Short Marking

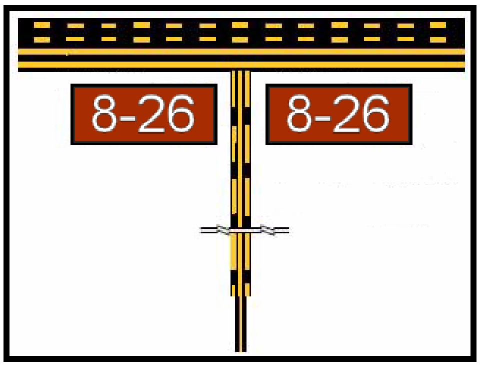

Figure 4: Enhanced Hold Short Marking with Surface Painted Holding Position Signs

The National Transportation Safety Board investigated two incidents of pilot deviation that involved departures of U.S. air carrier airplanes from the wrong runway at the Houston/William P. Hobby (Hobby) Airport, Houston, Texas. Both flights were cleared by the tower air traffic controller to take off on runway 12 right (12R), but the pilots inadvertently took off on runway 17 which intersects runway 12R at the approach end of both runways. The last 2,200 feet of runway 17 had been closed due to construction, making it unusable for turbojet airplanes. Both airplanes struck barricades approximately 3,800 feet down runway 17 and sustained minor damage. The (HOU) airport subsequently identified ways to prevent a reduction in safety by installing two temporary guidance signs – one on the left of taxiway “D” at runway 17 and one on the left of taxiway “E” at runway 17; the signs stated: "Runway 17 Closed to Air Carrier Aircraft." In addition special taxiway markings were enhanced extending across the threshold of runway 17 leading to runway 12R. The marking was a red line leading from taxiway “D”, across runway 17, to the runway 12R hold line. The NTSB recommendation (A-89-015) showed that evaluation of construction and subsequent development of temporary signage and markings during the construction would likely prevent errors by pilots.

Another example of new safety signage is the Surface Movement Area/Runway Traffic (SMART) board. SMART uses a programmable LED display board to deliver highly visible, clearly understood messages where and when needed. Several messages may be displayed in sequence, messages may flash or scroll and directions can be enhanced by moving arrows. The system has been approved by the FAA for testing at several 14CFR139 airports. ALPA feels that its general use approval should be expedited by the FAA.

Figure 5: Sample SMART Boards

These mechanisms could have been extremely helpful the morning of August 27, 2006, and would be an inexpensive safety enhancement.

B. NOTAMS

Notices to Airmen (NOTAMs) are notices containing information regarding the establishment, condition, or change in any component, the timely knowledge of which is essential to personnel concerned with flight operations. A NOTAM is disseminated to pilots through the company by way of operational notices and the dispatch release. It is also delivered through the Automatic Terminal Information Service (ATIS) broadcast, prepared by an Air Traffic Control Tower, to pilots prior to departure or arrival. NOTAMS are categorized into Flight Data Center (FDC), Distant (D) and Local (L) based on the nature of the condition and the area concerned.

NOTAM (L) information includes such data as taxiway closures and changes to airport lighting aids that do not affect instrument approach procedures. This information is disseminated locally but is normally available to airline dispatchers. The importance of receiving timely notification of all relevant NOTAMs is critical to the safety of flight. Title 14, Code of Federal Regulations (CFR) Part 91.103, Preflight Action, states in part:

> *Each pilot in command shall, before beginning a flight, become familiar with all available information concerning that flight.*

The NOTAM system was put into use in the 1920’s and its format has not been updated significantly. The system still relies on an antiquated teletype based format. Its origination was at a time when character count and message length were charged by the transmitting service. Our current system is still difficult to read and requires the end user to decipher important information. An example of this is the following NOTAM that was part of the Comair 5191 flight release:

> KCHA APT 2006080BFDBV01 08/015 WIE / UFN
> CHA AIRPORT CLOSED ACR DIVERSIONS EXC EMERGENCY

In an effort to decode the date/time stamp, on the above NOTAM, airline pilots, Comair dispatchers and specialists at both the Louisville and Nashville Flight Service Stations were called upon; none of these were able to decipher the meaning of the coding. It is safe to assume the accident crew could not either. Readability is only part of the NOTAM problem; the system used to disseminate this critical information to pilots is not working either. This is evidenced by the fact that neither the Comair flight release document nor the ATIS provided the crew with critical runway and taxiway information.

Review of the factual information gathered during the Comair 5191 investigation reveals that four critical NOTAMs were unavailable to the flight crew. They are:

1) NOTAM #A-1681, RWY 04-22 DISTANCE REMAINING SIGNS OTS (Runway 4-22 distance remaining signs out of service);
2) NOTAM #A-1682, TWY ALPHA N OF RWY 8-26 CLOSED UFN (Taxiway "A" North of Runway 8-26 closed until further notice);
3) NOTAM, Runway 8-26 unusable for landing or taxiing of aircraft over 12,000 lbs. GWT; and
4) NOTAM, Runway 8-26 daytime VMC (visual meteorological conditions) only.

While the factual record does not delineate the reason why, not all of these NOTAMs were made available to the Comair 5191 crew. All of these NOTAMs should have been available. This clearly indicates a deficiency in the NOTAM dissemination system.

The "taxiway Alpha North of Runway 8-26 closed until further notice" NOTAM (L) should have been distributed via ATIS broadcast. This NOTAM(L) had been a part of the ATIS broadcast during the six days prior to the accident, but it was not a part of ATIS broadcast "Alpha" and "Bravo", which were the two broadcasts available to the Comair 5191 crew. The ATIS broadcast did however contain one NOTAM(L) for "pilots use caution for construction on the air carrier ramp". (See NOTAM #A-1522, issued July 12, 2005) This NOTAM, which had been routinely included on ATIS broadcasts for over a year, could have led the Comair 5191 crew into believing that the greatest hazard they would encounter during taxi would be avoiding construction on the air carrier ramp. The other two NOTAMs had been in effect since 2001 and were published in the AFD but were not on the Jeppesen chart.

NOTAM (# A-1682) "Taxiway Alpha North of Runway 8-26 closed until further notice," was issued in an attempt to correct the existing charting mismatches. Due to this missing critical information the Comair 5191 crew had no reason to believe their taxi route to runway 22 would be different than their previous experience. Additionally, their airport diagram would be unable to accurately guide them to runway 22. Missing NOTAMs is only one part of the NOTAM system failure. Even when the information is present, critical information is likely to be missed.

A recent study of the NOTAM system, Hoeft et. al. (2004) found that only 68% of participants correctly identified critical information from an approach NOTAM.

The Comair 5191 dispatch flight release contains 15 NOTAMs for the Lexington Blue Grass Airport covering a total of 2½ pages. There was no logical method of arranging the NOTAMs on the release, therefore the NOTAMs containing specific types of information are scattered throughout the section. Below is an excerpt of the NOTAMs as they appeared on the release for LEX:

KLEX APT 2006080BB09V01 08/024 06 20AUG2200/ UFN
LEX 4/22 ASDA 7003 TORA 7003 TODA 7003 LDA 6603
WEF 0608202200
KLEX APT 2006080B546V01 08/023 06 18AUG1330/ UFN
LEX 22 ILS GP OTS WEF 0608181330
KLEX APT 20060802997V01 08/007 WIE / UFN
LEX 4/22 RCLL OTS
KLEX APT 20060706524V01 07/013 WIE / UFN
LEX 4 TDZ LGT OTS
KLEX APT 20040304BDFV01 4/1897 04 09MAR1944/ UFN
BLUE GRASS, LEXINGTON, KY.
VOR OR GPS-A AMDT 8A ....
CIRCLING MINIMUMS: MDA 1580/HAA 601 ALL CATS. VIS CAT C 1 3/4.
ALTITUDE AT HYK 5.00 DME 1580.
TEMPORARY FAS CONTROLLING OBSTACLE 1240 MSL/205 AGL TOWER AT 380007.65N-0843132.58W.

The problem with these is the lack of any organization or structure, and they are hard to read with all capital letters and using obscure abbreviations. A breakdown of the 15 NOTAMs revealed six addressing lights out of service, six addressing changes to approach procedures, one involving take off minimums and obstacle departure procedure, one an arrival transition, and one regarding declared distances for runway 4-22.

On the morning of the accident, the crew of Comair 5191 needed to identify and assimilate information that was relevant to each segment of their departure. Two NOTAMs dealt specifically with the expected departure runway and two others dealt with a runway that would be crossed in order to get to the departure runway.

Using the FAA's currently established, but yet to be implemented, principles in NOTAM design, the NOTAMs available for Comair 5191 would look like this:

Departure related NOTAMs
Blue Grass Airport, Lexington, KY (KLEX)

Airport NOTAM 08/24 issued: 08-20-2006 2200 UTC effective: 08-20-2006 2200 UTC until further notice

Runway 4/22 Accelerate-stop distance available 7003'
Takeoff runway available 7003'
Takeoff distance available 7003'
Landing distance available 6603'

Airport NOTAM 08/007 issued: 08-05-2006 1500 UTC effective: 08-05-2006 1500 UTC until further notice

Runway 4/22 runway centerline lights out of service

Airport NOTAM 07/013 issued: 07-11-2006 0000 UTC effective: 07-11-2006 0000 UTC until further notice

Runway 04 Touchdown zone lights out of service

Approach related NOTAMs
Blue Grass Airport, Lexington, KY (KLEX)

Airport NOTAM 08/023 issued: 08-18-2006 1330 UTC effective: 08-18-2006 1330 UTC until further notice

Runway 22 ILS glide slope out of service

FDC NOTAM 4/1897 issued: 03-09-2004 1944 UTC effective: 03-09-2004 1944 UTC until further notice due to a tower 205' above ground level and 1240' MSL, located 4.6 DME from the Lexington VOR (HYK) just north of the final approach course the **approach minimums** are **increased** as follows:

VOR-A or GPS-A approach

Cross CUGIG intersection (HYK 5.0 DME) at 1580' MSL
Circling minimums: All categories, MDA 1580/HAA 601'
Category C, visibility 1 ¾

NOTAMs are inconsistent in the display of effective date and time group. Some NOTAMs include a date and time group for effective dates, while others do not. This makes it extremely difficult or even impossible for a crew to understand when they went into effect. The NOTAM section of our submission begins with an example of a date-time group in a Chattanooga NOTAM found on the Comair 5191 release that no-one has been able to decode. It would be reasonable to expect the Comair 5191 crew to assume that the six NOTAMs dealing with lighting were recent, but this was not the case. The last two (2) NOTAMs involving the lighting for runway 26 had been in effect for over five years at the time of the accident.

In a recent study of the NOTAM system, Hoeft et. al. (2004) discovered the NOTAM system is prone to error for several different reasons. NOTAMs often contain large amounts of information, gathered from many different sources, processed through multiple agencies that do not have standard operating and or formatting practices between them.

Crews operating in and out of LEX during August 2006 stated during NTSB interviews, that Blue Grass Airport had a lot of closures and changes.

"*These changes occurred because the airport had been doing a lot of construction. Each day it would be something different. Alpha taxiway was closed for the first part of the month. Most of the information came from NOTAMs. There were a lot of items that were listed out of service on the NOTAMs during the previous month including the instrument landing system (ILS), lighting systems, taxiways, etc. You would hear the ATIS and not want to listen to it because it was long and you were busy during the approach phase but you would have to force yourself to listen to it to make sure you got all the new information. Not everything was on the NOTAMS. Sometimes the controller would tell you some information.*"[9]

This statement correlates with information found in the Hoeft et. al. study that the respondents were not satisfied with the current system. "The system lends itself to mistakes and misunderstandings because it is cumbersome and hard to follow, and has no structure to how they are grouped. Pilots are not using the system because of the difficulty of interpreting and understanding NOTAMs. There is a perception of being overloaded with information and a lack of trust in the system."[10]

The NOTAM system must be modified to establish user trust, ease of understanding, ease of interpretation, along with system accuracy and integrity. It is time to move the NOTAM system format out of the 1920s and squarely into the 21st century. The FAA's own Human Factors Design Guide (HFDG) contains principles which, if implemented, would accomplish this goal:

First Principle (from *HFDG* paragraph 10.2.3.1.1): *The text of a document shall be written in clear, simple language, free of vague, ambiguous, unfamiliar and unnecessary words*.

Second Principle (from *HFDG* paragraph 8.1.1.4): *Information shall be presented to a user in a directly usable form; a user shall not have to decode or interpret data*.

Third Principle (from *HFDG* paragraph 8.2.5.4.4): *The use of abbreviations shall be minimized*.

Fourth Principle (paragraph 8.2.5.8.1): *Text should be presented in a combination of uppercase and lowercase letters, following standard capitalization rules*;

Fifth Principle (from *HFDG* paragraph 8.1.1.8): *When task performance requires or implies the need to assess the timeliness of information, the display should include time and date information associated with the data.*

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[9] Operation Factors Group Chairman's Factual Report dated December 17, 2006 Pages 27-28 Interview Summaries

[10] Hoeft et. al. Freeing NOTAMs From Teletype Technology, Flight Safety Digest, Volume 23 No. 4, April 2004 pg 20

Sixth Principle (from *HFDG* paragraph 8.2.9.5): *Designers should base the order of items on natural rationale such as frequency of use, related functionality or the normal sequence of user actions.*

C. Recommendations

1) Redesign NOTAM format to conform with the guidance contained in the FAA's Human Factors Design Guide.

2) Develop and mandate a specific system by which all NOTAMs are provided to airline dispatchers to prepare a complete crew briefing.

3) Mandate that Enhanced Hold Short Markings With Surface Painted Holding Positions Signs be applied on all runways at all air carrier airports.

4) Require airports to aggressively implement Safety Management Systems (SMS) programs that involve all airport stakeholders (e.g. operators, pilot groups, air traffic control, etc) in any discussions or planning related to airport construction and modifications to ground operations.

5) Develop and mandate a process to provide graphic temporary airport construction information to flight crew members.

6) Require that all runway safety areas at airports served by air carrier aircraft be maintained at a standard 1000 foot clear area or the equivalent.

7) Expedite development and mandate implementation of variable-message-board technology for use as temporary airport signage to communicate construction details.

IV. HUMAN FACTORS/OPERATIONS

A. Executive Summary of Human Performance

Without a doubt on the morning of August 27, 2006, the crew of Comair 5191 thought they were departing runway 22 at LEX. Due to an inaccurate positional awareness of their location on the field and ineffective mitigation strategies, their degraded situational awareness resulted in the inadvertent departure off runway 26. Pilot and controller fatigue, as well as workload management and signage problems and charting inaccuracies all served to fuel this disconnect and allow this misperception to continue. Eventually, confirmation bias and plan continuation prevented the crew from correctly perceiving their environment and thereby preventing the accident.

An individual's situational awareness is unique, based on their previous experience, training, and intellect. They interpret outside stimuli to develop a realistic understanding of their environment. The concept of situational awareness encompasses perception, comprehension and projection into the future for a particular situation. The goal of any human factors investigation is to understand not what the crew had done to possibly cause an accident, but rather why their actions and choices made sense to them at the time (local rationality). It is important to understand that people make decisions and choose courses of action based on their current perception of reality. Essentially, whatever information was available and how it was interpreted will guide them in their decision making scheme.

Due to rapidly changing construction and lighting outages at the airport combined with each pilot's different arrival time and method into LEX, each started the morning of the accident with an immensely different understanding and perception of the airport layout. The vastly different preconceived visual model they each possessed regarding the airport environment prior to push-back combined with inadequate information received from various sources only served to ensure their situational awareness disconnect.

For the sake of the analysis, we chose to divide this event into numerous sections. Each section is inextricably related to the next and should be thought of as a continuum. Although each section contains numerous similarities, there are several differences in crew member dynamics as well.

Throughout the entire event from boarding the aircraft to the departure off the end of the runway, the crew faced numerous obstacles in attempting to adjust their situational awareness when presented with vague and ambiguous visual clues. The lack of correct and adequate information from sources such as ATIS, flight release, airport diagram and the air traffic controller inadvertently interfered with their perception of their location on the airport surface. Other factors such as fatigue, lack of ATC support and workload management all affected their ability to successfully recognize and readjust their situational awareness. Psychological phenomena such as confirmation bias and plan continuation played a supporting role in preventing the crew from accurately perceiving their dynamic environment in a way that would have helped reduce or eliminate their disconnect. The combination of these factors allowed the margin of safety to erode to a point where the accident was inevitable.

B. Human Performance Considerations

Errors, incidents and accidents in complex systems occur most frequently at the intersection of system flaws, operational pressures, and impaired or inadequate human performance. Historically, an in-depth understanding of a crew's situational awareness in an accident investigation has been challenging. This is especially true for accidents where, at first look, human error appears to be so egregious that it offers an easy explanation of the event. However, it is far more challenging and beneficial to understand why the crew made the decisions that ultimately led to the accident event. The investigation should seek out what previous experience, training and information was available or missing thereby shaping the crew's decision-making scheme. It is the knowledge that they bring to the flight combined with information (data-centric and/or perceptual) they receive while operating the aircraft that forms their understanding of their environment.

1. Situational Awareness

Based on the factual record all evidence indicates that the crew of Comair 5191 thought that they were in fact taxiing to and taking off on runway 22. In fact, it was only in the last few seconds of the CVR transcript that we see evidence that they began to realize that something was terribly wrong. Unfortunately, this realization or abrupt shift in situational awareness came only a fraction of a second before the aircraft exited the runway and the impact sequence began. It is important to understand that pilots, like all highly trained professionals, strive to do a good job and focus on the safety of their passengers and crew while facing conflicting goals in an uncertain and dynamic environment. Based on the factual information obtained during this investigation, it is almost certain that the crews' actions made sense to them up until the last few seconds of the event. So, what caused the crew to be situationally unaware of what was about to happen to them?

The modern definition of situational awareness (SA) encompasses perception, comprehension and projection, combining these to establish a mental picture of what is currently happening and what might happen in the near future (Endsley, 1988). In *The Field Guide to Understanding Human Error*, Dekker says that we use our experience, education and intellect to interpret outside stimuli to develop a mental picture of what is happening. We use this experience and interpretation of our perceptions to make decisions about how to proceed and to predict what the outcome will be. However, our perceptions may be in error due to internal processing problems or external information presentation problems. But, once we have what we believe to be a correct mental model of what we are processing and interpreting, subtle clues indicating a different reality are frequently ignored or misinterpreted. This process, or selective inattention, will be even more evident when workload is approaching the extent of our capabilities. Additionally, it is important to understand that when humans are faced with conflicting stimuli or disjointed perceptional information, we often subconsciously "fill in the blanks" to make our perceptions fit our local rationality. Data will normally be perceived in a way that fits our current awareness and mental model. Even if our perceptions cause us to begin to question our mental model, our first actions will be to seek out additional information to confirm our current model (confirmation bias). There are numerous physiological and psychological reasons why we may fail to correctly perceive our environment (Dekker, 2006).

Like many previous accidents, it would be easy to label this accident as a "loss of situational awareness". However, to make such an assertion does nothing to determine why this accident actually happened. It simply substitutes the phrase "loss of situational awareness" for the term "human error." Through this re-labeling we lose the opportunity to acquire valuable insight into how to prevent this type of accident. Findings such as these fail to answer the real question - why did the course of action that the accident crew chose seem reasonable to them at the time they were experiencing it? In Dekker's book, *Ten Questions About Human Error*, he postulates that there can never be a complete loss of situational awareness. It is more correct to say that a crew's situational awareness may deviate from reality. Dekker states that as the situation changes for the crew, they adapt to the new situation even if their perception of that environment is later determined to be deficient. What is important is that they had no idea at the time that their perception was deficient. Had they known this and been aware of the pending outcome, they certainly would have chosen another course of action. The pending outcome is obvious to us, the investigators, since we are seeing the event after the accident has already occurred (hindsight bias).

The investigation found that both pilots involved in the accident were trained as required by the Federal Aviation Regulations and Comair procedures in addition to receiving high marks from fellow pilots and evaluators. Many individuals from both of these groups including Comair ramp personnel who interacted with the crew the morning of the accident described both pilots as "*professional*" and "*normal*" in every way. In order to understand how such a well trained and proficient flight crew ended up taking off from the wrong runway, we have to reconstruct their local rationality without hindsight bias. That is to say, we need to understand their evolving perception of the situation in real time as it was unfolding. Dr. Dekker (2006) reminds us that "people do not act on the basis of reality; they act on the basis of their perception of reality". We need to examine from within the cockpit the effect of crew training, what information was available during preflight duties and what visual cues were available during the taxi and takeoff. Additional considerations should include physiological limitations, psychological limitations, crew resource management and workload considerations. Any of these can alter a human's ability to correctly perceive our environment and will directly affect our local rationality and decision making ability.

Research by Jentsch et al. 1999 showed that in both ground and flight operations, crews are more likely to have a situational awareness disconnect from reality when the Captain is at the controls. For the majority of the Comair 5191 flight, the captain was controlling the aircraft until after the exchange of controls for takeoff. It has been suggested that one possible explanation for why captains at the control may, more frequently, experience a situational awareness disconnect is simply because of task loading. Captains that are cognitively tasked with flying or maneuvering the aircraft are not as free to collect analyze and communicate information without distraction. Any distractions such as other crew members talking, radio communications, operational problems with the aircraft all compete for limited cognitive resources. They spend a significant amount of their cognitive resources just operating the aircraft (Jentsch, 1999). Moreover, because of the significant leadership and decision making role that the Captain plays in the operation of the aircraft, any situational awareness disconnect on his part has been shown to be more detrimental and likely to result in an accident or incident than that of the first officer.

This research applies to the Comair 5191 crew in several ways. First, Comair like most transport category operations, places responsibility for taxiing the aircraft on the airport surface resides directly with the Captain. Although he has direct physical control over both steerage and speed of the aircraft, the presence of the first officer to monitor this function adds an additional layer of safety and system redundancy to this critical phase of flight. Second, during shorter duration taxi operations, the first officer will spend a major portion of the taxi operation “heads-down” performing checklist tasks. This is especially true for first flight of the day checks that are required while the aircraft is in the taxi phase of the operation. The very nature of both the taxi monitoring function and operational checking requirements are in conflict. The addition of other responsibilities such as communication with ATC and cabin crew potentially erodes that additional layer of protection by overloading the first officer with conflicting goals. The removal of the first officer from the captain’s support structure, even if only temporary, results in a situation where the taxiing aircraft is essentially a single pilot operation. During post Comair 5191 accident interviews, several flight crew members commented on how first officers were typically heads down for the majority of shorter taxi routes. This supports the supposition that any error made by the captain may go undetected by the first officer because of his preoccupation with completing the required checklists tasks. Additionally, when the first officer does re-join the captain in monitoring the taxi phase of flight, any situational awareness confusion on his part will most likely go unreported for a period of time while he attempts to understand why something appears to be wrong.

As pilots, we understand that from an operational point of view some of these checks must be completed while en route to the runway. However, we suggest that every effort should be made to ensure that the least amount of “heads down” time as possible should be required in an attempt to decrease the workload on the first officer. This will permit him to fulfill his primary function, which is monitoring the captain during taxi, a critical phase of flight. ALPA is aware of airlines that after experiencing a significant number of runway incursion events have been successful in reducing these events by relocating some items from the before takeoff checklist to earlier in the flight such as at the gate.

2. Threat and Error Management

To truly comprehend what any crew experiences during normal line operations requires an understanding of threat and error management. Airline operations are in fact a balance of competing goals, time pressures, mechanical issues and human weaknesses. Pilots, especially captains, are managers of this system as it affects their individual flight. It requires a management style approach and the recognition that threats and errors are an unavoidable component of flight operations. However, the successful recognition and management of both threats and errors can make the difference between a typical revenue flight and an accident.

Threats are events or situations external to the flight crew that may affect a flight (e.g. weather, aircraft system anomalies, etc). They are conditions, that in and of themselves, do not guarantee an accident. But rather if recognized and managed appropriately, increase the level of safety for any particular flight operation. Errors are crew-centric and include the typical errors made on each flight due to the presence of the human operator. The fact that errors occur is not as important as whether or not the error is recognized and managed (trapped). Robust safety systems such as those found in the commercial aviation system recognize the inevitability of minor errors and trap those seen in daily flight operations. Many errors committed each day on our flights are harmless and in many cases go unrecognized. However, even if each individual error is deemed innocuous, the presence of an unusually high number of errors may indicate other crew or system problems that require further investigation. These factors include fatigue, workload, stress, ergonomic problems or operator impairment.

During the following analysis presented in this report, threats and errors will be identified for each flight segment. At the end of each particular flight segment discussion, we have included a table (or tables) which highlight each threat or error and its impact upon the outcome.

3. The Accident Flight Crew

During the investigation, consistent and insightful information regarding the nature/disposition of both flight crew members was obtained from fellow line pilots, check airmen, simulator training pilots and spouses. The factual record clearly indicates that both pilots appeared to be well trained, conscientious and standard in their normal operating practices while flying. Review of their flight time showed that both pilots were highly experienced by total flight time and flight time in the Canadair Regional Jet. Additionally, no FAR violations or company disciplinary records were discovered.

Ramp personnel that interacted with the crew the morning of the accident described them as "*professional*" "*courteous*" and "*like they always looked*". Both pilots were experienced, educated, properly trained and their peers found them easy to work with.

a) The Captain

The captain lived in the Cincinnati area where he was based and was married with two children. By all accounts he appeared to be very family oriented and enjoyed spending time with his wife and kids. In some of the interviews with other pilots, he was described as "*likeable*" and having a "*good personality*" and in general was a "*good guy*". When other first officers that had flown with him were interviewed, they spoke very highly of him describing him as "*by the book*" and that he "*followed checklists*". The check airman that performed his last line check described him as "*professional*" and he had an overall positive impression of the captain. He further reported that he had good CRM and interaction between fellow crew members. Overall, the accident captain created a good cockpit environment.

A first officer that flew with the accident captain several days before the accident described him as being in a good mood although they did talk about the low moral at

Comair. In that vein they discussed the current RFP[11] and that the accident captain was interested in flying for United Parcel Service.

b) The First Officer

The first officer was based in New York but lived in Florida with his wife and four dogs. Interviews with several pilots that had flown with him described him as a "*family man*" who spoke very highly of his wife. Professionally, they described him as a "*pretty sharp individual*" and that he appeared to be quite experienced. A line check airman that flew with the accident first officer on a five day trip two weeks before the accident reported that he was "*very good to standards*", "*very thorough pilot*" and one that "*adhered to operational standards*". His last simulator training event was described as "*benign*" and "*generic*" and contained no debriefing items.

A captain that flew with the accident first officer a week before the accident reported that he had an upcoming interview with Emirates Airlines.

These interviews certainly imply that this was a conscientious crew that had a history of excellent performance on the line and was able to handle the challenges of line flying.

4. A Time Line Perspective

In order to fully understand what happened to Comair 5191, we should first examine how the crew might have utilized information or perspective that they already possessed when they arrived at the aircraft the morning of the accident. From here, we will begin to understand how they interacted with their environment. This pre-airport basis of knowledge combined with information provided upon arrival at the airport and the taxi event encompasses the total scope of their perception of their environment. This comprehensive package of perception and knowledge defines their local rationality. As the flight progressed, the stream of information and perceptions was dynamic in nature. The crew did not know what additional piece of information they would get next, but rather would assess each piece of additional information or perception on its own merits and make conscious, educated decisions.

In order to successfully understand the local rationality of each crew member, it is necessary to examine the event from the crew's perspective. We need to understand how the crew interacted with the system as it was the morning of the accident. Simply listing the errors that occurred will not provide insight as to how those errors occurred. By examining and understanding how this crew operated in the system as it was that morning, we can hope to understand why they made the choices that they did, and maybe, more importantly, how the system contributed to these choices.

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[11] RFP: Request For Proposal. This is a business tool used by major airlines to reduce costs by offering hours of flying (lift) to their "regional providers" who then place bids for this opportunity. Regional airline management will place a bid for this flying and in some cases, like Comair, will ask their employees for concessions in an attempt to be more "competitive".

From here, we can better understand why this accident occurred and make meaningful recommendations to prevent future accidents. Table 1 below shows how this analysis and discussion is arranged. There are three pre-aircraft sections that discuss the crew individually and what local knowledge and perception they each possessed. Subsequently, the event is divided into seven distinct segments, each examined in sequence. It is important to realize that while for the thoroughness of analysis, this event has been dissected for closer examination, in actuality each segment is inextricably connected to the next. As the crew progresses from one to the next, their new perceptions build upon previous ones. Additionally, and maybe more importantly, the crew's foundation of knowledge and perception becomes more deeply rooted throughout the flight. That is, perception and knowledge will usually be used to support a previously held belief or local rationality. It supports errors in searching for information. This is known as "confirmation bias", where evidence supporting a course of action is prioritized and evidence contrary to a course of action is devalued.

	Date/Time frame	**Flight segment**	**Event or location on airport**
1	August. 26th, 2006	N/A	Arrival in LEX for each flight crew member.
2	August 27th, 2006	N/A	Arrival at the airport.
3	August 27th, 2006	N/A	Arrival at the aircraft.
4	05:36:07 to 05:58:50	One	Beginning of CVR recording until beginning of pushback from gate
5	05:58:50 to 06:02:01	Two	Beginning of pushback to the beginning of taxi.
6	06:02:01 to 06:02:55	Three	Beginning of taxi until intercept of Taxiway "A".
7	06:02:55 to 06:04:05	Four	Intercept of Taxiway "A" until final straight portion of Taxiway "A" prior to runway 26.
8	06:04:05 to 06:05:23	Five	Final turn on Taxiway "A" until crossing hold short line for runway 26.
9	06:05:23 to 06:06:07	Six	Crossing the hold short line for runway 26 until the setting of takeoff thrust.
10	06:06:07 to 06:06:36	Seven	Setting of takeoff thrust to the end of the recording.

Table 1: Division of the time line events. (Reference Photo 2)

a) Arrival in Lexington for each flight crew member:

The Captain arrived in LEX the afternoon of the 26th after deadheading (flying in the passenger cabin) on Comair flight 5088. This finished his duty day at just over 9 hours, which included almost 4 hours of flying. He arrived in LEX at 1526 hrs and was released to rest at the hotel, giving him over 13 hours ground time before reporting at 0500 hrs the morning of the accident. His wake-up call the morning of the accident was at 0430 hrs. This represents both a time of day and total sleep opportunity problem for the Captain. See Appendix 3 for a review of the fatigue analysis for more discussion.

Since his arrival into LEX the day before the accident was a deadhead segment, he was not afforded an opportunity to visually examine the airport configuration. His previous opportunity to visually examine the airport layout was on June 16th and 17th (about 6 weeks), where he made a daytime arrival and a nighttime departure. Despite this long interval, his experience with Comair, which frequently operates into LEX, had provided him a mental picture of the airport as compared to a pilot who has never been to LEX. Since he had no recent experience operating into and out of LEX, it is reasonable to assume that he had no preconceived notion of any recent signage or construction changes. This lack of local operational recency, the captain was required to rely on other sources of information during pre-flight and taxi to fully understand the airport layout, signage and construction on the morning of the accident. The aviation system is designed such that one's understanding of an airport can be realigned by other sources of information such as NOTAMs, ATIS and help from ATC. Should any or all of these sources prove to be insufficient in providing this realignment of their perception; crew members will begin their interaction with the airport facility with an incorrect situational awareness.

The first officer arrived in LEX early the morning of the 26th after operating a repositioning flight (flight 9471) from JFK. He arrived at 0140 hours which finished his duty day at just over 14 hours including 9 hours of flying. He was released to rest at the hotel giving him just over 27 hours ground time before reporting at 0515 hrs the morning of the accident. His wake-up time the morning of the accident could not be determined but could be estimated to be around 0430 hrs. This represents both a time of day and total sleep opportunity problem for the first officer. See Appendix 3 for a review of the fatigue analysis for more discussion. The 14 hour duty day on Friday was actually longer since he had commuted into his domicile that day. The investigation was able to determine that he in fact did commute to JFK that day, but was unable to determine the exact time. Because of not knowing when he started his commute, the exact length of this first day is unknown.

The first officer's arrival on the morning of the 26th on the repositioning flight ended with a visual approach to runway 22. The Captain that flew with the accident first officer on this repositioning flight reported that *"On the way in to runway 22, the left side lights were all lit but only about 1/8th of the right side lights on the approach end were lit."*[12] In fact, the runway 22 lights that evening were reported on the ATIS to be partially inoperative. The captain of the repositioning flight reported that even

[12] Interview summaries of the Operations Group Chairman Factual Report dated 17 December 2006, pg. 45 paragraph 2

when the runway lights were increased to maximum intensity, he only "*saw one string of lights*". Both pilots were very aware of the lighting configuration during the approach as they discussed the visual presentation. The centerline lights for runway 4/22 had been NOTAMed out of service. This must have left a strong impression of not many lights on runway 22.

As described above, it is reasonable that this was the lighting configuration that the accident first officer probably would have recalled when he was preparing for departure. His last time into LEX, prior to the re-positioning flight early the morning of the 26th, was on May 18th and 19th which included a nighttime arrival and a daytime departure. Presumably, the more recent exposure to the lighting problems on the early morning of the 26th would have played a significant role in his determination of what he expected to see the morning of the accident. As mentioned for the accident captain, recency of a visual picture can play a role in later supporting and encouraging confirmation bias. This may be the case when the individual is later presented with incorrect and insufficient information "*…is weird with no lights*"[13] that is unsuccessful in altering the established understanding of the airport.

As a starting point for understanding their local rationality, prior to the pilots arriving at the airport the morning of the 27th, we see that each has a vastly different visual impression of the airport layout and lighting. Even at this early stage of the event, each pilot has formed a vastly different mental model of how the airport will be configured.

In most situations the difference in the crew's mental model of the airport would not be an issue due to the multiple layers of safety built into the system. Some of these safety layers include taxi and takeoff briefings, charts, ATIS, dispatch flight release, NOTAMs and air traffic system support and guidance. These layers ideally provide a margin of safety that ensures safety even with some errors going untrapped. The elements of the system should be designed to ensure that even if each crew member has a different perspective, the combined effects of this difference is reduced resulting in a more closely related situational understanding.

This accident has commonality with several other wrong runway takeoff and landing events which are addressed elsewhere in this submission. Those systems, like the one encountered the morning of August 27, failed to effectively trap the errors preventing the accident. Industry recommendations from this accident should focus on increasing the overall system safety, especially in relation to taxiing and wrong runway selection events.

b) Arrival at the airport

The morning of the accident, all three crew members met in the hotel lobby and rode together to the airport. The hotel van driver reported that he dropped them off at

[13] Group Chairman Factual Report of Investigation Cockpit Voice Recorder 17 November 2006, pg 35

baggage claim around 0513 hours. He recalls that they appeared normal and were engaged in small talk during the ride. As they went through security and operations, no one interviewed remarked that anything seemed unusual about their appearance or actions. Another pilot for another airline who was interviewed remarked that they appeared professional and comfortable with each other.

c) Arrival at the aircraft

In an interview after the accident, a Comair customer service agent who was in another room of the operations area when the crew arrived described one of the pilot's conversations with other ramp agents as "*casual*" and that he heard laughing. Interviews with various Comair ground personnel all reported that the flight crew appeared to be courteous and professional in behavior. After the crew obtained the flight release they reported to the ramp area and the aircraft. When they arrived on the ramp they found three Comair aircraft facing the terminal and then proceeded to the third aircraft on the end. After the flight crew boarded the aircraft and started the Auxiliary Power Unit APU, they were advised by the ramp agent in charge that they had boarded the wrong aircraft. The investigation was not able to discover how the crew determined which aircraft to board and why the error occurred. However, this type of error can in some cases be representative of an action associated with fatigue. See Appendix 3 for a review of the fatigue analysis for more discussion. LEX, like many cities served by Comair, typically had more than one aircraft on the ramp early in the mornings. Usually, crew members are told which aircraft to board or they obtain this information from the dispatch release if available. After the crew was advised of their error, they proceeded to power down the aircraft and went to the correct aircraft. Several ramp workers reported that the crew was not upset at their error but rather made the comment "*Yeah one of those days*"[14]. Several minutes later the flight crew was seen boarding and preflighting the accident aircraft. The ramp personnel also reported that they heard no discussion from the crew regarding running late and did not seem to be rushed by this slight delay.

[14] Interview Summaries Operation Factors Group Chairman Factual Report 17 December 2006, pg 3.

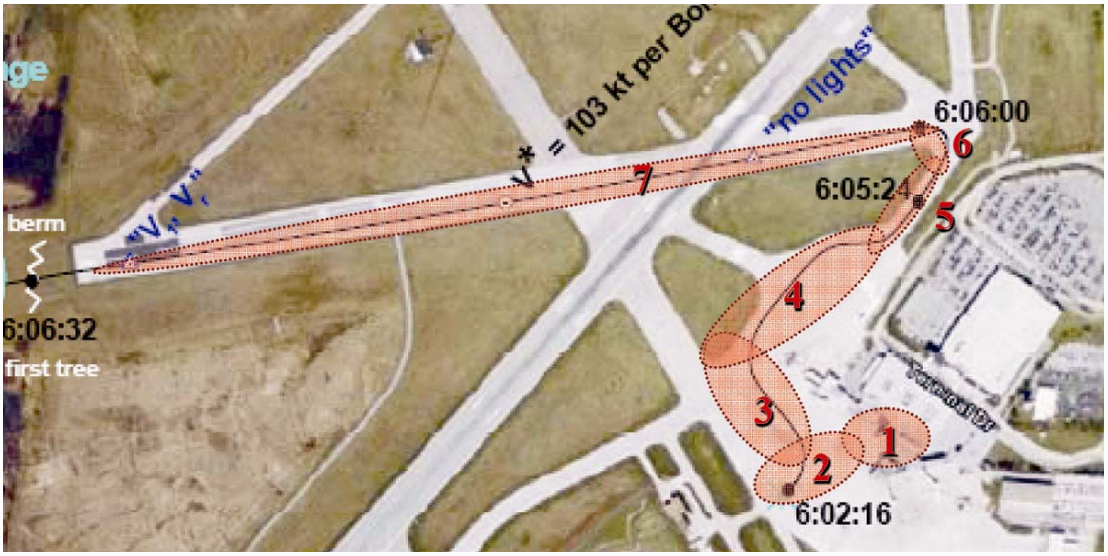

Photo 2: Accident Aircraft Flight Segments

d) Flight Segment One

Beginning of CVR recording (05:36:07) until the beginning of pushback from gate (05:58:50). Duration of 22 minutes and 43 seconds.

At this point in the event, both flight crew members have joined together to operate the flight. At this early stage they both possess very different mental models and visual understandings of the airport layout. Normally, a robust and safe system with multiple layers of protection would help align both crew members' local rationality, manage threats in addition to trapping many errors that can cause an accident.

The CVR and transcript begins at 05:36:07 and captures the crew talking to the flight attendant and performing their required preflight checks. The flight deck environment appears to be casual and normal for a crew that has just met and had never flown together. They appear to be establishing a relationship and the conversations could be considered normal and casual while accomplishing the necessary operational tasks at hand. The practice of establishing an effective relationship prior to flight has been shown to improve crew communication and coordination during normal and abnormal flight operations. This is a valuable tool that a captain can use to ensure that his fellow crew members feel comfortable and are more likely to bring any concerns to his attention. This would increase open communication and promote a safer environment. This casual conversation while they are working is supportive of the evidence by the ramp workers that the crew was not rushed. Later the passengers were boarded on time and the aircraft departed on schedule. A crew that perceived a time pressure would be less communicative in both quantity and quality and more non-verbally focused on the current task, pre-flight activities. During this flight segment there was approximately 216 comments or acknowledgements made by the captain, first officer, flight attendant or the cabin jump seat rider. The flight attendant only made two and the jump seat rider made nine. The rest of these were almost evenly distributed between the captain and first officer. Although there was extensive conversation between the two pilots during this segment of the operation, the crew was not required to be operating in a sterile cockpit environment.

As the crew begins preparation for this flight, they have no reason to believe that they are potentially in a “high threat” environment. In fact, operations at a smaller airport like LEX provide some comfort and expectations of simplicity, especially with regard to the taxi route. Supporting evidence of this comes from interviews with other pilots that have flown with the accident crew. They reported that typically each pilot would write down or place in the Flight Management System (FMS) scratch pad taxi routing at larger but not at smaller airports. The FMS scratch pad is a text entry line on the FMS. Although, taxi routes are not programmed into the FMS, many pilots have come to use the scratch pad as a temporary holding place for information such as complex taxi routes. Benefits of this technique include that it is easily erasable when finished and both pilots can see the entry. One proficiency check airman supported this observation by saying that he would not expect crews to use the scratch pad or write it down at a location such as LEX. Their routine conversation during pre-flight seems to support that they were relaxed and experiencing “just another day at the office”. As Comair crews fly into both large and small airports including some of the busiest airspace in the world, they are quite familiar with the hassles and complications of large airports. They are aware of the diligence required when operating in these challenging environments. Normally, LEX would not pose such a threat.

Closer examination of the crew’s perception of the airport’s current lighting, signage and charting problems explains how each pilot brought a different perspective to the flight deck that morning. The captain had no recent experience visualizing LEX at night as his last time flying (cockpit crew member) into LEX at night was months prior. However, the first officer had flown into LEX just after midnight on the 26th where he landed on a runway 22. As previously discussed, the captain of that flight reported that it appeared that there was only one string of runway lights. During the first officer’s takeoff briefing for the accident flight, he mentions in an audible exhaling sound *“…came in the other night it was like lights are out all over the place*”[15]. This represents the first officer’s most recent recollection and understanding of the lighting at LEX and shows his understanding of what he could expect to see the morning of the accident. Since this is what he expected to see as they departed, he shared this visual understanding with the captain.

The aviation system has procedures in place to help reduce hazards and threats to the users of the system. These mitigation strategies include the dissemination of information to flight crews so they can manage threats to the environment successfully. One such mechanism is the Automated Terminal Information Service (ATIS). The ATIS broadcast provided to the flight crew provided current weather, and that pilots should use caution on the air carrier ramp due to construction.

[15] Group Chairman’s Factual Report, Cockpit Voice Recorder, 17 November 2006, pg. 18.

Although there was still a NOTAM(L) in effect at the time of the accident indicating that taxiway "A" north of runway 26 was closed, this information was omitted from the "Alpha" and "Bravo" ATIS broadcasts received by the accident crew and was not provided in the flight release prepared by Comair. This valuable piece of information would have required the crew to positively identify runway 26 before they could have identified the closed portion of taxiway "A". We believe that if they could have clearly identified runway 26, they would have never attempted takeoff from it.

This valuable piece of information was available to other crews in the days prior to the accident. A Comair line captain interviewed after the accident reported that she had been flying into LEX frequently in the months prior to the accident and remembered that this NOTAM was on the ATIS. In Addendum 1 to the ATC Group Chairman's Factual report dated February 23, 2007, the NTSB ATC Group Chairman verified that from August 20th – 26th, the ATIS broadcasts advised taxiway "A" north of runway 26 was closed. The investigation failed to determine why the controller, the morning of the accident, did not include it on the ATIS received by the accident crew. As ALPA was not allowed to participate in the ATC Group, we have no insight into why the ATC Group failed to further investigate this deviation from FAA Order 7110.65R by the Controller on duty at the time of the accident.

Following the first officer's takeoff briefing, the captain now has what is his first understanding of the presumed runway lighting problems at the LEX airport (after hearing the general comment about numerous lights being inoperative). Since he had no recent operational experience at LEX while it was dark, this information from a fellow crew member with recent relevant experience would form the basis of what he expected to see when they taxi out and take off. This information as provided by the first officer in addition to the lack of details in the NOTAMs and ATIS, helped him form an incorrect mental picture of the actual lighting and construction at the airport.

At some point during this time frame it is reasonable to assume that the captain reviewed the flight release, based on the comment at 05:51:29 that the alternate CHA (Chattanooga, TN) "*is good*". Supplied by Comair flight dispatch, the release contained several NOTAMs regarding lighting outages for either runway 4/22 or 8/26 which include: Runway 4, approach lighting and touchdown zone lighting out of service in addition to runway 4/22 centerline lighting out of service. There were also NOTAMs for runway 8/26 runway edge lights and runway end identifier lights being indefinitely out of service. The first officer's comment "*lights out everywhere*" combined with the runway 22 lighting outages provided in the release gave the crew the supporting evidence that there were still numerous lighting outages on runway 22. The factual record indicates that this is exactly what they saw.

There is no specific Comair policy or FAR that requires first officers to review the flight release for NOTAMs and it is unknown if the accident first officer did so. Had the first officer reviewed the release, he may have realized that his recent visual experience the prior night with lighting issues was not the same as reported in the release. In fact, the NOTAM for the runway edge lights was removed as they were now working properly the morning of the accident. Several pilots that departed minutes before the accident flight reported that the runway 22 appeared to have complete runway edge lighting. Had the first officer been aware of this, this may have stimulated discussion between him and the captain and possibly tempered his previous comment about excessive lighting problems. Had this occurred, both pilots may have had a more realistic expectation of what they should see when they took the runway for takeoff. The first officer would have been able to see from the information in the release that the lighting was not as bad as he had experienced late Friday night, giving each pilot a chance to have a better understanding of what they could have expected that morning. Essentially, each pilot would have had a more similar visual mental model of the lighting problems in addition to being more correct for the actual field conditions.

Crew member briefings provide another layer of system safety by ensuring that all crew members are aware of how the flight will be conducted. Comair pilots are required to provide several types of briefings depending on the specific particulars of the flight. For example, crews are given guidance on crew member, taxi, takeoff and high threat taxi briefings. An interview with the FAA Air Crew Program Manager for Comair discovered that the requirement for crews to brief on taxiing was relatively new at the time of the accident. Although he could not say when it was implemented, he knew that it was added because of recent runway incursions at Comair. In a collaborative effort, the FAA and Comair Flight Operations Department agreed to add this briefing requirement. The FAA also required the Comair Training Department to emphasize taxi briefings and include an actual taxi event while in the simulator. He further discussed that the depiction of airport signage in the simulator could be improved in an attempt to increase realism since readability and accuracy was an issue. In an attempt to overcome this, taxiing was emphasized more during line checks after the program started. When asked if the taxi briefing strategy had resulted in improvements, he said it took a while to implement and that although he had heard of some events by other sources, he did not know how many. It is unknown if after the implementation of the taxi briefing procedure company wide, Comair was able to demonstrate not only compliance in crews but a successful reduction in runway incursion events in the months prior to the accident. If determined via FAA oversight and in house surveillance programs that a significant reduction had not occurred, this might have offered an opportunity to introduce additional mitigation strategies prior to the accident.

The crew member briefing serves as a valuable Crew Resource Management (CRM) tool that ensures that all crew members are aware of the details of the flight and encourages open communication. For flight crew members that have not recently flown together, the briefing should be in more detail to clearly establish how the flight is to be conducted. Sections of this briefing can later be summarized by stating “Comair standard”. Items that should be covered may include; weather, time enroute, delays, security issues, aircraft problems and any other information deemed necessary for the completion of a safe flight. The crew member briefing that the captain provided to both the first officer and flight attendant was lacking several items as described in Comair policy and procedures. Taxi briefings are required to be performed by the captain and should include details regarding the availability of airport charts and airport taxi vigilance. The taxi briefing was completed by the first officer, and several pertinent items were missing. The investigation was unable to determine why the first officer, instead of the captain, performed the taxi briefing.

Interviews with pilots that had flown with the accident first officer did not report that he had performed the taxi briefings on their flights. Interviews with a first officer that had flown with the accident captain a week before the accident reported that the accident captain did the briefings as required. During an interview, one Comair first officer said that the accident captain was authoritative but respectful to first officers as suggested by traditional CRM training. With regard to the accident crew's less then detailed taxi briefing and the fact that it was done by the first officer, it is hard to say to what degree this played a role in this accident. However, it seems reasonable to assume that a more detailed discussion about crossing runway 26 and the close proximity of both runway ends to each other probably would have served this crew well. Discussing this item would have helped, as designed, to enforce what to watch for and expect during the taxi event. Had the crew done this, the realization that while they were taking "runway 22" (their believed perspective that morning) for takeoff before they had yet to cross runway 26 could have been an opportunity to signal that something was wrong and to trap this error.

Comair also provides its crews with guidance regarding when and how to use high threat taxi procedures. At the time of the accident, LEX did not meet the requirements as a high threat taxi environment. Comair policy and procedures dictate that crew members have their airport diagrams out and available during taxi operations. It is reasonable to assume that they did. In fact, interviews with several other pilots that had flown with the accident flight crew members reported that on those flights they did utilize their taxi diagrams as required.

So it is very likely that the crew had their airport diagrams out, however, as discussed elsewhere in this submission, the Jeppesen chart the crew had available to them was not correct in regard to actual open taxiway segments and signage. The aircraft pushed back from the gate with both crew members having an incorrect understanding of the current lighting and construction at the airport. The single NOTAM regarding construction on the air carrier ramp sets a certain mental picture of what to expect during the initial portion of the taxi. This sets the expectation of construction on the ramp area and would provide the crew with a false sense of security that once clear of the ramp area they would be past any threats to taxiing, no problems or abnormalities would be expected.

As discussed earlier, this analysis uses a threat and error type classification of this accident event. During this entire segment of the flight, there were numerous threats to and errors made by the crew. Table 2 below illustrates threats and Table 3 illustrates specific errors made by the crew. There were six specific threats during this segment and none of these were managed by the crew. In fact, five out of the six threats identified by this investigation were not even known or realized by the crew. The remaining threat (the flight attendant's interruption of a checklist and subsequent omission of an item) was not managed effectively and resulted in a missed checklist item. However, this missed item (altimeter cross check) appears to not be a factor in this accident.

Threats		**Managed**
1	Crew fatigue.	No
2	Each crew member has a vastly different mental visual image of the current airport layout	No
3	Dispatch release that did not contain all of the NOTAMs. i.e. local NOTAM regarding taxiway "A" closed north of runway 26.	No
4	ATIS did not include the taxiway closure NOTAM	No
5	Airport current layout and signage not in agreement with the Jeppesen charts available to the crew.	No
6	FA interrupts crew asking for a briefing while reading before starting engines checklist. Crew misses altimeters on checklist	No

Table 2: Segment 1 Threat Table

Error description, category, response and outcome				
Time	**Errors**	**Category**	**Crew Response**	**Error Outcome**
05:38:04	Incorrectly read Flight compartment safety inspection checklist.	Procedural error	Failed to respond	Inconsequential
05:45:44	Incorrectly read Acceptance checklist.	Procedural error	Failed to respond	Inconsequential
05:50:06	FO gets clearance wrong, clarifies.	Communication error	Trapped error	Inconsequential
05:51:29	Capt. says alternate is "good". Read NOTAM ?	Procedural error	Failed to respond	Inconsequential
05:53:27	FA request to have the PA deselected in the cockpit. Apparently the Capt. left it selected while performing PA check.	Procedural error	Trapped error	Inconsequential
05:56:14	Captain performs a non-detailed briefing to FO	Procedural error	Failed to respond	Undesired state
05:56:25	FO briefs "flex thrust" however crew programs normal thrust and the Captain reads normal thrust during checklist	Procedural error	Failed to respond	Inconsequential

05:57:23	FO instead of Capt performs taxi brief and does it incorrectly.	Intentional non-compliance error	Failed to respond	Undesired state
05:57:36	Crew misses and/or reads incorrectly 3 items on the before starting engines checklist.	Procedural error	Failed to respond	Inconsequential
05:57:50	FA has to request a briefing and Captain delivers a less than detailed briefing	Procedural error	Failed to respond	Inconsequential
05:58:17	FO began the Before starting checklist when starting engines checklist was called for by the Captain.	Communication error	Trapped error	Inconsequential

Table 3: Segment 1 Error Table

Eleven crew-based errors were identified. A breakdown of these events would include: eight procedural errors, two communication errors and one intentional non-compliance based error. Of these 11 errors, only three were later trapped by the crew. Two errors (inadequate crew briefing and inadequate taxi briefing) could be classified as "failed to respond" which eventually led to an undesired aircraft/crew awareness state. Both of these errors played different roles in affecting the situational awareness of the crew. The first, the captain not performing a detailed first flight crew briefing provided a lost opportunity to illustrate to the first officer the expected level of detail and standardization that is expected. When the first officer later erroneously gives the taxi briefing, it is abbreviated and fails to identify potential threats for taxiing to runway 22. Additionally, the first officer's comment "*taxi instructions with ATC*"[16] is not only a missed opportunity to discuss the hazards of the taxi route, but also demonstrates a possible over reliance in ATC to keep them out of trouble. This vagueness and over reliance in ATC further erodes the margin of safety that any system can provide.

The errors discussed above in addition to the errors deemed "inconsequential" are suggestive of a fatigue related origin. Although most of them appear to have played no role in this accident, they may be more indicative of an overall system problem. Simply a system that is challenged by impaired human neurobehavioral performance. See Appendix 3 for an in-depth discussion of fatigue and associated human performance.

In summary, the concepts listed below highlight this portion of the flight.

- Each crew member arrives at the aircraft with a vastly different visual understanding of LEX.

[16] Group Chairman Factual Report, Cockpit Voice Recorder 17 November 2006, pg 18.

- Both flight crew members appear to be engaged in conversation and the social environment in the flight deck is casual and friendly.
- This segment of the flight is not under sterile cockpit restrictions.
- There is nothing threatening about taking off from a smaller non-congested airport such as LEX.
- The first officer's comment to the effect of lights being out everywhere and lack of a detailed taxi briefing by the captain helped skew their understanding of the current lighting and taxiway configuration.
- The ATIS and the flight release do not capture the NOTAM regarding taxiway "A" being closed north of runway 26.
- The flight release reported numerous lighting outages NOTAMs for runway 22. Both crew members read checklists incorrectly and miss several items indicating either competition for cognitive resources or reduced cognitive capability.

e) Flight Segment Two

Beginning of push back 05:58:50 to the beginning of taxi 06:02:01. Duration of 3 minutes and 11 seconds.

During this segment the crew begins the push back procedure, and individually, still possess a different mental picture of the airport layout. They have already briefed the taxi and takeoff and possess what they each individually believe to be an accurate mental picture of the airport layout. As per normal operating procedures during aircraft pushback, the crew started both engines. During this time, they were engaged in casual conversation. Comair policy/procedures and Federal Aviation Regulations specify that sterile cockpit procedures are not in effect until the aircraft moves under its own power.

Although two errors occur during this phase, they are inconsequential regarding the accident (See Table 4). However, they are still two additional examples of checklist errors committed by the first officer. Typically this pattern of behavior indicates that something is competing for cognitive resources and/or cognitive capacity is diminished. See Appendix 3 for further discussion.

Error description, category, response and outcome				
Time	**Errors**	**Category**	**Crew Response**	**Error Outcome**
06:01:50	FO reads incorrectly on the Starting engines checklist the "engines" line	Procedural error	Trapped error	Inconsequential
06:02:00	Reads the wrong checklist "complete".	Procedural error	Failed to respond	Inconsequential

Table 4: Segment 2 Error Table

In summary, the concepts listed below highlight this portion of the flight.

- Each crew member has a different understanding of the airport layout and details regarding the taxi route.
- The first officer continues to make minor errors in reading the checklist correctly.

f) Flight Segment Three

Beginning of taxi 06:02:01 until intercept of taxiway "A" 06:02:55. Duration of 54 seconds.

This segment of the flight marks the beginning of sterile cockpit procedures. It is also the first opportunity for the crew to begin comparing their current visual understanding of the airport layout (local rationality) with actual signage, markings and physical arrangement of taxiways as they begin their taxi. This segment marks the flight crew's first opportunity to detect any situational awareness disconnects that they may have and to adjust their local rationality. In other words, take what they already believe about the airport layout and adjust it for what they really see during the taxi. Exterior signage and charts are designed to ensure that the crew understands where they are regardless of any preconceived notion they may have had regarding the airport layout. Unfortunately, the crew was not aware that airport signage was not in agreement with the Jeppesen charts they were using.

As per the Comair Operations manual and Federal Aviation Regulations[17], sterile cockpit begins when the aircraft moves under its own power. Consequently, after the crew requested and received the clearance to taxi, the CVR transcript records a significant reduction in non-pertinent conversation. This is discussed in more detail later in this section. The first officer initiates a non-pertinent conversation that appears to be a continuation of an earlier discussion at the gate. Closer examination of the CVR transcript shows that the captain's response to this discussion is dramatically different than at the gate and pushback. His sentences are incomplete and the majority of his replies appear to be short clipped agreements. He appears to not be engaged in this conversation and may have been distracted by it. This change in casual conversation on the part of the captain was at the same time he had just passed the confusing taxiway "A6" sign in addition to the more distant single runway 4/22 and 8/26 sign. The captain's attempt to reconcile the conflicting information of the signage with his previous experience and mislabeled Jeppesen chart is one explanation for his significantly decreased participation in this continued conversation. It is possible that he was cognitively saturated.

Voice parameters that can aid in this determination are tone, volume, inflection and overall general nature of this conversation in comparison to other conversations during this event. By reviewing a written transcript, the majority of these parameters go un-resolved. Basic analysis of the probable durations of all non-pertinent conversation using what could be deemed a "normal" speech rate before and after the beginning of sterile cockpit procedures revealed a definite pattern. The captain

[17] Comair Operations manual 5.13.2 page 5-61 and 14 CFR Part 121.542.

significantly decreased his participation in non-essential conversation. Table 5 represents the findings from this analysis and reads left to right as the flight progresses through this point in time (sterile cockpit).

<table>
<tr><td>Amount of time before sterile cockpit -></td><td rowspan="6">S
T
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L
E</td><td>Amount of time after sterile cockpit -></td></tr>
<tr><td>26:08</td><td>4:21</td></tr>
<tr><td>Non-pertinent Conversation. -></td><td>Non-pertinent Conversation. -></td></tr>
<tr><td>6:38 (26% of the time)</td><td>00:19 (7% of the time)</td></tr>
<tr><td><u>Of this conversation</u>
Captain 3:17 (49.5 %)
First Officer 3:21 (50.5%)</td><td><u>Of this conversation</u>
Captain 0:04 (21%)
First Officer 0:15 (79%)</td></tr>
</table>

Table 5 Comparison of non-pertinent conversation before and after the beginning of sterile cockpit procedures

As shown in Table 5, the amount of time spent on non-pertinent conversation is almost identical for each crew member prior to the beginning of sterile cockpit procedures (49 % vs. 50 %). However, there is a dramatic decrease in the captain's participation afterwards (21 % vs. 79%) and in the area of "A6" taxiway ("A4" on the crew's Jeppesen charts). This shows that either the captain was unwilling or unable to engage in casual conversation after the beginning of sterile cockpit. Either possibility or a combination of the two may have been involved. Regarding the possibility that he was unwilling to engage in casual conversation is reasonable since this is a common and frequently effective social method of indicating to another person that we are no longer interested in further casual conversation. Socially speaking, we typically use two means to send this message; we no longer initiate any conversation and our answers to inquires from the other person become more truncated or maybe even ignored. From a social science point of view, this typically sends a strong message to the other person that we are no longer engaged in this dialogue. Although both crew members received Crew Resource Management training that recommends a direct approach, this is still a common method seen in real world line operations.

After pushback and prior to aircraft movement under its own power, the aircraft's heading was approximately 48 degrees while stationary on the ramp. Due to the lack of sufficient data available to the investigation, the exact aircraft geographical starting point on the ramp is undeterminable. However, based on the normal parking spot for Comair aircraft, ramp interviews and some of the FDR information, reasonable assumptions can be made. It appears that after pushback the aircraft was somewhere on the ramp east of taxiway "A" and abeam taxiway "C". From this approximate location, the view outside the flight deck windows would be vastly different for each crew member. The captain who is seated on the left side of the aircraft would be provided a much better view of the airport's taxiway as compared to the first officer. As detailed in the visual study performed after the accident, the captain would have been able to look out his left window and look west down taxiway "C" in addition to seeing several runway 4/22 signs and one runway 8/26 sign. Photo 3 shows this view.

Photo 3: View of Taxiway "C" from Ramp

The first officer would not be afforded such a clear view because of the physical presence of the captain and the reduced cross-cockpit visibility. From the first officer's seated position and looking straight ahead and to the right, he would be able to see primarily the terminal and ramp environment. For both crew members, signage and runway/taxiway lighting would have appeared normal and operational at this point in the flight. It is reasonable to assume that at this point in time, the crew's situational awareness on the ramp was close to, if not identical to reality for this stage of the taxi. They knew that they were on the ramp and that a left turn was required to intercept taxiway "A". In regard to the first officer's abbreviated taxi briefing describing "*lights out everywhere*", this would not yet be visually evident to either pilot. Both crew members would be seeing many blue (taxiway edge) and white (runway edge) lights in addition to numerous lighted taxiway and runway signs. The captain who has the least amount of detailed information about the first officer's earlier comment about "*lights out everywhere*" from the first officer would not see anything supportive of that yet.

After requesting and receiving taxi clearance from ATC, the aircraft begins a left turn to approximately a 320 degree heading to intercept taxiway "A". At 06:02:15, the captain calls for the taxi checklist. As this turn progresses to the left, the view outside the windshield changes more for the first officer than the captain. The first officer now has the opportunity to see clearly the view as described and shown earlier for the captain. It is important to understand what each crew member was doing when this outside view changed. Just because a new visual picture was offered to a crew member does not mean that they even saw or correctly perceived the environment.

As the turn towards taxiway "A" was initiated, the crew begins the taxi checklist by checking movement of the flight controls. This takes over 30 seconds. The captain would still be heads up; however, the first officer is required to check the captain's rudder input in addition to his movement of the ailerons and elevators on the flight control synoptic page. These checks are included in the total of nine items that he must check or verify via a flow pattern prior to reading the checklist out loud. The specific checklist has six items with the first four items designed to be verbalized in a challenge and respond format. From the time the aircraft began taxiing to when it began a right turn to intercept taxiway "A" was approximately 54 seconds. It is reasonable to assume that the majority of this time prior to intercepting taxiway "A" the first officer was heads down. In fact, as the aircraft makes the right turn to intercept the taxiway, the first officer is still reading the checklist. The visual picture is again changing and the first officer is now heads down.

This represents a very busy time for the first officer and it is important to note that sterile cockpit procedures were strictly adhered to. However, due to the amount of heads down time and items completed during this period, it is reasonable to speculate that if he did look up, it would have been brief. The extent of any visual perception is unknown. Due to the first officer's workload during this segment, it is reasonable to assume that his local rationality was probably unchanged from the ramp area. The checklist provided a significant distraction while taxiing the aircraft, further compounded by three communications on the ground control frequency between ATC and another aircraft. The exact intercept point of taxiway "A" is undeterminable, but it is reasonable to assume that it was south of taxiway intersection "A6" based on the location of the Comair gate area. A few seconds after taking up a heading corresponding to that of "A" north of "C", the first officer verbalizes that the taxi checklist is complete.

With regard to the speed at which they were taxiing, there is no evidence that it was too fast. In fact, a first officer that flew with the captain a week before the accident commented on how his speed, especially at smaller airports was "average". In the example he gave, they were at a smaller airport with a very short taxi and he was able to get everything done without having to ask the captain to stop or slow down. There is no reason to believe that taxi speed was an issue for the crew of Comair 5191.

This segment of the flight offers the crew their first chance to situationally orient themselves for the taxi to runway 22. The captain has a good view of the area and has time to perceive his environment as compared to the first officer who spends most of this time heads down and performing checklists. Essentially the first officer is task saturated with the taxi flow, checks and verbalizing the taxi checklist. We see from the CVR transcript and FDR that two errors occur during this period (See Table 6). Both errors were committed by the first officer and were not trapped by either crew member. However, by the nature of the errors they are inconsequential and appear to have played no role in the accident. It is important however, to understand that these errors, although inconsequential are a continuum of an earlier pattern exhibited by the first officer and are suggestive of possible fatigue (See Appendix 3 for fatigue analysis).

Error description, category, response and outcome				
Time	**Errors**	**Category**	**Crew Response**	**Error Outcome**
06:02:28	Radar is briefed off but it turned on	Procedural error	Failed to respond	Inconsequential
06:02:52	FO does not read checklist correctly for both brakes being checked.	Procedural error	Failed to respond	Inconsequential

Table 6: Segment 3 Error Table

In summary, the concepts listed below highlight this portion of the flight.

- The crew is afforded their first opportunity to compare their preexisting visual mental model of the airport with reality in an attempt to resolve any differences.
- Both crew members, especially the first officer, were task saturated during this flight segment

g) Flight Segment Four

The intercept of taxiway "A" at 06:02:55 until the final straight portion of taxiway "A" prior to runway 26 at 06:04:05. Duration of 1 minute and 10 seconds.

This segment of the flight as it curves after intercepting taxiway "A" and continues along taxiway "A" until the final left turn onto the straight portion of taxiway "A" prior to runway 26. This represents a significant segment of the taxi event because this is where the crew has the potential to recognize the mismatch between signage and the Jeppesen chart. There are three considerations related to human performance in this segment; signage, airport charts and the crew's workload. Photo 4 shows the view as the aircraft approaches the "A6" intersection. The Jeppesen chart shows this as "A4".

Photo 4: Taxiway "A" Approaching "A6"

As they approach taxiway “A6” this marks the first known point where there was a specific visual threat to the crew’s situational awareness. This was probably the first point where the captain’s situational awareness becomes challenged. This point of confusion combined with his original less than detailed mental visual image of the airport layout makes it reasonable to suggest that this is where the captain’s altered situational awareness becomes significant. Any previous recent night exposure he had to the airport layout was over a month ago and would not be helpful in resolving this conflict. This crew, like all instrument rated pilots, are quite familiar with the Jeppesen instrument charts and overall general airport design and layout. They understand as a matter of practice taxiway intersections are numbered sequentially from one end of a runway to the other, i.e. A1, A2, A3, etc. See Figure 6.

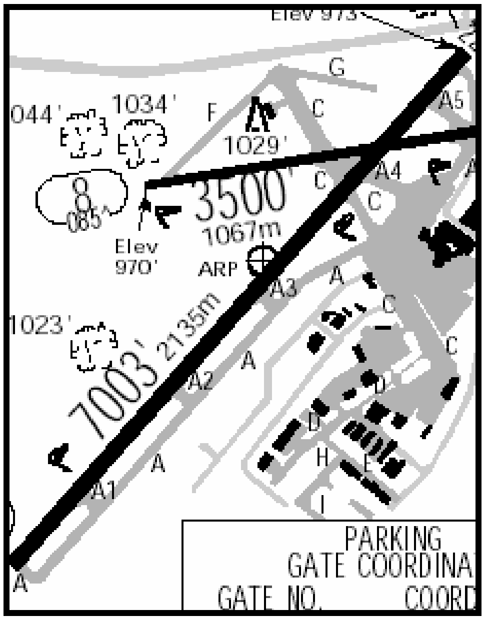

Figure 6: Jeppesen 10-9 Airport Diagram (current at time of accident)

When the captain saw the “A6” sign, this could have been interpreted as placing him north of runway 26 in the area of “A5” as shown on his chart. Additionally, after seeing the “A6” sign and not understanding its geographical relevance on the Jeppesen chart, he would naturally seek another data point in an attempt to clarify his confusion and support his current local rationality. The close proximity of the runway 4/22 and 8/26 sign behind the “A6” sign may have provided this data point. It is conceivable that these two signs suggested that the runway is now behind them and they are now approaching the runway 22 threshold. The crew’s Jeppesen chart shows that after you cross runway 26 there are two paths to runway 22; taxiway “A5” and taxiway “A”. Further supporting this idea could be how the first officer’s taxi briefing explained how they would get there; “*let’s take it out and um, take uuuh, alpha, two two’s a short taxi*”[18]. From the captain’s perspective, that is what they were doing, taking “A” to 22. They did not know that the section north of runway 26 was closed so they had no reason to believe that they would not use it to taxi (they never received the local NOTAM via ATIS, the flight release or ATC). The final left turn on “A” approaching 26 is very similar in distance and turn angle as the turn just past runway 26 on “A” to runway 22 (the closed portion). If the captain did have a vague recollection of how the taxiway is designed past runway 26, this section and its design is similar enough to support this idea.

This contradiction probably would have affected the captain the most since due to the first officer’s workload at this point, as he was probably not able to closely evaluate taxiway signage. Because of the first officer’s view from across the cockpit and the sign’s ground level location, visually acquiring this sign as it passed would have come during a narrow window of opportunity. The additional burden of having no

[18] Group Chairman Factual Report, Cockpit Voice Recorder, 17 November 2006, pg 19

signage on his side of the cockpit would only aggravate his decrease in situational awareness.

With regard to workload, each pilot has a unique task for this segment and this was a very busy time for both crew members; especially the first officer. In fact, one line captain interviewed with recent experience into LEX prior to the accident commented as follows: *"During the taxi at LEX the first officer may not be as involved in helping maintain crew situational awareness because they're busy doing the first flight of the day items so they're not as attentive"*[19]. When several line first officers were asked about the taxi in LEX, they replied that it was very short. One first officer commented: At Lexington there are "*lots of inside activities for the FO to do*"[20] and it kept him busy.

As the aircraft turns to intercept taxiway "A" and approaches taxiway "A6" (see Photo 4) the first officer is reading the taxi checklist and the captain is responding as appropriate. From the factual reports, we can see that from the intercept of taxiway "A" and approaching the taxiway "A6" sign the crew is completing the taxi checklist. This includes checking the flight controls and the command and challenge checklist. At 06:03:12 the aircraft is established on taxiway "A" and the captain says "*finish it up your leisure*" implying for the first officer to perform the before takeoff checklist. At this point the first officer would be heads down inside the cockpit performing the extensive flow required for the before takeoff checklist.

In regard to the captain's workload, he was responsible for taxiing the aircraft, maintaining situational awareness and monitoring the progress of the first officer with the before takeoff and first flight of the day checklist. As previously discussed, during this segment the captain's responses to the first officer's non-pertinent conversation becomes truncated. Quite simply, it is possible that his attentional resources were exceeded and he simply devoted more effort to other activities as opposed to being fully engaged in the conversation that the first officer had started. Due to the nature of how humans process incoming information, we allocate our limited attentional and cognitive resources to the task with the highest priority. This form of selective inattention may be a conscious or sub-conscious decision. Additionally, it is important to understand that the more tired we are or the more distracted by noise or other conversation, the more limited our cognitive resources may be. In a worse case scenario, if the incoming information and data exceeds our current cognitive capacity, even the primary task we are focusing on will suffer. The presence of fatigue will serve to further reduce our cognitive capacity. See Appendix 3 for a more in-depth discussion. We believe that upon passing the "A6" intersection, the captain was task saturated trying to maneuver the aircraft in a consistent turn (which requires more cognitive effort than a straight segment) and attempting to reconcile how the

[19] Interview Summaries, Operation Factors Group Chairman Factual Report, 17 December 2006, pg 26.
[20] Interview Summaries, Operation Factors Group Chairman Factual Report, 17 December 2006, pg 28.

confusing and contradictory visual information he just acquired fits into his current local rationality. It is important to understand that when we are in such a situation we may not be completely aware of the selective inattention that we are displaying and will continue to perform the primary task (taxiing the aircraft). In other words, we will continue to perform our task and not stop because we will realize that we have recognized the conflict and are taking steps to managing it successfully. We will maintain this belief unless something captures our attention that the situation is getting worse and now quite possibly a new level of action is required (stopping the aircraft).

With regard to the first officer and his workload, due to lack of signage on his side and distraction with checklists, it is reasonable that he was not able to maintain or update any significant degree of situational awareness at this time. After all, this was a small airport, he was very busy, and it was a short taxi and he, like most first officers, has previously experienced captains always taking them to the correct runway. This expectation combined with workload distraction, lack of signage on the right side of the aircraft and comfort between these crew members would only serve to contribute the first officer's situational awareness disconnect that they were fine and getting close to the runway for takeoff. The first officer, like the captain, did not know about the various threats and errors associated with this flight. Their taxi briefing did not adequately emphasize a clear understanding of associated hazards while taxiing to runway 22. The first officer had no ability to appreciate the potential confusion the captain might be experiencing and his personal workload kept him from ascertaining if there were any problems. Essentially, by this point the captain was taxing the aircraft by himself with a local rationality that did not match reality but yet was supported by several misinterpreted data points.

The first officer was tasked with monitoring the radio for calls from ATC in addition to performing and reading the checklists. The request for the first officer to begin the before takeoff checklist was implied by the captain at 06:03:12 which places the aircraft established on taxiway "A" in the area of but probably prior to "A6". See Photo 4. At this point the first officer would be required to go heads down to perform the forty-four actions or confirmations that are required on the before takeoff flow. He completes this part of the flow and verbalizes the checklist up to the beginning of the passenger announcement at 06:04:38. From a few seconds before the first officer begins to verbalize the before takeoff checklist, the CVR transcript captures no further non-pertinent conversation. This part of the checklist, including first flight items, encompasses 44 various actions/confirmations/interpretations during this time. The amount of time that the first officer took to complete these is 1 minute and 26 seconds all while the aircraft was in motion. This represents approximately one action/confirmation or interpretation every 2 seconds. Because of this extremely high workload during this time frame, it is reasonable to assume that he was not able to look outside for taxiway and runway signage.

The geographical location of the aircraft while the first officer was task saturated was from approaching taxiway "A6" intersection until the turn on to the final segment of taxiway “A” to holding short at runway 26 at 06:04:36. Photo 5 shows the view in front of the aircraft as it makes its final turn onto this segment.

Photo 5: Taxiway "A" Approaching Runway 26

At this point of the taxi event, both crew members situational awareness as compared to reality probably differs from each other for different reasons. Notably, it is wrong in both cases. This will be further explored in the next flight segment. Confirmation bias and plan continuation now play an integral role in why this series of errors and misperceptions was not trapped at this point in time. Three threats are identified to exist during this flight segment and by their very nature, it is reasonable to assume that the crew was not consciously aware of any of them (See Table 7). As a result, none of these were recognized, discussed or managed to any degree. All three will play a significant role in the danger to this flight. With sufficient layers of protection in a safe system, any one of these threats by themselves would not be catastrophic. However, the addition of these threats with the existing threats and errors already discussed made this situation extremely dangerous.

Of the three errors identified in this section, two of them are procedural in nature and result in an inconsequential outcome (See Table 8). The third error, the violation of sterile cockpit procedures plays an unknown role in this accident. It is possible that this attempted conversation with the captain may have been distracting to the captain as discussed earlier. However, it is reasonable to assume that the reduction in the captain’s participation in this conversation as compared to the discussion at the gate shows some degree of task prioritization either consciously or sub-consciously. Cognitively speaking, his resources are elsewhere during this time frame and are not focusing on the first officer’s banter. The presence of fatigue would only serve to further reduce the crew’s capacity to recognize and prevent errors in perception and the projection of their situation awareness into the future. See Appendix 3 for a more in-depth discussion. Considering the nature of how the information that had just been visually presented to him in the "A6" area differs from his original local rationality, it seems reasonable to speculate that he was trying to resolve this difference in his current and newly perceived situational awareness. The various threats and errors discussed above are shown below.

Threats	**Managed**
"A6" intersection is marked on their chart as "A4".	**No**
First officer's cognitive resources are limited due to task saturation.	**No**
The small amount of visual cues and lack of signage on the first officer's side of the aircraft.	**No**

Table 7: Segment 4 Threat Table

Error description, category, response and outcome				
Time	**Errors**	**Category**	**Crew Response**	**Error Outcome**
06:03:12	Non-standard call for before takeoff checklist (Capt)	Procedural error	Trapped	Inconsequential
06:03:16	First violation of sterile cockpit procedures	Intentional non-compliance error	Failed to respond	Undesired state
06:04:01	FO does not read APR armed	Procedural error	Failed to respond	Inconsequential

Table 8: Segment 4 Error Table

In summary, the concepts listed below highlight this portion of the flight.

- The intercept of taxiway "A" represents the crew's first opportunity to realign their situational awareness with that of reality.
- Because of several conflicting observations and lack of recent previous experience operating out of LEX in dark conditions, the captain's situational awareness continues to be degraded.
- There were no signs on the right side of the aircraft. The first officer's workload made it unlikely that he was able to interpret any signage that he could see from across the cockpit.
- This segment of the taxi denotes the first violation of sterile cockpit and a noticeable difference in how interactive the captain is to the first officer's casual discussion.

h) Flight Segment Five

The final turn on taxiway "A" prior to runway 26 at 06:04:05 until crossing the hold short line for runway 26 at 06:05:23. Duration of 1 minute and 18 seconds.

This segment of the flight represents the final opportunity for the crew and ATC to trap this error before the beginning of the takeoff roll. Cognitively speaking, confirmation bias and plan continuation play a significant role. During this period, both crew members are busy. The captain is essentially taxiing the aircraft without the first officer as he was completing before take-off checklist items. Closer examination of this segment will show that both crew members probably felt comfortable and at least confident enough with their perceived position on the airport to continue the flight by eventually requesting takeoff clearance.

As briefly mentioned in the last segment, the turn onto the last segment of taxiway "A" and up to the hold short line was a dynamic cognitive environment. For reasons previously discussed, the captain probably now believes and is fairly confident that he is approaching the hold short lines for runway 22. From a plan continuation standpoint he, like all humans, will continue to believe this perception or local rationality unless something dramatic and contradictory presents otherwise. The first officer, due to workload and limited time for task allocation, has missed the few cues available to him as to their location on the airport up to this point in time. As they approach and stop at the runway 26 hold short line, both pilots have no reason to believe that they have not in fact arrived at the hold short line for runway 22. However, it is important to understand that they have both arrived at this erroneous conclusion for different reasons. Again, in order to fully understand what was happening during this 78 second time period, it is necessary to examine both communication and workload management parameters. Later in this section, this will help to understand any potential perception problems leading to the crew's situational awareness disconnect from reality before taking the runway for takeoff.

The taxiway and runway signage that the first officer would have missed earlier in this area assuming he was heads down the entire time include: the taxiway "A6" sign and the runway with 8/26 signage in the distance behind it. Additionally, he would have also missed the gentle turn on "A" including the approximately 45 degree turn on the final segment of taxiway "A" and the only runway 26 sign which was on the left side of the cockpit. There was no runway 26 sign at the hold short line for runway 26 on the right hand side of the aircraft. Due to the cross cockpit distance and low height of the sign above the ground, it would not be visible on the left side of the aircraft once they were holding short of runway 26. A visibility study following the accident with pictures taken from the first officer's seat approaching the hold short line may have helped confirm our belief that once the aircraft turned onto the final segment of taxiway "A" the sign was only visible for a few moments for the first officer. Additionally, after this final turn when he had the greatest chance of seeing this runway sign, he was probably heads down reading the checklist. It was not determined where along the taxiway the sign for runway 26 went out of view from the first officer's perspective.

As the aircraft makes the final left turn onto the straight portion of taxiway "A" prior to the hold short line for runway 26, this encompasses 31 seconds of time (06:04:05

to 06:04:36) and numerous simultaneous events. The captain is turning the aircraft to the left and may in fact still be trying to mentally resolve the situational awareness disconnect that has occurred over the last two minutes. Not only is he attempting to maintain the center line of the taxiway but he is also looking for and finding the hold short line for the approaching runway (Runway 26). He is inundated with both visual and auditory stimulation from both the first officer and ATC communication with another aircraft in his headset.

The first officer is again heads down reading the rest of the before takeoff checklist and announces that he is going to the back (euphemism for using the number two radio tuning unit to select the PA system) to make the passenger announcement. The captain at this time and with the aircraft still in motion agrees and takes on the additional cognitive task of monitoring the number one radio for ATC transmissions. This reallocation of duties is a normal function for the captain when the first officer makes his required passenger briefing advising the flight attendant to prepare for takeoff. One second later, four ATC/other aircraft transmissions take place as the captain brings the aircraft to a complete stop at the hold short line for runway 26. Photo 6 below shows this location.

Photo 6: Hold Short of Runway 26 on Taxiway "A"

The last of the four ATC transmissions was from an airborne Eagle flight 882 reading back a navigational clearance to LEX ATC. It is uncertain what the first officer is doing from the time the captain agrees to monitor radio one at 06:04:24 and the first officer actually begins his passenger address until 06:04:38, almost 12 seconds later. During this time there were the previously mentioned ATC and other aircraft radio transmissions in addition to the aircraft coming to a complete stop 2 seconds before the first officer starts his public address. Like many first officers, he may have been waiting to ensure the aircraft stopped prior to the hold short line before changing his focus from aircraft operation to making the public address. The hesitation before starting the PA until 2 seconds after the aircraft stopped is considered good flight crew technique to aid in preventing runway incursions.

Two seconds before the captain brings the aircraft to a stop at the hold short line of runway 26, he changes the range on his MFD from 40 NM to 80 NM. The radar was already on and interviews with one of the crew members of an aircraft that departed in the previous five minutes reveal that he noticed lightning north of the airport. It is possible that the captain while looking forward and stopping the aircraft at the hold short line, also saw lightning to the north, prompting him to change the range of the radar for closer examination.

At 06:04:34 the captain's weather radar display range changed from 40 to 80 NM. The captain's possible visual sighting of weather in combination with the earlier remarks by preceding flights about weather deviations would support the idea of the captain taking a few moments to change his radar range and make a closer evaluation of any potential convective weather concerns. He had two different data sources showing him that weather might be close to the airport. From the time he made the range change to the time he resumed involvement with the required call outs on the before takeoff checklist was only 15 seconds. During this time interval the evaluation of any potential weather threat consumed additional cognitive resources that could have been better used recognizing that his surrounding environment may have not matched his current situational awareness model. Since he was continuing with preparation for departure, he had internally resolved any confusion that he might have. The fact that he used this time to move forward in the mental evolution of preparing to takeoff by assessing any potential weather hazard is indicative of his comfort with his situational awareness and mind set toward preparing to depart. Quite simply, he knew where he was and was making a reasonable final assessment (of weather) prior to committing to the takeoff. As such, the captain was no longer attempting to ascertain his location on the field.

The first officer returns after the PA ending the captain's 15 second break from taxing the aircraft by immediately engaging him in the completion of the before takeoff checklist. At 06:04:54 there appears to be some confusion on the CVR over the number of items on ED2 (electronic display number 2). Comair procedures require that the captain verify that all the CAS messages are appropriate for the aircraft configuration and any deferred MEL/CDL items. The investigation revealed that the standard six items seen on most Comair flights should have been displayed. However, there appears to be some discussion regarding six or seven items and some of this conversation is unintelligible. Seven seconds later they appear to have resolved their confusion and continue with the checklist. The investigation was not able to resolve what the extra message on the CAS (crew alerting system) was and how it was resolved.

What is important to gain from this verbal interaction is that it shows another example of both crew members appearing to be comfortable with their location on the airport surface and the focusing on a relatively minor issue. They thought they knew where they were and were just finishing up the required checks to ensure the aircraft was safe to fly. At first, it was the captain who had displayed this behavior with the examination of the potential weather issue while the first office was making the passenger announcement. Now the first officer rejoined the flight deck activities and showed no sign of being concerned about the location on the airport. Both pilots at this point were mentally in agreement that they were holding short of runway 22 and they continued their preparation for takeoff. It would be reasonable to assume that if either crew member were extremely concerned about their location on the airport surface, the continuation of preparation for takeoff would have ceased until this was resolved.

This is not what is shown for the accident flight, as they are almost ready to depart. The captain apparently feels comfortable enough not to ask for help or verification of their current location and the first officer, having limited visual clues and rejoining after a significant absence from observing the navigation on the airport surface, is probably comfortable as well. The fact that; A) neither crew member asks each other for confirmation on their location, B) captains always taxi to the correct runway (especially at small airports), and C) ATC would have said something by now if this wasn't correct (part of the taxi briefing was "taxi instructions with ATC") supports the notion that they were comfortable with their location.

An additional visual clue that might have falsely led the crew to believe their location was correct and support their current belief structure was the barricades that they did not expect to see across runway 26. It would be easy to understand how this could have been misconstrued for the closed section (non-pavement) of taxiway golf on the opposite side of runway 22 across from "A5". This would only further support any situational awareness disconnect already in place and feed into their conformational bias that they were in the correct location. This supported the idea that they had in fact taxied to the end of taxiway "A" at runway 22. As the barricades were not mentioned on the flight release or the ATIS, this would have been an unexpected visual clue. Since the chart shows the pavement non-existent, it would make sense that they would have not expected to receive a NOTAM or hear about this on the ATIS. This would only continue to support their local rationality regarding their correct location. See Figure 7.

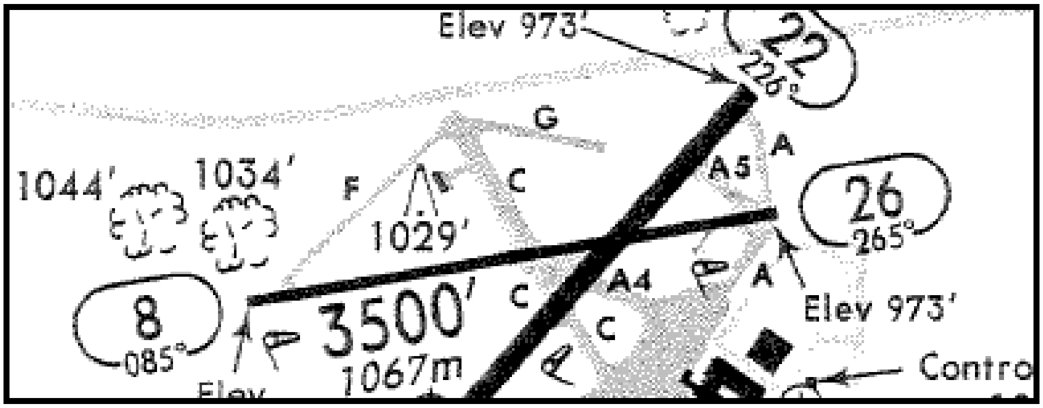

Figure 7: Jeppesen 10-9 Airport Diagram (current at time of accident)

After the before takeoff checklist is complete, the captain verifies with the first officer "*all set*". The first officer then makes the request for takeoff clearance incidentally using the wrong flight number "*churliser Comair one twenty one ready to go*[21]". This could represent a simple slip of the tongue or may indicate that the first officer was allocating additional attentional resources in an attempt to clarify any slight confusion (not enough to stop the pace, but still trying to convince himself that any disorientation was due to his been absent for so long) that he might have had about their location. Since he just recently re-joined the captain after being "out of the loop" and task saturated for almost the entire taxi, he might have been thinking that something just didn't seem correct and might be unsure as to what it was, explaining his call sign error. After this, LEX ATC issues the takeoff clearance at 06:05:17 apparently not noticing that the aircraft is holding short of runway 26 not runway 22. The aircraft begins to move at 06:05:22.

While the aircraft was holding short of runway 26 (for 46 seconds) the air traffic controller had an opportunity to trap this error as he was not actively managing any other traffic. In fact, it is unknown what he was actually doing during this time period.

Review of this flight segment reveals that there were three specific threats to this flight; first officer task saturation, no runway 26 sign in first officer's side of aircraft, and ATC fails to notice aircraft location on airport when takeoff clearance was requested (See Table 9). Due to the crew not being aware of any of them, they were not managed to any degree. The first officer was certainly not aware that he was too busy and was missing clues to their actual location at the airport. In fact, there was no evidence to suggest that he knew that the captain was either not sure of or currently having a misperception regarding the aircraft's actual location. Additionally, when the aircraft arrived at the hold short line for runway 26, the absence of a runway 26 sign on the first officer's side of the aircraft would not have been a concern. In fact, he would not have known that the placement of a runway sign on his side of the cockpit may have helped him adjust his situational awareness. Other signage and

[21] Group Chairman Factual Report, Cockpit Voice Recorder, 17 November 2006, pg 33.

markings that could have been helpful in preventing this accident include: A yellow taxiway sign pointing to runway 22 and enhanced hold short markings may have all alerted the first officer as to their incorrect location once he was now heads up. Thirdly, the lack of ATC support for helping to prevent this error and the resultant accident was never a consideration for the crew. Not only were they not aware that they were even making this mistake, but were also unaware that ATC was not supporting them as they might have believed. As mentioned before, pilots are quite aware that when they make mistakes during taxi, ATC will be forthright in pointing that out and suggesting corrective action. The lack of such action on the part of ATC would only support the pilot's perspective that everything was well since at such a small airport with no other active ground traffic it would seem impossible for the controller to not see the aircraft was lined up incorrectly. Pilots assume that as they are being cleared for takeoff, the controller has visually acquired their location on the airport. This seems like a reasonable assumption.

As the aircraft was sitting at the hold short line, to the captain's 10 o'clock position was a red runway 26 sign. It is unknown if the captain ever saw the sign and if so how it could have been misinterpreted. The fact that this seemingly overwhelming visual cue as to their position was not considered lends credence to the fact that it was never seen by the captain.

There were two specific flight crew errors committed during this phase of the flight. Both were by the first officer and once again were checklist related (See Table 10). The crew failed to respond to either; however both were inconsequential for this particular accident.

Threats	**Managed**
First officer's cognitive resources are limited due to task saturation.	**No**
There is no runway 26 sign on the first officer's side of the aircraft.	**No**
ATC fails to recognize that when the aircraft calls for takeoff clearance they are holding short of the wrong runway.	**No**

Table 9: Segment 5 Threat Table

Error description, category, response and outcome				
Time	**Errors**	**Category**	**Crew Response**	**Error Outcome**
06:04:24	FO does not read altimeter line item correctly.	Procedural error	Failed to respond	Inconsequential
06:05:15	FO uses wrong flight number when requesting takeoff clearance.	Communication error	Failed to respond	Inconsequential

Table 10: Segment 5 Error Table

In summary, the concepts listed below highlight this portion of the flight.

- The crew was comfortable enough with their situation awareness when they asked for and accepted the takeoff clearance.
- Fatigue related behaviors are clearly seen during this segment and the resultant impairment preventing the pilots and controller from trapping the error preventing the accident.
- The captain was no longer assessing geographical awareness on the airport due to cognitive task saturation.
- While holding on the taxiway, the crew is distracted with assessing the weather and an extra CAS message.
- While holding short of runway 26, this is one of two points in time where ATC could have trapped this error.
- The lack of ATC correction when the crew called ready for takeoff only served to support the crew's incorrect situational awareness and confirmation bias that their location was correct.

i) Flight Segment Six

Crossing the hold short line for runway 26 at 06:05:23 until the setting of takeoff thrust at 06:06:07. Duration of 39 seconds.

At this point of the flight the crew is mentally committed to performing the takeoff. It is well established to all pilots of any experience level that you do not takeoff unless you are comfortable and you are safe to continue. From the factual information gathered in this investigation, it is apparent that the accident crew was under this perception. In fact, it is not until about 650 feet into the takeoff roll that we get our first verbal indication ("…*is weird with no lights*" and "*yeah*") that they are perceiving that something may not be correct. From the CVR transcription it appears that at about 100 feet from the end of the runway it becomes more obvious that they are aware that they are in danger ("*whoa*").

As the crew crosses the hold short line for takeoff, closer examination of workload and visual opportunities to trap the error should be examined. At 06:05:23 the captain calls for the line-up checklist one second after the aircraft begins to move. At this point the crew's attention is again divided. The captain begins to maneuver the aircraft onto the runway; his visual focus would be straight ahead and to the left looking down the runway. At this point he has already passed the runway 26 sign on his left and from his vantage point he can not see the runway numbers painted on the runway. It is reasonable to speculate that his attention was focused on looking to the left of the aircraft down the runway to verify that the area was clear and to place the aircraft on the centerline.

With the captain's visual focus in this direction, he would miss other relative cues such as the barricades preventing the continuation of taxiway "A" to runway 22 after runway 26. As discussed in another section, the barricades were not very visible and in fact not even seen by other crew members that departed that morning. It is reasonable to speculate that the accident crew did not see them as well. The fact that the lights on the barricades were turned perpendicular to the barricade itself significantly decreased their conspicuity. If the barricades had been seen in addition to being reported in a NOTAM or ATIS, this would have given the crew a significant geographical point to help adjust their situational awareness and very likely have trapped the error. If they were seen, as previously mentioned they could easily be mentally explained that they were the closed portion of taxiway golf.

A closer examination of the workload of each crew member is required in order to fully understand the dynamics of this segment of the flight. After being cleared for takeoff, the captain calls for the line-up checklist and initiates aircraft movement. At this point the first officer is now heads down performing the flow and the reading of the line-up checklist. This checklist has eleven items that have to be checked prior to reading the six items on the checklist out loud. It can be assumed that upon hearing the request for the line-up checklist, he began this task at 06:05:23 and finished when he completed reading the checklist at approximately 06:05:49 (three seconds after reading the last part of the checklist) then adjusts his seat at 06:05:51 and is offered the controls at 06:05:57 and accepts two seconds later at 06:05:59. By this time, he has been mostly heads down, and now he finds the aircraft one second later at 06:06:00 achieving runway heading. This was a very dynamic time for both crew members.

From the time the aircraft began movement across the hold short line until it was placed on the runway heading was 37 seconds. During this time the first officer was completely task saturated and essentially heads down performing the required checks and adjusting his seat. Comair crews are taught to use the seat reference balls on the center windshield post to perform correct seat adjustment which was probably what he was doing. Coincidently, it was also during this time that there were several external visual cues available to possibly trap the error. Because of his workload and the cognitive task allocation of available resources, he missed visualizing these clues such as the runway numbers (which because they were very far to the right of the aircraft would have only been visible to the first officer for a few seconds and not to the captain at all), the construction barricades and taxiway “A” continuing beyond runway 26 leading to runway 22.

It should be noted that during this time frame, the air traffic controller had numerous opportunities to trap this error as well. A closer examination of his workload during this very dynamic phase is relevant. After the accident aircraft requests takeoff clearance at 06:05:17 and the controller grants it, the controller begins a dialog with Eagle flight 882 about weather avoidance and then 11 seconds later hands them off to Indianapolis Center. It is noteworthy that from the time that Comair 5191 read back the takeoff clearance until the set power call was made by the FO was 46 seconds (06:05:21 until 06:06:07). Of this 46 second time period, the controller spent 14 seconds or 30% of this available time (06:05:25 until 06:05:39) performing departure controller functions. This was a time that, had he not been working by himself, he may have had additional attentional resources to trap this error. A second controller as required by the FAA would have been assisting the Eagle flight with their departure instructions and concerns for weather. An opportunity occurred to trap the error during the 46 seconds that the aircraft was holding short of the wrong runway. Another opportunity occurred after clearing the flight for takeoff when the controller failed to notice the aircraft turning down the incorrect runway. The fact that the controller was tasked with an additional Departure control duties further decreased his chances of trapping this error. Many of the behaviors exhibited during this segment by the controller are characteristic of a fatigued individual. See Appendix 3 for a more in-depth discussion.

At 06:05:50, the Takeoff and Go Around (TOGA) buttons on the thrust levers are selected which provides flight director guidance for the takeoff. Although the heading bug was still on the runway 22 runway heading, the flight director command bars align straight ahead at a pre-set pitch attitude. The act of selecting the flight director has an additional benefit by advising the FMS that you are now on the programmed runway (a runway update). The investigation was not able to determine which runway was placed in the FMS. However, since the crew briefed runway 22 and set the heading bug[22] on the runway 22 heading (where it remained for the rest of the flight), it seems reasonable to assume that runway 22 was the FMS programmed runway as well. It is important to note that even after a runway update is done, the aircraft's systems will not advise the crew that the current runway does not match the runway programmed in the FMS. It is simply a function that helps the FMS in non-GPS aircraft obtain a better fix of its location. This helps reduce the time it takes when airborne to solve the navigational solution as to its current position. As a generic runway is displayed on the MFD when a runway is programmed and a runway update does not change the visual picture on the MFD but rather internally advises the FMS of its current location. There would be no visual or auditory advisory to the crew that they were on the wrong runway. Comair crews are provided no specific guidance to ensure that they are on the correct runway. One line check airman interviewed after the accident echoed this notion and stated that "*there was nothing in the company procedures that would have helped this crew except that the crew was responsible for their own situational awareness*"[23]. One ground instructor and line captain that was interviewed was unsure if any guidance was provided.

As the aircraft is on the runway centerline and beginning its takeoff roll, and the controller has looked away to perform administrative tasks, it is appropriate to examine the workload, role and focus of each pilot. After the aircraft crossed the hold short line, the visual focus of each pilot has again changed. As previously mentioned as they were taxiing out, the captain was looking outward and the first officer was looking inside performing his checklist duties. Upon the transfer of controls and the

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[22] Comair teaches their crews to place the heading bug on runway heading unless a turn is required below 400 feet AGL. In this case they may place the bug on the required heading. The accident crew had the heading bug on the runway 22 magnetic heading the entire flight. Unfortunately, there is no existing guidance offering crews a way to use this procedure to help verify that they are on the correct runway. In some cases it would be correct to takeoff with the heading bug on runway heading; in other cases it is normal to takeoff with the heading bug off to the side on a heading other than runway heading. Comair crews are used to seeing both heading bug visual presentations.

[23] Interview Summaries, Operation Group Chairman's Factual Report, 17 December 2006, pg 13.

set thrust call, the crew roles became reversed. The captain now is looking inside at instruments and the first officer is getting his first good look straight down the runway. However, just prior to this point, the captain has been looking down the runway for a few seconds and probably saw a runway that is very similar in appearance to what he expected to see based on his local rationality. The investigation discovered that he had been to LEX before and as such probably knows that the runway always appears shorter than normal. The majority of the pilots interviewed from Comair and other carriers made this observation. Topographically speaking, runway 22 has a peak in elevation at about the 2,000 foot mark from the runway 22 threshold. The visual study performed by the investigation showed that only the first 2,000 feet of runway 22 are visible which precludes pilots from seeing the end of the runway. Runway 26 also has a similar topographical presentation with increase in elevation around 1,500 feet from the threshold. This and several other visual parameters would make these visual presentations very similar. During an interview with a Comair first officer, he specifically mentioned that when you pull out onto runway 22 in LEX, you could see a hump and it appears short. Table 11 presents the similarities between the visual picture of looking down runway 26 and the expected view down runway 22.

Cues that served to support the local rationality that they were actually on runway 22	
Runway 26 the morning of the accident:	**Runway 22 the morning of the accident:**
1. A runway with an increase in elevation at about 1,500ft or so from the threshold.	1. Has an increase in elevation about 2,000ft from the threshold.
2. A runway that had what could be misconstrued as only having a few operative lights. These would be three of the four corner lights at the intersection of the two runways.	2. The weekend of the accident half of runway 22 lights had appeared inoperative. They briefed and were expecting to see many lights out.
3. A runway that had another runway intersecting it a few hundred feet from the threshold.	3. Has another runway (26) intersecting it a few hundred feet from the threshold.
4. A runway with no centerline lights.	4. The centerline lights were NOTAM out-of-service
5. A runway that the first half was well lighted from ambient airport lighting. The parking garage lighting made this area very visible.	5. A well visible runway that does not appear dark. Ambient lighting as well as runway lights when operating normally make this runway very visible.
6. A runway that you were not able to see the opposite end.	6. You can not see the opposite end.
7. A runway that has a dark-hole appearance at the end.	7. A dark-hole appearance at the end.
8. A runway is paved 150 feet wide and appears at first glance to be 150 feet wide. Painted to 75 feet.	8. Designed and painted 150 feet wide.

Table 11 Comparison of the actual view down runway 26 and the expected view down runway 22 from takeoff position.

These eight similar characteristics of each runway would only serve to support the crew's local rationality through confirmation bias. It is important to understand that by this time, although the runway picture may have appeared slightly abnormal; cognitively speaking they needed much stronger clues to unravel their local rationality disconnect. Essentially, the crew at this point was mentally committed to begin this takeoff and up to this point had no doubt that they were now on runway 22. One of the more compelling components to these cues feeding his conformational bias was the first officer's comment during the abbreviated taxi briefing regarding "*lights out everywhere*". The captain having maneuvered the aircraft this far is now mentally committed to the takeoff, and is seeing exactly what was briefed. In fact, up until this point he had encountered all signage and taxiway lights as being operational. This visual picture cognitively fit his mental model and as such continued the takeoff by now going heads down and setting the thrust as requested.

In Table 11 above, seven of the eight items are essentially self explanatory. However, item two should be further explored. There were three white runway lights combined with a taxiway sign down field that gave the illusion of a partial string of runway lights. Photo 7 below shows these lights.

Photo 7: View down Runway 26 From Beginning of Takeoff Roll

On the right side of runway 26 at the intersection of runway 22, there were two runway lights represented in a linear fashion and at a similar angle as to appear parallel to runway 26. On the left side was a single runway 22 light in the southeast corner of the intersection. This gave the opposite side corresponding illusion of a runway 26 runway edge light. It is also obvious that there is another runway up ahead which would not have been a surprise since it is reasonable to assume that both crew members were aware that there will be a crossing runway within a few hundred feet of beginning their takeoff roll. This, in fact, is exactly what they saw.

An interview with a Comair captain with recent post-accident experience in LEX indicated that the first half of the runway 26 environment "*did not look too dark*"[24]. This statement was supported by photographs taken during the Safety Board visual study. Prior to the accident, neither Comair nor the FAA provided any guidance for departures from a runway with inoperative edge lighting. Interviews with line pilots at Comair including one check airman support this lack of guidance on unlit runway departures as several were unsure if it was allowed. One pilot suggested that they would be allowed if "*ATC authorized it*"[25]. It is unknown if the accident crew noticed the darker than normal runway appearance as abnormal. However, if they had, no guidance existed at the time of the accident to suggest that they would not be allowed to depart.

By reviewing Table 11, we can see that there were several visual cues that may have served to support the confirmation bias that both crew members were experiencing. They pulled out onto the runway certain that it was runway 22 and with the help of these similarities they saw what they expected to see.

Once they were out on the runway, the role that the two 4/22 runway signs at the crew's 10 o'clock and 3 o'clock position played is unknown. It might be plausible to assume that the sign at the 3 o'clock position was far enough in their peripheral vision that it was not seen. This might have been because of their normal operational focus was straight ahead. This focus may have exacerbated due to the crew's possible initial perception that the visual environment was different than they were use to for most takeoffs.

An additional consideration is the concept of plan continuation. Pilots are mission oriented people that make hundreds, if not thousands, of decisions a day when flying. We are trained to and expect each other to progress forward with the current plan unless evidence is presented to the contrary. It is reasonable to speculate that as the captain was positioning the aircraft on the center line, he was noticing the visual features listed above. Unfortunately there was no overwhelming evidence to change the perception that he had taken as fact and accepted and supported for the last 10 minutes. Being impaired by fatigue will increase a person's propensity for plan continuation and the failure to properly incorporate new information into their current mental model. See Appendix 3 for a more in-depth discussion regarding fatigue. The visual image he saw down the runway came very close to matching his expected visual view based on his local rationality. Perhaps its appearance was a bit surprising, but with no overwhelming evidence to say otherwise, the crew will continue as trained and maintain the current plan of action. This is especially true when a

[24] Interview Summaries, Operation Group Chairman's Factual Report, 17 December 2006, pg 26.
[25] Interview Summaries, Operation Group Chairman's Factual Report, 17 December 2006, pg 41.

particularly well scripted set of actions and a high level of commitment such as a takeoff in a turbojet aircraft has already begun.

Within a few seconds of obtaining the runway heading and noticing the cues as described in the table, the first officer has finished the tasks that had him heads down and he continues verbally with the plan that is already set into motion (the takeoff). He advances the thrust levers and calls for "*set thrust*"[26]. Now that the captain is reasonably convinced all is well after noticing the expected visual cues and having already turned the controls over to the first officer, he goes heads down to set the engines thrust as requested. Now the visual focus has changed as he is no longer looking outside.

The first officer is now getting his first good look down the runway as the aircraft is rapidly accelerating. He may or may not have noticed several of the items listed in Table 11 but he arrived at this point with a local rationality that the captain had positioned him on runway 22. Although it is plausible that he may feel that something is not quite right, the aircraft is now in motion and he has no significant evidence in the few seconds available as he is beginning to steer the aircraft with his feet to make the call for an abort. In fact, it would be a very normal human trait to assume that since you have been visually "out-of-the-loop" for so long, you would expect to be less than 100% sure of your exact location and would immediately dismiss any hesitation on your part as being part of your visual re-acclimatization. In fact, a Comair line check airman interviewed after the accident addressed this possibility. He reported that he noticed during line checks "*some first officers were not speaking up when the captain did something in error*". He felt that this was not out of a hesitancy to speak up but "*more as a situational awareness reason*"[27]. A Comair first officer with recent experience in LEX prior to the accident reported that he has experienced a similar problem. He said that he has asked captains to stop near runway 26 so that he could figure out where they were. He said that this has occurred when he had his head down and momentarily looked up and did not know if he was at runway 26 or runway 22. He also reported that this could especially occur if it was night or raining. Another Comair first officer reported that LEX represented a "*worst-case scenario*[28]". Furthermore, he said that he could see how the first officer on the first flight of the day would be inside the cockpit heads down and not outside looking where they were going.

The investigation did not fully explore checklist design for Comair's operation as compared to other operators with similar types of aircraft equipment. Based on the previous check airman's comment about situational awareness and the workload

[26] Group Chairman Factual Report of Investigation, Cockpit Voice Recorder, 17 November 2006, pg 35.
[27] Interview of Summaries, Operation Factors Group Chairman's Factual Report, 17 December 2006, pg 15.
[28] Interview of Summaries, Operation Factors Group Chairman's Factual Report, 17 December 2006, pg. 35.

experienced by the accident first officer, the amount of items required to be performed while taxiing out should be closely examined in that the quantity may be excessive and distracting. It is conceivable that many of these items could be done while still at the gate or immediately after pushback allowing more time to be available for the first officers to maintain better situational awareness and back the captains up as required during the taxi phase of flight.

Threats	**Managed**
First officer's cognitive resources are limited due to task saturation.	**No**
Since runway 26 was painted as a VFR runway, the aircraft did not taxi over the runway numbers making them more visually conspicuous.	**No**
ATC fails to recognize when the aircraft taxies onto the wrong runway.	**No**

Table 12: Segment 6 Threat Table

In summary, the concepts listed below highlight this portion of the flight.

- The first officer, after finishing the before takeoff checklist now gets his first good look at where they are. He has no signage clues on his side of the airplane to support or refute his idea of their current location. He immediately makes a radio call to ATC that they are ready for takeoff.
- Once they are given the take off clearance, the first officer now is forced to go heads down again for the line-up checklist.
- While crossing the hold short line for runway 26, this is the second point in time where ATC could have trapped this error.
- Numerous similarities seen when pulling out onto runway 26 as compared to runway 22 only served to support their current local rationality.
- The partial appearance of runway lights is compelling and further supports their local rationality and the earlier statement "*lights out everywhere*".
- The crew began this takeoff under the impression that they were on the correct runway.
- The captain who was the only pilot that was essentially heads up the entire taxi, now hands the airplane over to the first officer who has no reason to believe that he is anywhere other than runway 22.
- Once the decision to takeoff has been made, due to training and experience it is very challenging for crews to abort without a very real aircraft-centric warning or an order from ATC. This illustrates plan continuation.
- There is no procedure in place that provides guidance to the crews to ensure that they are on the correct runway.

j) Flight Segment Seven

The setting of takeoff thrust at 06:06:07 until the end of the recording at 06:06:36. Duration of 29 seconds.

As previously discussed in the prior flight segment, the flight crew's local rationality still told them that they were on runway 22. It is unknown which visual cues from Table 11 they may or may not have seen. But this combined with the very real desire for plan continuation is guiding their actions by now. They have no reason at this point in time to believe that they are in danger, therefore no reason to abort the takeoff.

In order to understand how the crew made the choice that they did (continue the takeoff), we need to closely examine once again their local rationality, their training and the policy and procedures that guide all Comair crews. When the call to "*set thrust*" was made, the captain is now heads down (the first officer is now looking outside) setting the fan speed (thrust) on ED1 and verifying that the oil pressure on both engines is above the minimum required. Additionally, he is also looking at both ED1 and ED2 to ensure that no EICAS messages have appeared that would necessitate an abort. When the captain finished setting thrust he made the required call of "*thrust set*" at 06:06:11. At this point the captain now returned his focus to the exterior environment of the aircraft and for the first time since the flight left the gate, both crew members are simultaneously focusing on the same exterior visual picture.

They are now approximately 200 feet further down the runway (4 seconds later) from when the first officer requested that the captain set the thrust. This places them about 600 feet from the intersection of runways 26 and 22. Five seconds later, at approximately 125 feet from the intersection of the two runways, the first indication of the crew beginning to feel uncomfortable enough to actually verbalize an observation. At 06:06:16 the first officer makes the comment "*…is weird with no lights*" to which one second later the captain replies "*yeah*". This is an extremely critical point in the takeoff.

Professional turbojet crews are trained to an exceptionally high standard of how well scripted a takeoff procedure is designed. They know that under no circumstance do you offer any comments other than what is expected of you in your current role during this procedure. They have very specific calls based on thrust settings and aircraft speed. Based on training records and interviews with pilots that had previously flown with both crew members, it appears that the accident crew understood and abided by this principle. This comment by the first officer was really more of a suggestion to the captain that his comfort level had significantly decreased and he is looking for some support or guidance. We feel that this comment represents a well known communication effort frequently referred to in CRM circles as "hint and hope". This type of communication is occasionally effective and is frequently seen in professional crews and normal line operations. Despite their CRM training which discourages this method, crew members that may still be trying to decide if the error they think they are perceiving is real or only a by product of their own misperception may employ this method. As indicated in an interview with a Comair line check airman, the accident first officer was described on a previous trip as one that was "*not shy about anything and had no hesitancy to do things*[29]". This only seems to reinforce the belief that had the first officer been sure that something was in

[29] Interview Summaries, Operation Factors Group Chairman's Factual Report, 17 December 2006, pg 37.

fact seriously wrong, he would have spoken up and stopped the takeoff. Unfortunately, the captain does not sense or grasp what the first officer is really saying by this unreliable method of communication as confirmed by his simple agreement and continuation of the takeoff with no more discussion. His short clipped response may have in fact been indicative of his focus on something appearing wrong, but is also not sure what he is seeing. By this point of the takeoff, the aircraft is now traveling at approximately 65 knots and accelerating rapidly. The visual picture of the runway environment is starting to look much different than it did at the beginning of the takeoff roll. Essentially, their local rationality and situational awareness is beginning to conflict with the visual cues they now are seeing. Table 13 below shows how the previous cues that helped support both crew members' earlier local rationality and situational awareness have decreased.

Cues that served to support the local rationality that they were actually on runway 22	
Runway 26 the morning of the accident:	**Runway 22 the morning of the accident:**
1. No runway lights at all. Very dark.	1. Despite the concern for "lights out everywhere", some lights would probably be expected.
2. A runway with no centerline lights.	2. The centerline lights were NOTAM out-of-service
3. A runway that is now very dark in appearance	3. A well visible runway that does not appear dark. Ambient lighting as well as runway lights when operating normally make this runway very visible.
4. A runway that has a dark-hole appearance at the end.	4. A dark-hole appearance at the end.
5. A runway is paved 150 feet wide and appears at first glance to be 150 feet wide. Painted to 75 feet.	5. Designed and painted 150 feet wide.

Table 13 Comparison of the actual view down runway 26 and the expected view down runway 22 from approaching the intersection of the two runways.

Now, as they are rapidly approaching the intersection of the runway and closer to the crest, more of the runway is visible. In reviewing the table above, they have now lost several of the similar visual cues that might have helped convince them that they were in fact on the correct runway. One of the most compelling is the illusion of partial runway lights. It is important to note that approaching the intersection of the two runways, this illusion disappears and we believe that this change elicits the first officer's comment about things looking "*weird*" without lights. See Photo 8.

Photo 8: View Down Runway 26 from Runway 22 Intersection

As the aircraft rapidly approaches (within seconds) the high speed abort regime of 80 knots, their confidence in their situational awareness is probably starting to wane. They originally arrived at this critical point in the takeoff, comfortable that they were on runway 22. After approaching the crest in the runway and being unable to see features at the other end, which was a significant change from the first half of the runway, their situational awareness would be challenged. This abrupt change in situational awareness can be disorienting and cause one to pause in an attempt to resolve the conflict between your mental model and what you are now visually perceiving.

Nine hundred feet later and six seconds after the captain agrees with the lights comment, the captain calls 100 knots. The first officer replies "*checks*" as required. This is a Comair required call out and serves several functions: It provides the crew with an airspeed crosscheck, an incapacitation check and advises the captain that they are now in the high speed abort regime. This means that mentally, they are in a well known, trained and practiced regime of the takeoff where pilots are required to make the split second decision and that beyond this speed the suggested requirements for an abort are fewer and more critical. Their possible confusion caused by the direct and abrupt challenge to their situational awareness after crossing the runway intersection is now in full swing, but the parameters for aborting a takeoff have changed as well.

Other factors that crew members may consciously or sub-consciously consider when becoming uncomfortable for an unknown reason in a dynamic environment such as a takeoff are; the lack of any aircraft based warnings, no warning or cautionary calls from ATC, no signage perceptually strong enough in this very short period of time to make a major paradigm shift in their perception of their situation. At least, certainly not enough to execute the very well documented and potentially dangerous procedure that is a high speed rejected takeoff. Historically, industry wide, numerous accidents have occurred when airline crews have initiated high speed rejected takeoffs (RTO) that resulted in an accident when it was later determined by the investigation that the continuation of the takeoff would have been a safer course of action. Crews are made aware of this in training and industry based media sources that have examined this problem. In this regime pilots are no longer using a cognitively intense examination of the situation and their environment. But rather, they become more skill and rule based and apply their perceptions to the experience and training they have received. Table 14[30] describes the guidelines and recommended practice for Comair crews in regard to aborting a takeoff.

At speeds below 100 knots, the takeoff shall be rejected for any of the following:	At speeds equal to or greater than 100 knots but below V_1, it is recommended to reject the takeoff only for:
1. System failures	1. Engine failure and/or fire
2. Unusual noise or vibration	2. Perception the aircraft is unsafe or unable to fly
3. Tire failure	
4. Abnormal acceleration	
5. Engine failure and/or fire	
6. Unsafe takeoff configuration	
7. Unable to fly	
8. Fire warning	

Table 14 Recommended guidance to Comair crews for rejected takeoff

As evident from the guidance provided to Comair crews, their perception at the time of the beginning of the takeoff and passing 100 knots does not meet the RTO criteria as trained for either above *or* below 100 knots. The reason for the difference is that once above 100 knots, the safety margins are less. Crews are also aware that their actions will be closely examined by their superiors since a maintenance log book entry and report to the chief pilots is required should a high-speed abort be conducted. Although the crew might have been experiencing an increased discomfort in the comparison of their established situational awareness as compared to the visual evidence before them, they were still obviously unaware how extremely dangerous their current situation actually was. Once again, even though they were probably beginning to re-evaluate or maybe even alter their local rationality, it still did not match reality and the criteria for a high-speed abort did not exist. Had they been able to see and been aware of the rapidly approaching end of the runway and that they were just seconds away from a potentially serious situation, they would have made the high speed rejected takeoff as trained. They simply did not know what was coming next.

[30] Page 7-18 of the Comair Flight Standards Manual Volume II.

At 06:06:31, the captain makes the call "*V one, rotate*" and one second later the comment "*whoa*" was made by the captain when the aircraft was only 60 to 75 feet from the end of the runway. This is likely his observation of the end of the runway pavement and grass. This distance is just within the forward distance lighted by the landing and nose lights which is about 107 to 110 feet[31] respectively. The "*whoa*" comment and departure from the runway occur within 2 seconds of each other followed by the impact with the berm and the rest of the impact sequence resulting in cessation of the CVR.

As evident by closer examination of this final flight segment, the crew's probable major shift in their perception and direct challenge to their situational awareness occurs within seconds of entering the high speed RTO regime. The crew's awareness of the danger of a high speed RTO and the lack of extremely strong visual cues that would clearly indicate where they were to the reasonable choice to continue the takeoff. The exclamation of the captain as they were leaving the runway is yet another example of evidence that the rapidly approaching end of pavement caught them completely by surprise. Their geographical location on the airport (departing runway 26 pavement) combined with the extreme velocity of the aircraft ensured the rest of the accident sequence with no other course of action.

- The crew begins the takeoff with the very real drive to continue once the process is set into motion.
- They are probably still trying to see how the unusual runway presentation fits into their well established visual mental model and local rationality.
- As the velocity increases and approaches 100 knots, the decision to abort becomes very difficult.

k) Summary

It is without question that the crew of Comair 5191 thought that they were in fact departing off of runway 22 the morning of August 27, 2006. The vastly different preconceived visual model they each possessed regarding the airport environment prior to push-back combined with inadequate information received from various sources only served to ensure their situational awareness disconnect. Fatigue, lack of ATC support and workload management all affected their ability to recognize and readjust their situational awareness. Other psychological phenomena such as confirmation bias and plan continuation played a supporting role in preventing the crew from accurately perceiving their dynamic environment in a way that would have helped reduce or ameliorate their disconnect. Finally, the lack of and adherence to adequate procedures allowed the margin of safety to erode to a point where the accident was inevitable.

[31] Canadair Regional Jet Flight Crew Operating Manual Volume 1, Chapter 16 Lighting.

5. Other flights the morning of the accident at Lexington

The morning of the accident Skywest flight 6819 and American Eagle flight 882 departed several minutes prior to Comair 5191 pushing back from the gate. Both aircraft were "regional jets" and were both given the same taxi clearance as Comair 5191. At 05:57:38 the crew of Skywest 6819 called for taxi and two minutes later at 05:59:33 the crew of American Eagle also requested permission to taxi. Comair 5191- followed with their request to taxi two and a half minutes later at 06:02:01. All three aircraft were given the same taxi instructions to taxi to runway 22. Although it appears superficially that only the third aircraft, Comair 5191 became confused, a closer examination of each taxi event suggest otherwise.

a) Skywest Flight 6819

The captain of the Skywest flight was interviewed by the Human Performance / Operations group. He did not hear the ATIS but was briefed by his first officer and recalls no mention of any anticipated problems for the taxi. He recalls that their taxi clearance was "*Skywest taxi to runway 22*"[32]. He reported that he did not recall any NOTAMS regarding taxiing to runway 22. He stated that the controller did not seem busy to him and that there were no obstructions to visibility.

He reported that the route they taxied was what they had expected and was similar to the route he took the last time he was in Lexington on August 1st. It is important to note that the barricades on taxiway "A" north of runway 26 were not put in place until August 20th. It appears that this crew, like the accident crew, did not have the NOTAM for the taxiway closure north of runway 26 as well. Due to recently having departed from LEX and not being aware of the closure, he had a certain expectation of what the taxi to runway 22 would be like. In fact, this was his local rationality or mental model that morning before he began to taxi. He further reported that because it was such a short taxi, the first officer was very busy and "*not a lot of time for him to look out*"[33]. So, like the accident crew, the situational awareness was almost exclusively controlled by the captain.

It is important to note that he described the taxi to runway 22 as a straight taxi route and as previously mentioned similar to the route on the 1st. He reported that he did see the runway 26 sign at the runway hold short area but never saw any barricades north of runway 26. As he was crossing runway 26 he did not see the runway painted numbers for runway 26 or the divergent taxiway lines. The taxi route that he took the morning of the accident would not have been the same as it was the morning of August 1st as he had thought or suggested. Since he never saw the barricades north of runway 26, it is unknown why he didn't inadvertently taxi over them on his way to runway 22 as earlier in the month. Although he successfully managed the taxi to runway 22, it might be questionable to say that his situational awareness during the

[32] Interview Summary, Operational Factors Group Chairman's Factual Report, 17 December 2006 pg. 42.
[33] Interview Summary, Operational Factors Group Chairman's Factual Report, 17 December 2006, pg. 43.

taxi the morning of the accident was good. It could, in hindsight be considered successful, but not ideal or good. From this interview it appears that there might have been some situational awareness disconnect for the Skywest crew that morning. However, he successfully trapped any potential error that might have occurred in the area around runways 22 and 26. The fact that he reported seeing the runway 26 sign might have been the event that prevented the accident from happening to them. Either way, he clearly did not have an adequate understanding of the layout in this area and his previous experience in LEX earlier in the month and the lack of information that was provided to them helped shape the situational awareness disconnect that he experienced.

b) American Eagle Flight 882

Both crew members of the American Eagle flight were interviewed after the accident by the Human Performance/Operations group. The captain reported that he had been flying in and out of LEX for a couple of months and that he had seen construction "*come and go*"[34]. He reported that typically there was something on ATIS about construction but he did not hear the ATIS the morning of the accident. He is confident that he departed off runway 22 full length since taxiway "A" was not closed. He reported that he was behind the Skywest aircraft as they were holding short of 22 and was concerned that he would be stuck on runway 26 as the previous aircraft had not been given a taxi into position and hold clearance. Interestingly, he said that when he was holding short of runway 22 there was grass to his right but he was not sure if he was on "A5" or not. He did not remember seeing any barricade lights to his right at any time as reported by the Skywest captain. The chart he was referencing was dated July 05, 2006 and was not obtained by the investigation. It is unknown how this short remaining taxiway between the two runways was marked on his chart. However, the signage at the airport labeled this section as taxiway "A". He remembers seeing the painted numbers on runway 22 when he taxied into position for takeoff and that this confirmed for him that this was the correct runway. However, to state that he had a correct situational awareness during this taxi event would be incorrect. The next morning after the accident, even though the taxiway layout was the same as it was the day before; he received taxi instructions that were to taxi to runway 22 via taxiway "A5" and then later to back taxi runway 22. This was much different from the morning of the accident in that there was no back taxi request made the morning of the 27th and that there was not a taxiway sign marked as "A5". Although he reported that he never saw an "A5" sign, he did not elaborate. Nevertheless, he still managed to successfully navigate to runway 22.

The Eagle flight first officer was interviewed by the group as well. Although he did not recall the exact taxi clearance given the morning of the accident he knew they were cleared to runway 22. He further stated that he recalled this taxi event because he was confused himself because of the runway layout. He reported that it was a short taxi and that he was confused after he had completed his duties and looked up and was trying to figure out which was the right runway. What originally confused him

[34] Interview Summary, Operation Factors Chairman's Factual Report, 17 December 2006, pg 49.

was he saw the captain start to turn on what turns out to be runway 26 but then soon realized that he was turning to go to runway 22. He said that part of what confused him was that they were not turning onto the runway as they crossed 26, then he saw further ahead a runway 22 sign and it made sense. Essentially this crew member reports his initial reaction to turning onto runway 26 was that they were at runway 22. After the captain continued crossing runway 26 and continued the turn with him also seeing the runway 22 sign, clarified his confusion. Additionally, he also never saw the barricades north of runway 26 and having also received information Alpha on the ATIS, was also unaware of the taxiway “A” closure beyond runway 26. He suggested several times in his interview that in part, his confusion upon reaching runway 26 may have been due to the early wake-up and time of the morning (circadian disruption) and that it was dark.

While both of these aircraft successfully navigated to the correct runway, the interviews show that there was some degree of uncertainty on the part of these crew members, either realized or not. In two cases the confusion of the location on the airport was rectified and confirmed by only one visual clue. In one case the runway 22 sign and in the other the painted numbers on runway 22 were seen and were sufficient to keep the aircraft on track.

6. Recommendations

1) Require aircraft manufacturers and operators to examine and modify those checklists that are performed during sterile cockpit periods with the goal of minimizing the amount of time pilots spend performing checklist items during taxi.

2) Examine and set flight duty and rest limits based on fatigue research, circadian rhythms and scientifically justified sleep and rest requirements. All airline employees should be provided with fatigue awareness training.

3) Require operators to have taxi procedures that ensure that adequate mitigation strategies are in place to prevent taxiway incursions, runway incursions and wrong runway departures.

4) Operators should examine and monitor data from internal safety surveillance programs to ensure that taxiway incursions, runway incursions and wrong runway departures are being reduced.

V. AIR TRAFFIC CONTROL

A. Accident Summary

On the morning of August 27, 2006, a single Air Traffic Controller was on duty at LEX Air Traffic Control Tower. His duties that morning included operating the Clearance Delivery, Ground Control, Local Control and radar Departure functions.[35]

At approximately 0605 EDT, after having been cleared to taxi to runway 22 three minutes earlier, the crew of Comair 5191 advised the tower that they were ready for takeoff. At the time of this transmission, the aircraft was located on taxiway "A", short of runway 26. Shortly thereafter, the controller scanned runway 22 for traffic and issued Comair 5191 its takeoff clearance with the additional instruction to "*fly runway heading*." At the time the takeoff clearance was issued, the aircraft was holding short of runway 26. After a brief exchange with Eagle Flight 882, the controller then turned his attention to administrative tasks inside the tower cab.[36] Comair 5191 taxied onto runway 26, began its takeoff roll, and crashed less than 2000 feet beyond the departure end of runway 26.

B. Takeoff Clearances

Since the crash of Comair 5191, there have been two documented events of pilot confusion in the area of runway 26 and 22. These events are detailed in the Operations Group Chairman's Factual Report, Addendum 1, dated February 21, 2007. Because of these events, the Air Traffic Manager of the LEX issued an amendment to LEX Order 7220.10E which states:

A takeoff clearance for Runway 22 shall not be issued until the aircraft has been physically observed having completed a crossing of Runway 26.[37]

Additionally, FAA Order 7110.65R, Air Traffic Control, paragraph 3-1-7, <u>Position Determination</u>, states the controller must:

Determine the position of an aircraft before issuing taxi instructions or takeoff clearance. (note – the aircraft's position may be determined visually by the controller, by pilots, or by the use of Airport Surface Detection Equipment).

The takeoff clearance from the tower controller to the accident crew made no mention of a specific runway. The takeoff clearance was issued while the aircraft was on taxiway "A" and prior to reaching the intersection with runway 8/26.

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[35] Pages 2, Section D, subsection 1 History of Flight, paragraph 1, Air Traffic Control Group Chairman's Factual Report of 05 OCT 2006.
[36] Page 9, paragraph 4, Section 7, Personnel Information, Air Traffic Control Group Chairman's Factual Report, 05 OCT 2006.
[37] Attachment 12, added 23 FEB 2007, to Air Traffic Control Group Chairman's Factual Report of 05 OCT 2006.

C. Notices to Airmen (NOTAMS)

Notices to Airmen (NOTAM) are notices containing information regarding the establishment, condition, or change in any component of which the timely knowledge of which is essential to personnel concerned with flight operations. A NOTAM is disseminated to pilots through the company operational notices, the dispatch release and the Automatic Terminal Information Service (ATIS) broadcast to pilots prior to departure or arrival. The ATIS broadcasts are prepared and transmitted to pilots by an Air Traffic Control Tower. NOTAMS are further categorized into Flight Data Center (FDC), Distant (D) and Local (L) based on the nature of the condition and the geographic area concerned.

NOTAM(L) information includes such data as taxiway closures and changes to airport lighting aids that do not affect instrument approach procedures. This information, under the current distribution system, is disseminated locally but is normally available to airline dispatchers. A flight crew's primary means of receiving NOTAM(L) information is by an airport's ATIS broadcast prepared by Air Traffic Control and the airline's flight release document.

The importance of receiving timely notification of all relevant NOTAMS is critical to the safety of flight. Federal Aviation Regulation (FAR), Title 14, Code of Federal Regulations (CFR) Part 91.103, Preflight Action, states in part:

Each pilot in command shall, before beginning a flight, become familiar with all available information concerning that flight.

The Air Traffic Control Group Chairman's Factual report clearly documents the NOTAM (L) information available on the ATIS broadcast. These critical omissions were a major factor in the crew of Comair 5191 developing a distorted understanding of the conditions existing on the airport.

The Federal Aviation Administration Order 7110.65R provides instructions to controllers regarding the dissemination of NOTAMs(L). Paragraph 2-9-3 (g) of the Order states an ATIS broadcast should include:

"Taxiway closures which affect the entrance or exit of active runways, other closures which impact airport operations, other NOTAMs and PIREPs pertinent to operations in the terminal area"

A review of all the NOTAMs made available to the accident crew in comparison to the NOTAMs that were actually in effect on the morning of the accident reveals there were critical omissions of information. The NOTAMs in effect at the time of the accident can be found in the Survival Factors Group Chairman's Factual Report dated December 21, 2006.

Of the NOTAMs that were in effect at the time of the accident, the following two were not provided in the Comair 5191 dispatch release or broadcast on ATIS:
NOTAM # A-1682, issued 08-20-2006 at 1405 hours local:
"T/W ALPHA NORTH OF R/W 8-26 CLOSED UFN"

NOTAM # A-1681, issued 08-20-2006 at 1405 hours local:
"R/W 4-22 DISTANCE REMAINING SIGNS OUT OF SERVICE"

The following 6 NOTAMs were provided to the Comair 5191 crew in their dispatch release only:

NOTAM # A-1680, issued 08-18-2006 at 1710 hours local:
"EFF SUNDAY AUGUST 20, 2006 FROM 1800 HOURS LOCAL UFN R/W 4/22 DECLARED DISTANCES AS FOLLOWS: ASD 7003'; TORA 7003'; TODA 7003'; LDA 6603'"

NOTAM # A-1670, amended 08-05-2006 at 0940 hours local:
"R/W 4/22 CENTERLINE LIGHTS OUTS OF SERVICE UFN"

NOTAM # A-1664, issued 07-11-2006 at 1600 hours local:
"R/W 4 TDZ LIGHTS OUT OF SERVICE UFN"

NOTAM # A-1620, issued 04-21-2006 at 1402 hours local:
"T/W ALPHA EAST SIDE LIGHTING SYSTEM FROM CHARLIE TO R/W 4, OOS, SUNDAY APRIL 23, 2006 AT 1930 LOCAL TIME UFN."

NOTAM # A-1614, issued 03-22-2006 at 1222 hours local:
"CRANES WITH BOOMS NOT EXCEEDING 120 FEET OPERATING IN THE RAMP AREA 1115 FEET EAST OF RUNWAY 4/22 UFN. BOOM WILL BE BELOW ELEVATION 1098."

NOTAM # A-1612, issued 03-06-2006 at 1436 hours local:
"PAEW ON OR ADJ TO APPROACH END OF R/W 4 UFN"

The only NOTAM that was broadcast over ATIS was:

NOTAM # A-1522, issued 07-12-2005 at 1820 hours local:
"EFFECTIVE 07-13-05 PAEW ON AIR CARRIER RAMP FROM 07:00 HRS LOCAL TIL UFN" [38]

At the time the crew of Comair 5191 was listening to the LEX ATIS to prepare the flight, ATIS information "Alpha" was current. From the Air Traffic Control Group Chairman's Factual Report dated October 5, 2006, ATIS information "Alpha" stated:

"Lexington bluegrass information alpha, 0854 automated weather, wind 190 at 8, visibility 8, few clouds 6,000, sky broken 9,000, temperature 24, dew point 19, altimeter, 3000. ILS and visual approach in use, landing and departing runway 22. Runway 22 glide slope out of service, pilots use caution for construction on the air carrier ramp, hazardous weather

[38] Attachment 3, Survival Factors Group Chairman's Factual Report dated December 21, 2006

information available on HIWAS, flight watch or flight service frequencies, all departures contact ground control on 121.9. Advise you have information alpha."[39]

The transcript shows that of the nine current NOTAMs in effect at the time, only one of them regarding airport construction was actually broadcast to the crew. Shortly after the crew completed their briefing, ATIS information "Bravo" was issued by the controller. It included weather from the 0954Z automated weather observation and the same NOTAM from the 0854Z ATIS broadcast.

Out of all the local NOTAMs that were in effect at the time, the controller appears to have only selected the oldest local NOTAM for inclusion in his recorded ATIS broadcast. By including local NOTAM A-1682, "T/W ALPHA NORTH OF R/W 8-26 CLOSED UFN" (taxiway A North of runway 8-26 closed until further notice) it would have been necessary for the flight crew to positively identify runway 26 before they could have located the closed portion on the north side of it. The failure to include this NOTAM(L) in the ATIS broadcast was a critical omission that led the crew to misidentify the active runway.

In summary, the Federal Aviation Regulations require that the pilot in command be familiar with all available information concerning the flight. It is clear from the ATC Group Chairman's Factual Report that critical information was not relayed to the flight crew by either the ATIS or the flight release. In fact, because the NOTAM (L) A-1682 information was not provided to the crew of Comair 5191, the flight crew did not have an accurate understanding of the actual airport conditions. This lack of understanding may have contributed to the flight crew's incorrect positional awareness in believing they were on runway 22, when they were actually on runway 26.

D. ATC Staffing

While one-controller operations are allowable under FAA Orders, breakdowns in communication, ATC oversight and controller workload (fatigue and abundance of duties) clearly played a major role in this accident. Federal Aviation Administration Order 7210.3U, Chapter 2, Administration of Facilities provides direction to Air Traffic Managers in the administration of their operations. No where in the Order does it say that a single controller operation is prohibited. Throughout the interviews with ATC management conducted by the NTSB, all said there was well-known "verbal" guidance that a facility always staff a shift with a minimum of two controllers on duty. While the FAA has Operating Orders dealing with every phase of their operations, Mr. Bruce Johnson, Vice President of Terminal Services for the Federal Aviation Administration is quoted in his NTSB interview as saying that he was "*unsure of the proper format*" of getting this verbal guidance into a written form to his managers[40].

In September of 2006, the NTSB requested the FAA provide them with the report on those facilities that were not routinely staffed with two controllers on the midnight shift. Three towers

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[39] Page 4, subsection 2. Weather Information, Air Traffic Control Group Chairman's Factual Report of 05 OCT 2006

[40] Page 26, Paragraph 2, Section 7, Personnel Information, Air Traffic Control Group Chairman's Factual Report, dated 05 OCT 2006.

were found to be not routinely staffed with at least two controllers on the midnight shift. These towers were:

NAME OF FACILITY	ATC LEVEL	AVG OPERATIONS/DAY	
		FY 05	FY 06
Lexington, KY (LEX)	ATC 7	662	639
Duluth, MN (DLH)	ATC 6	285	273
Fargo, ND (FAR)	ATC 6	402	362

Since the Comair 5191 accident, the Air Traffic Control Towers in Duluth, MN and Fargo, ND have been closed on the midnight shift. The Air Traffic Manager at Lexington Blue Grass Airport told the NTSB that he has been given a "*blank check*" to staff the midnight shift with two controllers. Mr. Johnson is quoted in his NTSB interview as saying "*the FAA had operations money so providing overtime funds was not an issue.*"[41]

If funding was not the issue at the time, then what was? Mr. Duff Ortman, Lexington Blue Grass Airport Air Traffic Manager stated that he was authorized 21 controllers for his facility. On the day after the accident, he had only 15. Mr. Ortman states that he had advertised for controllers over the summer, but was not able to fill the open positions. He then creatively looked to other ways to staff the facility. At the time of the accident the facility still did not have the 21 controllers that were authorized. During the first quarter of calendar year 2006, Mr. Ortman had only been able to staff the midnight shift with two controllers on 40 of the 70 days.

E. Controller Fatigue

At the time of the accident, the controller was nearing the end of his final working segment of a standard, 2-2-1 rotating shift. This meant he was working in the pre-dawn hours of the one night shift at the end of a of a five shift cycle. On the last day of the cycle, this shift required him to work two eight hour shifts within a single 25 hour period, separated by a nine hour off-duty period. During the mid-day, off-duty period, the controller was able to take a two hour nap before rising and engaging in normal activities in the early evening. He then reported back to work at 2330 to begin the overnight shift on which the early morning accident occurred.

Dr. Gregory Belenky, M.D., Research Professor and Director of the Sleep and Performance Research Center at Washington State University, examined the data on the controller from the NTSB Factual Reports. This analysis revealed evidence of fatigue in the controller and linked this to adverse circadian phase and sleep restriction. As documented in the factual reports, errors of omission, failure to proactively manage work-load, slowed response times and inappropriate responses are typical of fatigue related behaviors.

Dr. Belenky notes that research has shown that sleep propensity is highest between 0400 and 0600 and task performance is lowest between 0600 and 0800 in the morning. A mathematical model that combines circadian phase with sleep history in an attempt to predict performance estimated that the controller was operating at 72% of his effective capacity at the time of the

[41] Section 7, Personnel Information, Mr. Bruce Johnson, FAA, Vice President Terminal Services, Page 27, paragraph 8, Air Traffic Control Group Chairman's Report of 05 OCT 2006

accident. For comparison purposes, this level of effectiveness equates to someone who had been awake for almost 21 hours straight or who had a blood alcohol level of slightly less than 0.08 g/100ml.

This level of fatigue can be directly attributed to the 2-2-1 shift cycle the controller was working. While this staffing model is efficient for FAA management and liked by many controllers for its ability to maximize the number of days off, there is research indicating that the 2-2-1 rotation disrupts the sleep/wake cycle and degrades performance during the latter part of the one night shift coinciding with the time of the Comair 5191 accident.

The investigation suggests FAA management accepted a degraded level of performance from controllers working under this schedule. In his NTSB interview, Mr. Johnson was asked about how a controller should deal with fatigue. An excerpt of his interview provides the following information[42]; "*He stated that the controller needs to do what's appropriate for them prior to working the midnight shift to ensure they weren't fatigued during their shift. When asked how a controller would know something wasn't working, Mr. Johnson explained that if the controller were tired during the shift, he would need to evaluate what he did prior to the shift and make corrections. When asked if anyone had ever called in sick due to fatigue, Mr. Johnson said that he wasn't aware of anyone. In order to call in sick, one must be incapacitated and typically fatigue doesn't count. As a tower supervisor, he had never had anyone call in sick for fatigue*" From these statements we find the FAA expects a controller to "tough it out" if he is fatigued at work, without even the option of calling in sick available to him.

The controller's ability to function at full-capacity was impaired by fatigue as evidenced by the referenced fatigue study. The study clearly shows that the controller's ability to function effectively was degraded to the point where he made a decision to turn his attention away from the aircraft at a critical time to work on a non-critical task.

F. Controller Duties

The controller involved in the Comair 5191 accident was responsible for four separate air traffic functions on the morning of the crash. These were the Clearance Delivery, Ground Control, Local Control and Departure functions. Had there been a second controller on duty at the time of the accident, the overall workload in the tower would have been substantially reduced. In the four minutes between the time Comair 5191 called for a taxi clearance and takeoff clearance, the single controller at LEX was involved in doing radar departure functions. Eight seconds after the controller issued the final takeoff clearance to Comair 5191 he had a 14 second communication exchange with the previously departed Eagle Flight 882 aircraft. Immediately after the conclusion of this exchange, the controller immediately turned away from the local control position to handle his administrative duties. In his actual interview to the NTSB, the controller stated that after he issued the takeoff clearance, he turned to the center console to do the traffic count." In this excerpt, the controller does not mention his exchange with EGL 882. However

[42] Section 7, Personnel Information, Interview with Mr. Bruce Johnson, FAA Vice President of Terminal Services, Page 29, paragraph 1, Air Traffic Control Group Chairman's Factual Report dated 05 OCT 2006.

the ATC Factual Report clearly makes the point that once the controller's departure duties were completed, his attention was turned away from the scope and onto administrative duties (traffic count).

Further in his interview with the NTSB, the controller stated that after he cleared Comair 5191 for takeoff, he looked at the D-BRITE but could recall seeing Comair 5191 again[43]. He was also asked in his interview what he could have done to prevent the accident. He replied "*he probably would not do the traffic count at that time*." [44] As noted previously, this controller was working by himself and was actively operating multiple control positions.

While working with flight control strips and information directly related to current operations is necessary for the Air Traffic Controller, administrative detail or paperwork that diverts attention away from active traffic control operations must be secondary to controlling traffic and maintaining separation between aircraft. While the flight crew selected the wrong runway, had the controller remained focused on local control, he was in a position to trap the crew's error and cancel the takeoff clearance.

G. Recommendations

1) Require that 7110.65R and all local Standard Operating Procedures ensure that administrative tasks do not draw a controller's attention away from controlling air traffic.

2) No takeoff clearances should be issued to an aircraft until that aircraft has crossed all runways the taxi route intersects and it is approaching the hold short line for the runway of intended use.

3) Amend the existing 7110.65R Order to require controllers to include the runway number in all takeoff clearances regardless of the number of active runways in operation.

4) Require that pilot's readback runway number as part of the acknowledgement of a takeoff clearance.

5) FAA must establish an infrastructure that provides for the dissemination of all NOTAM information (including NOTAM(L) information) via operationally approved data circuits.

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[43] Section 7, Personnel Information, Christopher R. Damron, FAA, LEX Tower/Approach Controller, Page 19, paragraph 10, Air Traffic Control Group Chairman's Factual Report dated 05 OCT 2006.

[44] Section 7, Personnel Information, Christopher R. Damron, FAA, LEX Tower/Approach Controller,
Page 11, paragraph 1; Air Traffic Control Group Chairman's Factual Report dated 05 OCT 2006.

6) Line controller positions must be prioritized within the FAA's hiring process with the goal of fully staffing these positions. These positions are vital to the safety of the Air Transportation System. Full staffing also minimizes stress and employee fatigue.

7) Establish shift rotations for controllers based on scientific principles that maximizes the effectiveness of rest periods and minimizes the potential for controller fatigue.

8) Ensure that when regular control tower operations and terminal radar operations are being provided from the same facility, a minimum of two controllers are on duty.

VI. SURVIVAL FACTORS

A. Airport Rescue and Fire Fighting (ARFF) RESPONSE

The goal of the ARFF response is to access the scene as quickly as possible to effect timely rescue and fire fighting. The response path to this accident scene was circuitous and less direct than it could have been. A quick and effective ARFF response has many advantages. These include the saving of lives and the preservation of wreckage for investigative work. It was noted in the interview of the first responder that when he arrived, the fuselage was still intact and the site looked completely different from when he returned after transporting the first officer to the hospital. The aircraft was destroyed by post-crash fire as it was not easily or rapidly extinguished. Providing a fast response will help reduce the amount of agent required to extinguish the post-crash fire.

The response time noted from the Survival Factors factual report for the first ARFF vehicles was approximately 8 minutes. The path taken by the ARFF response vehicles is shown in Figure 8. The response path was noted as going through Gate 2, then via Man O' War Boulevard, onto Versailles Road, then accessing the scene via the first road on the left after the airport. Also depicted is what would have been a more direct path that would have taken the vehicles via taxiway "C" to runway 26 to the gate in the perimeter fence, then through the pasture to the accident scene.

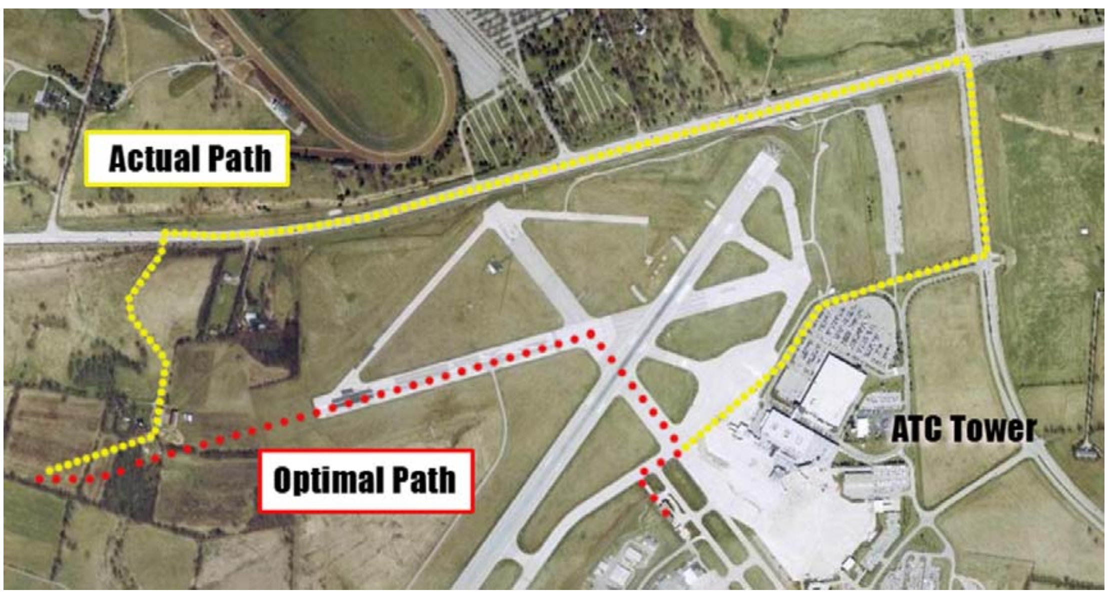

Figure 8: ARFF Response Path - Actual versus Optimal

The response time for each of these paths was estimated and the results showed the following.

Estimated Actual Response; assumes 90 seconds to get truck out of the fire house
Vehicle performance assumed for Class 1 ARFF vehicle (1,500 gallon water) per Advisory Circular (AC) 150/5220-10C - Guide Specification for Water/Foam ARFF Vehicles

Leg #	D	Max Speed	T-Leg	Cum. Time	Notes
	(ft)	(mph)	(sec)	(mm:ss)	
1	622	15	32	02:01.5	Station to taxiway "C"
2	565	15	29	02:30.4	Ramp to gate
2-3	0	0	38	03:08.4	Time to open gate per video 3
3	1581	30	41	03:49.7	Gate to airport entrance
4	1355	35	33	04:22.3	Airport entrance to Versailles
5	5647	60	76	05:38.0	Versailles to left onto gravel
6	2033	15	96	07:13.6	Gravel road (uphill, narrow, damp)
7	791	15	39	07:52.8	Down through field
Total	**12594 (2.4 Miles)**				

Optimal Path; assumes 90 seconds to get truck out of the fire house
Vehicle performance assumed for Class 1 ARFF vehicle (1,500 gallon water) per AC 150/5220-10C - Guide Specification for Water/Foam ARFF Vehicles

Leg #	D	Max Speed	T-Leg	Cum. Time	Notes
	(ft)	(mph)	(sec)	(mm:ss)	
1	622	15	31.5	02:01.5	Station to taxiway "C"
2	1355	60	26.9	02:28.4	Taxiway "C" to Runway 26
3	226	25	10.6	02:39.0	End of Runway 26 thru grass to gate
4	1581	25	47.5	03:26.5	Gate to accident site
Total	**3785 (0.7 Miles)**				

Table 15: ARFF Vehicle Response Times: Actual versus Optimal

These calculations make assumptions for full stops at each leg start and end, and accelerations and decelerations are estimated based on the noted Advisory Circular. The distance to reach the accident site via the direct route is 0.7 miles, less than 1/3 of the distance of the actual path of 2.4 miles. The optimal response time is less than the actual estimated time by nearly 4 minutes. This is significant for fire extinguishing, due to the fact that the longer a fire burns, the more thermal inertia it generates, making fire fighting more difficult.

ARFF response difficulties in this accident have also been noted in other accidents. One example is the accident involving TWA 427 and Superior Aviation Cessna 441. Below is an excerpt from a letter written to the FAA Administrator David R. Hinson from then NTSB Chairman Jim Hall[45].

> The Safety Board is concerned that the response of the ARFF units was delayed because of difficulties experienced in opening airport security gate 36. The Airport Authority later determined that the gate had been functioning properly but had failed to open

[45] Appendix I of Aircraft Accident Report NTSB/AAR-95/05 dated November 22, 1994.

because the ARFF personnel had passed their magnetic cards through the card readers too quickly.

While the solution to this problem would be for emergency response personnel to pass the gate cards through the card reader more slowly, the ARFF Incident Commander testified at the Safety Board's public hearing that when the gate did open, it did so very slowly. The Safety Board believes that passing a gate card through a card reader too quickly by emergency response personnel, who would normally be anxious and hurried while responding to a disaster, is understandable. However, response time is critical in fighting fires, especially aircraft fires. The time lost in repeatedly trying to open a gate, and then waiting for the gate to retract to the open position, could jeopardize lives.

The Safety Board acknowledges that fences and restricted gate access are required for security at airports; however, devices used to provide this security should not interfere with an expeditious response by emergency personnel. Therefore, the Safety Board believes that the Federal Aviation Administration (FAA) should require that all airports certificated under 14 CFR Part 139 identify gates that ARFF personnel and their equipment might need to access while responding to emergencies. Further, the FAA should require the necessary changes to ensure that ARFF personnel and their equipment can pass through these gates without hesitation or delay. Additionally, the gates that are identified and the procedures required to access them should be included in the Airport Emergency Plan.

Therefore, as a result of its investigation of these accidents, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Require that all 14 CFR 139 certificated airports identify gates that aircraft rescue and fire fighting personnel and their equipment might need to access while responding to emergencies, and make the necessary changes to ensure that emergency personnel and their equipment can pass through these gates without hesitation or delay. Additionally, the gates that are identified and the procedures required to access them should be included in the Airport Emergency Plan (Class II, Priority Action) (NTSB Recommendation A-95-77).

ARFF personnel cannot be expected to respond directly to the accident scene without knowing its specific location. ATC personnel must actively participate in directing the ARFF vehicles to the scene as they have a better vertical vantage point.

The following is the complete transcript from the Lexington Control Tower to the Airport Fire Station:

1007:23	LC[46]	this is Lexington alert three west side of the runway with a Comair regional jet taking off
1007:27	FD[47]	alert three west side of runway

[46] LC represents Lexington Air Traffic Control Tower Local Control

[47] FD represents Airport Fire Department

1007:29	LC	yeah west side of the airport just off the approach end runway eight
1007:32	FD	off the approach end of runway eight
1007:33	LC	yeah
1007:35	FD	runway eight
1007:36	LC	off the approach end of runway eight he was taking off two two
1007:39	FD	off the approach end of runway eight
1007:40	LC	yeah he well he is off the west side of the runway
1007:43	FD	west side of the runway all right bye

The accident was noted in the FDR factual report as occurring at 10:06:36 (end of recording), so the controller's call to ARFF dispatch was 47 seconds after the accident. The ATC Factual report states that these two separate pieces of information (FDR and ATC) were time-correlated with each so a comparison could be made. These times are noted as correlated in the ATC Factual Report. Following this initial notification the controller did not participate any further in the rescue response.

While the controller did make note that the accident was off the side of the runway, the controller did not make use of the airport's grid map. This map is required under FAR 139.203 as part of the airport's certification manual and called for being used in AC 150/5200-31A on Airport Emergency Plans. The noted Regulation describes the grid map as follows: "*A grid map or other means of identifying locations and terrain features on and around the airport that are significant to emergency operations*". Clearly, this was not put to use in the actions following the accident; how can this be corrected? In the field of flight operations, the answer is simple: training. ATC and ARFF personnel need to train together on a regular and recurring basis allowing the efficient utilization of two agencies resulting in faster response times.

There has been little done in the US regarding training air traffic controllers in handling emergency situations. In the UK, the issue was addressed after poor emergency handling was noted as a factor following an aircraft accident. The issue is discussed thoroughly in the paper *MAYDAY, MAYDAY, MAYDAY* presented by Dr. Sue Baker, Head of Human Factors and Mr. Ian Weston, Head of Safety Investigation and Data Department, United Kingdom Civil Aviation Authority. They draw attention to the fact that air traffic controllers in the UK received little training in handling emergencies. Their behavior when responding to actual emergencies was to normalize things, preferring to deal with problem-free aircraft, leading to a distortion of priorities.

In contrast, after the CAA implemented an emergency training program, there was a similar in-flight emergency involving a controller who had received the training in handling emergencies the day before the event. It was evident that the event was handled much more efficiently and with less stress on the controller. The safe landing of the aircraft was directly attributed to the efficient handling by the air traffic controller.

Keeping the controller involved in the emergency response allows use of the increased vertical vantage point of the controller to visually locate the accident site versus that of the fire trucks, or ARFF dispatch. In an accident such as this one, controller involvement could provide responders insight as to the severity of the event and the most direct path to the accident site.

Chapter 10-1-6b of FAA Order 7110.65R Air Traffic Control states:

Workload permitting monitor the progress of emergency vehicles responding to a situation. If necessary, provide available information to assist responders in finding the accident/incident scene.

The factual information regarding ATC activities shows no attempt on the part of the controller to assist the ARFF vehicles in driving the most direct route to the accident scene. This was a factor as well in the Little Rock accident involving an MD-83, where miscommunications between the ARFF vehicles and ATC led to the ARFF vehicles taking a circuitous route to the accident site, possibly costing up to 12 minutes in delay.

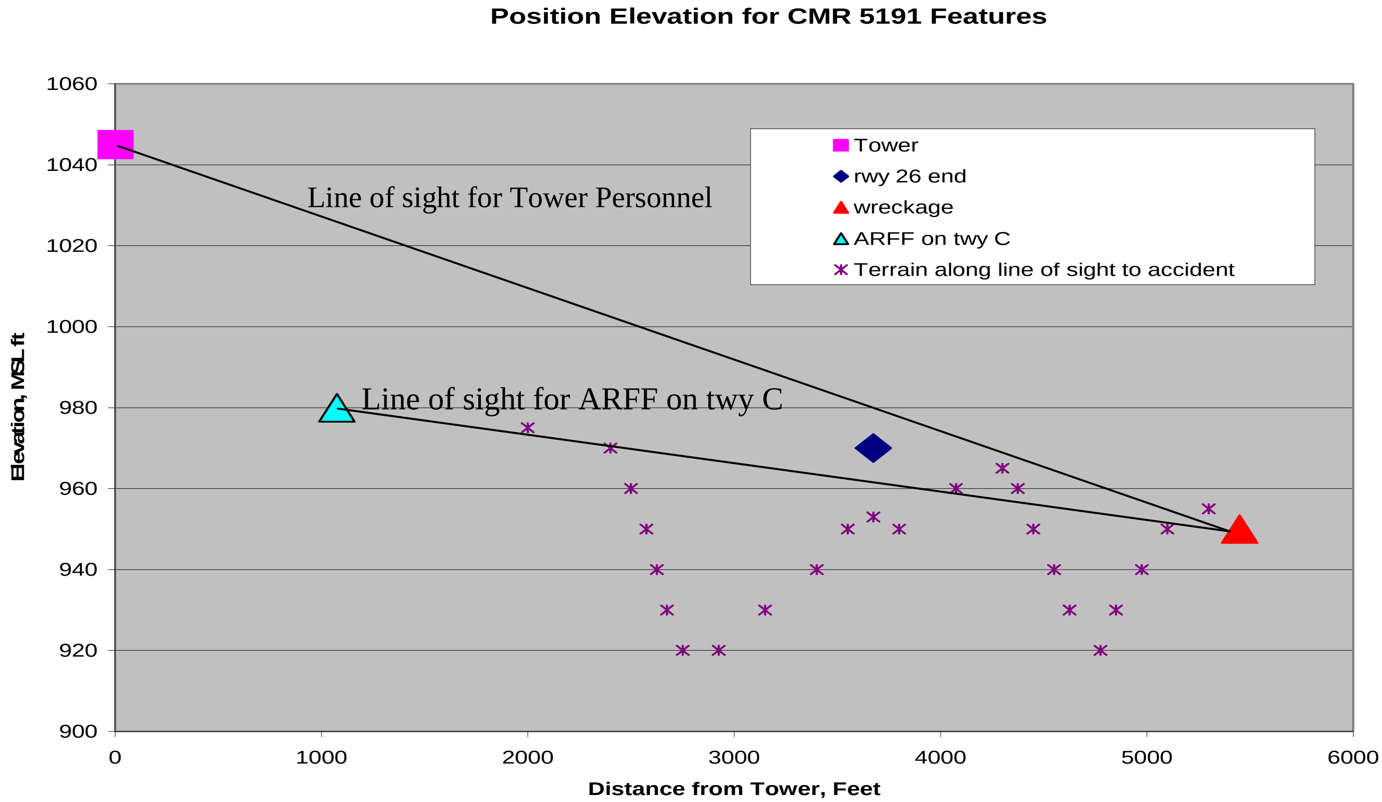

Figure 9: Line of Sight - Tower and Firehouse to Accident Location

Figure 9 shows the estimated line of sight for the controller in the control tower, with the tower floor at an elevation of 1,045' to the accident site, and the view from an ARFF vehicle on taxiway "C" coming out of the fire house. It is apparent that neither point would have a completely unobstructed view of the accident scene. However, it appears that the controller would have had a more direct line of sight.

The controller's high vantage point could have been utilized more efficiently had the controller employed the grid mapping system. The controller could have issued a grid number[48] to the dispatcher which the ARFF personnel could have used to determine the most direct routing to the accident site. However, in this accident the controller issued a general direction and made no contact with the ARFF responders after that.

It is understood that the controller has an emergency checklist that they must complete. However to expedite the ARFF response, it would have been more beneficial from his vantage point had he described what he saw directly to the dispatcher or rescue vehicles. To better address this issue, FAA Order 7110.65R must be amended to provide direction to controllers to assist and monitor emergency responders.

The lack of direct routing of ARFF vehicles was also identified at the Milan Linate accident involving an MD-83. In this accident, the MD-83 collided with a Cessna Citation in fog, and subsequently crashed into a baggage handling building. The ARFF vehicles followed the roadway to the building. However, if they had traversed the ramp directly; it would have reduced the distance and number of turns by half.

AC 150/5210-19, Driver's Enhanced Vision System (DEVS) (12-23-96) establishes a standard for ARFF vehicles to have moving map displays in the vehicle cab, with capability for indicating the accident site position. This AC was developed as a result of the accident involving two aircraft colliding at Detroit Metropolitan Airport in December 1991. The recommendation in the AC is a good step in improving the response times of ARFF in low visibility conditions.

It has become apparent that a critical link remains missing: pinpointing the accident site. For that, two things are needed: an Emergency Locator Transmitter (ELT) on the aircraft and a system on the airport that determines the ELT position and displays it in the control tower.

The air carrier fleet is only partially equipped with crash-activated ELTs. Title 49, Subtitle VII, Part A, Subpart III, Chapter 447, § 44712, requires turbojets with payloads of 18,000 lbs or less to carry ELTs. This leaves the majority of air carrier aircraft without the requirement to carry an ELT, which is a major compromise when trying to locate downed aircraft. 14CFR 91.207(f)(2) continues to allow air carriers to fly regularly scheduled flights without ELTs. The idea that positive radar control will aid in locating an accident has proven false, even though this was the argument when ELTs were originally required.

Even if all aircraft had ELTs installed, another important task will remain. Airports (either ATC towers or the ARFF station) must have a means to display the location ELT site. The aircraft's position could then be superimposed on the airport grid map required under 14 CFR 139.203. The Advisory Circular (AC) 150/5200-31A on Airport Emergency Plans advises that accident notification should include "*the location of the accident, if known*," and that "*If possible, use a*

[48] AC-150-5200-31A page 83 section 7-1-9 d(2)(d)5 Unique Planning Consideration Alert Warning

grid map to describe the location."[49] Air traffic controllers need the tools to be able to do this effectively.

Rescue personnel stated in their interviews that, upon arrival, the hull was intact but on fire. The two ARFF vehicles that responded to the crash site were equipped with digital recording cameras. Unfortunately, neither truck's cameras were activated by the firefighters. Failure to capture this video information for this accident did not allow the Survival Factors Group the opportunity to examine and critique the response. This missed opportunity to capture the scene minimizes the analysis of the effectiveness of the fire fighting effort, and its use for future training opportunities.

B. Runway Safety Area

AC 150/5200-18C, Airport Safety Self-Inspection notes the inspection of the safety area should determine if there are any hazardous ruts, depressions, humps or variations from the normal smooth surface.

One area of focus of this AC is to prevent objects from causing additional damage to an aircraft or vehicle traversing the runway safety area. The FAA has varying standards for dimensions of runway safety areas, allowing them to be smaller for shorter runways[50]. Allowing this diminishes safety for smaller aircraft that typically operate from shorter runways. There is also design guidance for runway object free areas (OFA) centered on the runway centerline. The clearing standard requires clearing the OFA of above ground objects protruding above the runway safety area edge elevation.

The overlay of the standard Runway Safety Area (1,000' x 500') on this wreckage path diagram shows the aircraft hit several obstacles while in the Runway Safety Area, including an earthen berm that caused significant damage to the landing gear and numerous trees that resulted in catastrophic damage to the left wing (see Figure 10).

[49] Section 7-1-9(d), Unique Planning Considerations, Alert and Warning.
[50] AC 150/5300-13 on Airport Design provides the following on the runway Obstacle Free Area (OFA).

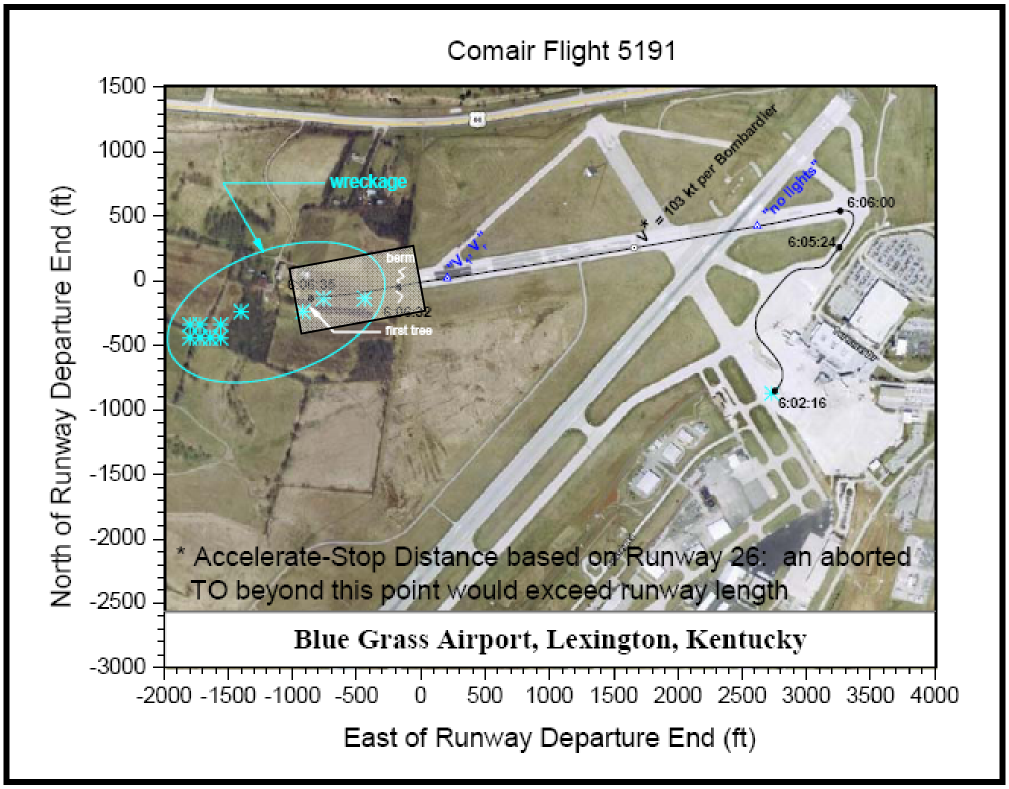

Figure 10: Wreckage Path Overlaid with Standard Runway Safety Area Dimensions (from Aircraft Performance Group Chairman's Aircraft Performance Study)

C. Recommendations

1) Amend FAA Order 7110.65R to provide guidance for controllers to assist and monitor emergency responders.

2) Require all aircraft to be equipped with crash activated ELTs and that all ARFF or ATC Towers have the means to locate the accident scene.

3) Require that all ARFF vehicles be equipped with digital recording cameras that activate automatically during an emergency response.

VII. TECHNOLOGICAL ADVANCES

A. Runway Awareness Advisory System (RAAS)

Several technologies exist today to provide pilots with additional positional awareness while taxiing or otherwise operating in and around the airport environment. These technologies vary widely in cost, type of data they provide to pilots, and how that data is presented. These technologies show potential for being able to prevent the recurrence of accidents like Comair 5191.

One such technology is the Runway Awareness Advisory System (RAAS), produced by the Honeywell Corporation. On February 27, 2007, Air Safety Representatives from the Air Line Pilots Association met with engineers from Honeywell at Paine Field in Washington to receive a briefing and flight demonstration of the RAAS.

RAAS is integrated with the Enhanced Ground Proximity Warning System (EGPWS) that is, according to Honeywell, installed on approximately 90% of air carrier aircraft. RAAS provides audible advisories to pilots while taxiing and on approach. These advisories increase the positional awareness of the flight crew. RAAS uses inputs from the EGPWS such as GPS position, heading, groundspeed and a runway database.

RAAS produces ten audible advisories that are airport, runway, and distance specific. Five of these advisories provide routine feedback on the aircraft position as a matter of keeping the crew aware of their position. The other five are considered non-routine and will provide crews with an advisory of a potential runway incursion. During the demonstration flight, our crew taxied across runway 11-29 at Paine Field. We received the message “approaching one-one” prior to reaching the runway. As we approached the departure runway we received the message “approaching three-four left”. After taxiing into position we received the message “on runway three–four left”. If RAAS had been installed on Comair 5191, the flight crew would have received the message “approaching two-six”. The crew would have then received the message “on runway two-six, three thousand five hundred remaining”.

The Table 16 provides the descriptions of the ten advisories produced by RAAS.

Routine Advisory	Purpose
Approaching Runway – On Ground	Awareness of a runway approached by the aircraft during ground operations (e.g., "Approaching one-one").
On Runway	Awareness of which runway the aircraft is lined-up with during ground operations (e.g., "On runway three-four left").
Approaching Runway – In Air	Awareness of which runway the aircraft is tracking on final approach (e.g., "Approaching one-six right").
Landing Distance Remaining	Awareness of aircraft position relative to the runway end (e.g., "One-thousand remaining").
Runway End	Awareness of the position of the aircraft relative to the runway end (e.g., "One hundred remaining").
Non-Routine Advisory	**Purpose**
Taxiway Take-off	Awareness of excessive taxi speeds or a take-off on a taxiway (e.g., "On taxiway! On taxiway!").
Insufficient Runway Length – On Ground	Awareness of which runway the aircraft is lined-up with, and that the runway length available for takeoff is less than a defined nominal take-off runway length (e.g., "On runway three-four left, six hundred remaining").
Extended Holding on Runway	Awareness of an extended holding period on the runway (e.g., "On runway three-four left, on runway three-four left").
Distance Remaining – Rejected Take-off	Awareness of aircraft position during a RTO (e.g., "Two-thousand remaining").
Approaching Short Runway – In Air	Awareness of which runway the aircraft is tracking, and that the runway length available for landing is less than a defined nominal landing runway length (e.g., "Approaching three-four right, three-thousand remaining").

Table 16: RAAS Advisories

RAAS was first certified by the FAA in December 2003. The system was approved for the CRJ series aircraft with a Supplemental Type Certificate (STC) issued in July 2004. Currently, there are six air carriers using RAAS. These carriers are Alaska Airlines, FedEx, Lufthansa, Malaysia Airlines, Condor, and Lufthansa CityLine. Lufthansa CityLine operates CRJs equipped with RAAS. Additionally, there are approximately 900 business jets equipped with RAAS worldwide.

According to a study conducted by Honeywell, RAAS could have a direct impact in preventing 62% of runway incursion incidents and accidents. In addition, the system could have played a more indirect role in another 32% of runway incursion incidents. Earlier this year, the RAAS system was credited with helping a crew lessen the potential for a runway incursion. The following statement was provided by an airline crew using RAAS in actual conditions:

On February 14th, 2007 at 0030 our flight was departing out of Milwaukee during a period of significant snowfall. Visibility varied between 1 and 11/2 with blowing snow and gusting winds, approximately 6 inches of snow fell in 4 hours resulting in partial obscuration of taxiway signs. Needless to say it was a challenging night; however the recently installed Runway Awareness and Advisory System (RAAS) performed incredibly well in raising the level of awareness in the cockpit.

"after deicing on Signatures ramp our taxi instructions were to taxi via taxiway Z, E to 1L. 7L, 13, and 7R were closed, covered with snow and with the signs partially obscured we proceeded slowly. Approaching 7L RAAS announced and confirmed the runway; then just shortly after crossing 7L the Tower Controller changed our taxi clearance to "cross 13 at G; continue around the inner taxiway to R, cross at 25R at R to 1 L due to snow removal". Given the high level of certainty we had in the cockpit it was an easy adjustment to make the 30 degree turn and comply with the taxi clearance. Through out the entire taxi operation the Runway Awareness and Advisory System operated flawlessly, raised awareness and was a welcome presence in the cockpit. One couldn't have picked a better night to showcase this system, it was impressive."[51]

B. Electronic Flight Bag

Installation of graphic cockpit displays (airport electronic displays) that depict the airport surface with own-ship position (enabled by GPS or other position sensing system) has been the highest rated safety enhancement for reducing runway incursions as determined by the Commercial Aviation Safety team (CAST). The mission of the CAST is to "Provide government and industry leadership to develop and focus implementation of an integrated, data driven strategy to improve commercial aviation safety." The goal of the CAST is to: "Reduce the commercial aviation fatal accident rate by 80% by 2007." However, the CAST report shows this element of the program as not currently on plan, i.e., the implementation is not going as recommended.

Airport electronic displays are highly intuitive graphical displays that provide flight crews instantaneous information on the aircraft's position and orientation as they navigate the airport's apron, taxiway and runway surfaces. These displays can show own-ship position as one function which may be displayed as part of an Electronic Flight Bag (EFB) to enhance situational awareness. Currently, the technology available to display own-ship position on an electronic airport display is permitted only on Class 3 (installed equipment) EFBs, which have seen a limited market penetration due primarily to prohibitive acquisition cost. While an equally capable solution exists in the form of the Class 2 EFB, the current FAA approval process for this application has turned out to be cost-prohibitive due to the certification requirements (Type B versus Type C software). FAA is currently considering modifying those requirements in order to

[51] Statement of Capt. Scott Mesmer, Pace Airlines/MLW Aviation, DAL Base Manager

allow display of own-ship position (on the ground) with a more economical certification / approval process. Ironically, this technology is available and in use today on many aircraft in the General Aviation fleet.

Comair, prior to entering bankruptcy in 2005, had been in discussions with vendors and performing cost benefit analysis of the Class 2 EFB as a retrofit to their existing fleet of Canadair Jets. Subsequent to the bankruptcy filing these talks ended and no further discussions have been held. Allowing this change will lower the barriers currently preventing Class 2 EFBs from entering the marketplace which will then introduce a significant technological jump in situational awareness to the air carrier fleet.

If the crew of Comair 5191 had been operating an aircraft equipped with an airport electronic display showing own-ship position, their aircraft position on the airport surface would have been shown in real time, and this would have resulted in their having been presented a visual cue much more informative than a paper taxi diagram clipped on their map holder. Even with the airport taxi diagram (e.g. the Jeppesen 10-9 chart) displayed on the EFB with the taxiways that were improperly depicted (as was the case on the paper charts provided to the accident flight), the crew would still have been able to see their own position with respect to the airport runway layout as they taxied along. An EFB depicting own-ship with airport electronic display would have provided robust, unambiguous cues as to which runway was being approached and entered prior to the initiation of the takeoff roll. The graphic display would have provided many more cues than were available to the crew of Comair 5191 and consequently may have been instrumental in trapping the error that led to this accident.

C. Recommendations:

1) Require operators to install and maintain systems that provide pilots with audible annunciation of position during operations on or near runways.

2) Facilitate the introduction of the airport electronic display with own-ship position for Class 2 Electronic Flight Bags by clarifying AC 120-76A to include display of own-ship position on the ground as Type B software.

VIII. SIMILAR EVENTS

A. Lexington Blue Grass Airport

1. Part 121 Airline Crew: November 1993

The investigation was able to determine that other pilots had also become confused while taxing at the Lexington Blue Grass airport recently and in the past. The most notable is an NASA ASRS report from 1993 about a 14 CFR Part 121 airline crew that was cleared for takeoff runway 22 and had inadvertently lined up on runway 26. The crew was cleared for an immediate takeoff but requested a delay for closer examination of their on board weather radar. A few seconds later, they realized that their heading was not correct for runway 22. Almost simultaneously, the controller noticed that they were on runway 26 and then cancelled their takeoff clearance. Fortunately, they had two mitigation strategies in place to help them on their flight that the Comair accident flight did not; a procedure for checking their heading bug as compared to runway heading and controller vigilance that helped trap the error.

2. Learjet: January 1, 2007

In January of 2007, Safety Board Investigators interviewed the crew of a Learjet that departed from Lexington under dark conditions. Although the crew successfully managed to taxi to and takeoff runway 22, their interview revealed valuable information. The crew reported that they had been in to Lexington several times in the last year. On this occasion had performed a taxi briefing prior to leaving the ramp area and that because of the accident, they had a heightened sense of concern regarding taxiing at Lexington. The first officer described that they could hardly see runway 22 when they were holding short of runway 26. He further stated that they could not clearly see runway 22 until they were on top of runway 26 commenting that "*it can be vague*". This crew's perspective is valuable because it demonstrates the decreased conspicuity for runway 22 when approaching or on runway 26. In other words, even though it is very close by, runway 22 does not present itself as a significant visual cue that might help a crew with their situational awareness. He also reported that even though they were familiar with the airport, had a 3 item taxi checklist and had thoroughly briefed the taxi; upon reaching runway 26, the captain thought that runway 22 was mistakenly straight ahead. The first officer noticed the apparent confusion and pointed him in the right direction. The first officer also had no recollection of every seeing a runway 26 sign at any time during their taxi for takeoff. He further stated that they were cleared for takeoff before they had passed runway 26 to which he added "*caught me off guard*". He was asked if he had any insight as to how this accident could have happened. He suggested that runway 22 having low conspicuity and ATC clearing a flight for takeoff before passing runway 26. He also offered that "*going through the motions*" and "*minimum rest*" as well.

The captain of the Learjet reported that prior to January 1, 2007 his last time in Lexington was on July 25, 2006. He was further asked if the January 2007 departure was any different than the July 2006 departure with regard to the taxiway configuration near runway 26 to which he replied "*no*". This is contrary to the fact that the barriers were not there in July but were still in place in January. This suggests another crew member that did not have a complete understanding of the taxiway configuration recently despite still having navigated the area successfully.

Earlier in our submission, we discussed the visual cues available to the accident crew as the pulled out onto runway 26 and how these cues had remarkable resemblance to what the accident crew had expected to see. The first officer of the aforementioned Learjet crew was asked if he saw that the runway lights were on for runway 26, to which he replied "*yes*". It is our belief that the Comair 5191 crew during the first part of the takeoff also thought that they were looking at partial runway lighting configuration.

Both of these incidents discussed thus far clearly represent how easily a properly trained, briefed and airport familiar crew could still become confused in the runway 22 and runway 26 threshold areas.

3. Other Comair Crews

Interviews with other Comair line pilots demonstrate additional examples of confusion while taxiing in the area highlighted by this accident. These events were reported to have occurred both before and after the August 27, 2006 accident. However, because of one or more successful mitigation strategies these events did not culminate in an accident. As seen in other interviews, many of these crew members also did not recall seeing the barricades north of runway 26.

In addition to Comair crew members reporting difficulty seeing the barriers north of runway 26, other examples of taxi confusion exists. For example, one Comair line captain and ground school instructor reported that a few years ago at night and after a long day of flying was taxiing to runway 22 as directed only to find himself turning at alpha 4 (current alpha 6 as per signage). He discovered his error on repositioned the aircraft to the end of runway 22 for takeoff. Additionally, a Comair first officer reported that he has in the past been crossing runway 26 and had thought "*we're here*" but then your "*brain kicks in*" and you realize that you are not at the correct runway. When asked how he might have solved the confusion he replied that possibly sign played a role but he wasn't really sure.

An experienced Comair line captain that had been flying into Lexington the entire month of August, 2006 reported that the area around runway 26 and 22 did not look right. She further reported that the taxiway closure north of runway 26 made the area more confusing. Fortunately, she was able to prevent taking the wrong runway for takeoff because of her repetitive exposure in Lexington before Taxiway "A" north of runway 26 was closed. She suggested that the Jeppesen chart and signage was of no help since they were wrong.

Another Comair crew member that was flying into Lexington the entire month of August, 2006 said that due to the construction "*each day it would be something different*". He reported that in Lexington he had asked captains to stop near runway 26 so that they could confirm where they were. He said that this was because there had been times when he had his head down while taxiing and when he looked up he did not know where he was. This would be especially true if it was night or it was raining. He also reported that the Monday after the accident, the NOTAM regarding Taxiway "A" being closed north of runway 26 was not on the ATIS and that he did not see Taxiway A5 which was on his chart. Despite having flown into Lexington all month, he found the area "*extremely tight*" and that the chart "*did not do it justice*".

Closer examination of interviews and these specific events demonstrate that even after the accident and the increased awareness of the confusion at Lexington, crews still found this to be a challenging environment for ground operations. The accident crew was at a significant disadvantage not having this insight.

B. Worldwide

The Comair wrong runway departure in Lexington was not a first for the aviation industry. Worldwide there have been numerous accidents and incidents with some of the more high profile events occurring in the last 10 years. Closer examination of these events demonstrates commonality with the Comair 5191 accident.

By examining other events, we may gain insight into the specific threats and errors that challenged those accident/incident crews. This information when compared to the facts discovered in the Comair 5191 accident investigation may be insightful in understanding common system failures amongst these events. In order to develop meaningful recommendations to prevent future accidents this examination should be considered.

Date	Report Number	Flight/Aircraft	Location
12-23-1983	NTSB/AAR-84/10	Korean 084	Anchorage, AK
10-4-1984	DEN85FA002	N127MW	Aberdeen, SD
8-6-1986	NYC86LA202	N921FP	Rutland, VT
11-22-1994	NTSB/AAR-95/05	TWA 427	St. Louis, MO
10-31-2000	ASC-AAR-02-04-001	Singapore 006	Taiwan
1-25-2002	ANC02IA011	China Airlines 011	Anchorage, AK
10-23-2005	20/2206	Pegasus 872	Oslo, Norway
10-31-2006	DCA07IA008	Alaska 61	Seattle, WA

Table 17 Wrong runway and runway incursion incidents and accidents.

The Table 17 lists the incidents and accidents examined in this comparison. While each event had its own unique set of circumstances, there was enough commonality throughout the events to gain insight on system wide failures. For some of these incidents, the exact conditions were not the same or even reported i.e. night time etc.

However, one common theme found in the majority of these events was dark or reduced visibility conditions. Because of this, it would make it difficult for air traffic control to provide the expected additional layer of protection to the overall system during ground operations. Other threats and errors include first officer's workload, incorrect signage and charting errors. One commonality in all of these events is the close proximity of the intended runway for takeoff and the surface actually used in the attempt. In some of these cases, taxiways or closed runways were mistaken for the active runway. All of these items seen these events, like those seen in the Comair 5191 accident, erode the margin of safety, as evident by the event.

Closer examination of the final report for the Oslo, Norway Boeing 737 attempted takeoff from a taxiway in October 2005 yields some important data. This was a departure that intended to be an intersection takeoff with permission to back taxi if desired. The flight crew inadvertently turned on to a parallel taxiway and began the takeoff roll. Fortunately, the air traffic controller observed the event and called for the aborted takeoff, a layer of protection not afforded to the crew of Comair 5191. Although there were numerous reasons why this event occurred, the final report discusses the concern over aircraft being cleared for takeoff prior to reaching the intended runway. Many of the examples above, including Comair 5191, have this underlying event in common. In fact, this has been addressed in several foreign events in New Zealand and Taiwan to name a few. The excerpt below was a recommendation from the investigation of the Oslo Boeing 737 incident.

> *"At airports where taxiways run parallel to the runway, there is a risk that air crews become confused and try to use a taxiway for take-off. The AIBN recommends that Avinor considers implementing a procedure where take-off clearance is not issued before the air traffic controller has verified that the aircraft has passed a point where the only remaining possibility for departure is on the intended runway. (SL Recommendation 31/2006)"*

This recommendation in addition to various individual airport policy changes to the like, play a vital role in preventing this type of error. This approach to further developing a robust safety system that tolerates human error on the part of the pilots and controllers is ideal. Recommendations such as the preceding example attempt to add another layer of protection to the aviation system. This is but one graphic example of a common thread to all of these events that require closer industry examination to flush out common the system faults in these events. In August of 2006, had there been a requirement for air traffic controllers to identify that the aircraft requesting clearance for takeoff was in fact at the correct runway and no longer had other runways or taxiways to cross, it is possible that the Comair 5191 accident could have been prevented.

In summary, similar historic accident and incident information provides us with examples of effective mitigations and lessons learned. Close examination of these historic events clearly show that if these shortcomings are not adequately addressed, wrong-runway / runway incursion events will continue to occur.

IX. CONCLUSIONS

Because the crew had different experiences with regard to their recent operations into and out of LEX, on the morning of August 27, 2006, their individual mental perceptions at the beginning of this flight of what taxiway layout and airport lighting they would expect to see during their taxi-out were different. However, as their taxi progressed, what they were seeing related to airport lighting brought their perceptions into alignment with one another. The crew was then presented with misleading taxiway signage and lighting cues that led them to believe that they were approaching runway 22; their intended runway. These cues were lighted barricades on the opposite side of the runway, the absence of taxiway lights beyond the barricades and a nearly identical taxiway to runway angular relationship that supported their confirmation bias that their position on the airport was correct. As the aircraft took position on runway 26 for takeoff, it is apparent that nothing appeared out of the ordinary to them. There were numerous visual similarities between runway 26 and runway 22. Two specific examples were the lack of runway centerline lights as expected per a local NOTAM that the lights were inoperative and the presence of a hump in the runway was visually consistent with runway 22. The crew then entered runway 26 after being cleared for takeoff and began their takeoff roll.

Comair 5191 was operating at an airport that was near the end of a 5-year construction project. Because of this construction, numerous runway and taxiway lights were inoperative and various sections of the airport / taxiway environment were closed. Because of a deficiency in the FAA / NFDC / Jeppesen chart revision process, pertinent changes to the airport configuration were not reflected in current airport diagrams. Therefore, the charts available to the crew were not consistent with the actual configuration and did not accurately reflect what they would be encountering that morning during their taxi operation. Had this anomaly in the charting process not existed, the charts that were provided to this crew and all crews operating into and out of LEX would have been correct.

At the time of the accident, there was one controller on duty at LEX. As such, his duties that morning were expanded to encompass four different controlling functions. Available evidence indicates the controller did not maintain vigilance ensuring the correct taxi route and runway were used. After the controller cleared the aircraft for takeoff, he almost immediately turned his back to address administrative duties. Had he maintained an increased level of vigilance related to controlling this aircraft, he may have noticed that the aircraft had entered the incorrect runway. As part of his duties, the controller was responsible for issuing ATIS broadcasts at LEX. Critical NOTAM information which would have enhanced the situational awareness of the crew was omitted from the ATIS broadcasts. Due to staffing issues, the controller was forced into a situation where he was working alone. A fatigue study conducted after this accident indicates that due to scheduling rotations, the controller was operating in a fatigued state.

FINDINGS

1. Air Traffic Control management did not ensure that schedules provide adequate rest prior to controllers going on duty.

2. The controller did not maintain vigilance with the taxiing aircraft to ensure that the aircraft was properly positioned on the airport prior to being cleared for takeoff.

3. The controller did not maintain vigilance with the aircraft to ensure it was departing from the correct runway.

4. The FAA did not provide adequate oversight of the construction at LEX Airport and its affect on published airport material and information.

5. The FAA did not ensure that guidelines for proper ATC facility manning were properly followed. This resulted in an increased workload for the controller at a critical phase of operation.

6. The controller did not include critical NOTAM information on the ATIS broadcasts which resulted in the crew not receiving local NOTAM that Taxiway "A" north of runway 26 was closed.

7. Jeppesen did not ensure that their data-reception program (NFDC link) had adequately captured all intended information for chart revisions.

8. LEX Airport Authority did not issue NOTAM's identifying differences to airport signage and pavement configurations compared to published charts.

9. The flight crew did not follow Comair Standard Operating Procedures regarding thorough taxi briefings.

10. The flight crew did not correctly identify their intended departure runway.

11. The aviation industry and the FAA have not established standardized flight crew procedures to verify that their aircraft are on the proper runway.

12. The takeoff abort policy in use by Comair restricted the captain's ability to consider runway and airport environmental factors in a possible abort decision.

13. The air traffic controller took approximately 47 seconds to alert the ARFF dispatcher after the accident had occurred.

14. The first ARFF vehicles were delayed approximately 38 seconds while a security gate was opened for the vehicle.

15. The first responders to the accident scene rapidly discovered the first officer within the wreckage, extricated him from the aircraft at great risk to themselves, and drove him to the hospital, saving his life.

16. The 2 ARFF vehicles that responded to the accident site had digital video recording devices on them. However neither vehicle's devices were activated to record the response and accident scene.

17. A system to display the accident location to the controller would have allowed him to assist the ARFF vehicles in responding more rapidly and directly.

18. The controller in the tower had the height advantage in seeing the accident location. However, the he did not provide directional assistance to the ARFF vehicles in locating the site after the initial accident notification.

19. While the controller followed all required procedures for issuing a valid takeoff clearance, FAA Takeoff Clearance orders as found in 7110.65(R) are inadequate.

20. Two additional incidents of aircraft inadvertently accessing runway 26 occurred after the LEX accident. A local ATC SOP change was then put in place to not clear runway 22 traffic for takeoff until after they had passed over runway 26.

21. RAAS technology that exists today and is already certified on the CL-65-2B19, but not currently installed, would have increased the accident crew's situational awareness.

22. RAAS technology can be operational on CL-65-2B19 aircraft within a short period of time.

23. The FAA can facilitate the approval of Electronic Flight Bags with airport electronic display showing own-ship position that, if installed, will help raise crew positional awareness to a high level.

24. According to the Washington State University Fatigue Study, the flight crew was mildly impaired due to fatigue from adverse circadian phase and sleep loss.

25. According to the Washington State University Fatigue Study, the air traffic controller was moderately impaired due to fatigue from adverse circadian phase and sleep loss.

26. The flight crew's perception of their location on the airport was altered by not receiving the NOTAM regarding taxiway "A" being closed north of runway 26.

27. The flight crew's perception their location on the airport was altered by the mismatch between airport signage and the airport diagram they had available.

28. Due to the workload of the first officer, he was not able to adequately monitor the captain's progress while taxiing.

29. The air traffic controller missed an opportunity to catch the crew's error when they were holding short of runway 26 prior to calling for takeoff clearance.

30. The air traffic controller missed another opportunity to catch the crew's error when they began their takeoff roll on runway 26.

31. Since the crew expected to see many lights out of service on runway 22, this was confirmed by what they saw on runway 26.

32. There were no specific procedures or technologies utilized that would have helped the flight crew members verify they were on the correct runway.

X. SAFETY RECOMMENDATIONS

1) Redesign NOTAM format to conform with the guidance contained in the FAA's *Human Factors Design Guide.*

2) Develop and mandate a specific system by which all NOTAMs are provided to airline dispatchers to prepare a complete crew briefing.

3) Mandate that Enhanced Hold Short Markings With Surface Painted Holding Positions Signs be applied on all runways at all air carrier airports.

4) Require airports to aggressively implement Safety Management Systems (SMS) programs that involve all airport stakeholders (e.g. operators, pilot groups, air traffic control, etc) in any discussions or planning related to airport construction and modifications to ground operations.

5) Develop and mandate a process to provide graphic temporary airport construction information to flight crew members.

6) Require that all runway safety areas at airports served by air carrier aircraft be maintained at a standard 1000 foot clear area or the equivalent.

7) Expedite development and mandate implementation of variable-message-board technology for use as temporary airport signage to communicate construction details.

8) Require aircraft manufacturers and operators to examine and modify those checklists that are performed during sterile cockpit periods with the goal of minimizing the amount of time pilots spend performing checklist items during taxi.

9) Examine and set flight duty and rest limits based on fatigue research, circadian rhythms and scientifically justified sleep and rest requirements. All airline employees should be provided with fatigue awareness training.

10) Require operators to have taxi procedures that ensure that adequate mitigation strategies are in place to prevent taxiway incursions, runway incursions and wrong runway departures.

11) Operators should examine and monitor data from internal safety surveillance programs to ensure that taxiway incursions, runway incursions and wrong runway departures are being reduced.

12) Require that 7110.65R and all local Standard Operating Procedures ensure that administrative tasks do not draw a controller's attention away from controlling air traffic.

13) No takeoff clearances should be issued to an aircraft until that aircraft has crossed all runways the taxi route intersects and it is approaching the hold short line for the runway of intended use.

14) Amend the existing 7110.65R Order to require controllers to include the runway number in all takeoff clearances regardless of the number of active runways in operation.

15) Require that pilot's readback runway number as part of the acknowledgement of a takeoff clearance.

16) FAA must establish an infrastructure that provides for the dissemination of all NOTAM information (including NOTAM(L) information) via operationally approved data circuits.

17) Line controller positions must be prioritized within the FAA's hiring process with the goal of fully staffing these positions. These positions are vital to the safety of the Air Transportation System. Full staffing also minimizes stress and employee fatigue.

18) Establish shift rotations for controllers based on scientific principles that maximizes the effectiveness of rest periods and minimizes the potential for controller fatigue.

19) Ensure that when regular control tower operations and terminal radar operations are being provided from the same facility, a minimum of two controllers are on duty.

20) Amend FAA Order 7110.65R to provide guidance for controllers to assist and monitor emergency responders.

21) Require all aircraft to be equipped with crash activated ELTs and that all ARFF or ATC Towers have the means to locate the accident scene.

22) Require that all ARFF vehicles be equipped with digital recording cameras that activate automatically during an emergency response.

23) Require operators to install and maintain systems that provide pilots with audible annunciation of position during operations on or near runways.

24) Facilitate the introduction of the airport electronic display with own-ship position for Class 2 Electronic Flight Bags by clarifying AC 120-76A to include display of own-ship position on the ground as Type B software.

XI. APPENDICES

Appendix 1: Acronymns

AC	Advisory Circular
ADO	Airport District Office
AFD	Airport Facilities Directory
AIBN	Accident Investigation Board, Norway
ALPA INT'L	Air Line Pilots Association, International
APR	Automatic Performance Reserve
APU	Auxiliary Power System
ARFF	Airport Rescue and Fire Fighting
ATC	Air Traffic Control
ATIS	Automated Terminal Information System
CAA	Civil Aviation Authority
CAMI	Civil Aeromedical Institute
CAS	Crew Alerting System
CAST	Commercial Aviation Safety Team
CDL	Configuration Deviation List
CFR	Code of Federal Regulations
CMR	Comair
CRJ	Canadair Regional Jet
CRM	Crew Resource Management
CVR	Cockpit Voice Recorder
D-BRITE	Digital Bright Radar Indicator Tower Equipment
ED1	Electronic Display 1
ED2	Electronic Display 2
EDT	Eastern Daylight Time
EFB	Electronic Flight Bag
EGPWS	Enhanced Ground Proximity Warning System
ELT	Emergency Locator Transmitter
FA	Flight Attendant
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FDC	Flight Data Center
FDR	Flight Data Recorder
FMS	Flight Management System
FO	First Officer
GPS	Global Positioning System
GWT	Gross Weight
HFDG	Human Factors Design Guide
ILS	Instrument Landing System
LEX	Lexington, Blue Grass Airport
MEL	Minimum Equipment List
MFD	Multi Function Display
NFDC	National Flight Data Center
NFDC	National Flight Data Center
NOTAM	Notice to Airmen
NOTAM(D)	Notice to Airmen - Distant
NOTAM(L)	Notice to Airmen - Local
NREM	Non Rapid Eye Movement
NTSB	National Transportation Safety Board
OFA	Obstacle Free Area
OFZ	Obstacle Free Zone
PA	Public Address (system or message)
RAAS	Runway Awareness Advisory System
REM	Rapid Eye Movement
RFP	Request for Proposal
RTO	Rejected Takeoff
SMART	Surface Movement Area / Runway Traffic
SMS	Safety Management System
SOP	Standard Operating Procedure
STC	Supplemental Type Certificate
TOGA	Takeoff and Go-Around
UK	United Kingdom
UTC	Universal Time Coordinated
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

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Appendix 2: References

Ahlstrom, V., & Longo, K. (2001). *Human factors design guide update (report number DOT/FAA/CT-96/01): A revision to chapter 8-computer human interface guidelines* (FAA Technical Center No. DOT/FAA/CT-01/08). Atlantic City International Airport, NJ 08405: National Technical Information Service, Springfield, Virginia (271).

Baker, S., & Weston, I., 2001, "MAYDAY, MAYDAY, MAYDAY". International Society of Air Safety Investigators (ISASI) Vancouver Conference, Sterling, VA

Dekker, Sydney (2005) Ten Questions About Human Error, "A New View Of Human Factors and Safety System" ISBN 0-9058-4745-6 Lawrence Erlbaum Associates Inc

Dekker, Sydney (2006) The Field Guide to Understanding Human Error. ISBN 0-7546-4826-5 Ashgate Publishing Ltd

Endsley, M. R. 1988, Situation awareness global assessment technique (SAGAT). Proceedings of the National Aerospace and Electronics Conference (NAECON). (New York: IEEE), 789-795

Jentsch, F., Barnett, J., Bowers, C.A., & Salas, E. (1999) "Who is flying this plane anyway? What mishaps tell us about crew member role assignment and air crew situation awareness". *Human Factors*, 41 (1), 1–14.

Wagner, D., Birt, J. A., Snyder, M., & Duncanson, J. P. (1996). *Human factors design guide* (FAA Technical Center No. DOT/FAA/CT-96/1). Atlantic City International Airport, NJ 08405: National Technical Information Service, Springfield, Virginia (1007).

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Appendix 3: Fatigue Study

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Schedules, Sleep, Fatigue, and Performance in the Crash of Comair 5191

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Introduction: Fatigue, Sleep Loss, and Performance

We examined the role fatigue played in the crash of Comair 5191 based on the CVR transcript and the NTSB factual reports. This analysis is intended as a supplement to the Air Line Pilots Association International submission to the National Transportation Safety Board.

Fatigue

Fatigue is a complex state. Fatigue-related degradation of performance results from the combined effect of sleep/wake history (time awake), circadian phase (time of day), and time spent on the same task (time on task) (Wesensten, et al., 2004) (see Figure 1). We define fatigue subjectively as increasing self-reported fatigue, effort, and confusion and objectively as degrading performance. Objective measurement is preferable as self-report is unreliable (Rosekind, et al., 1999).

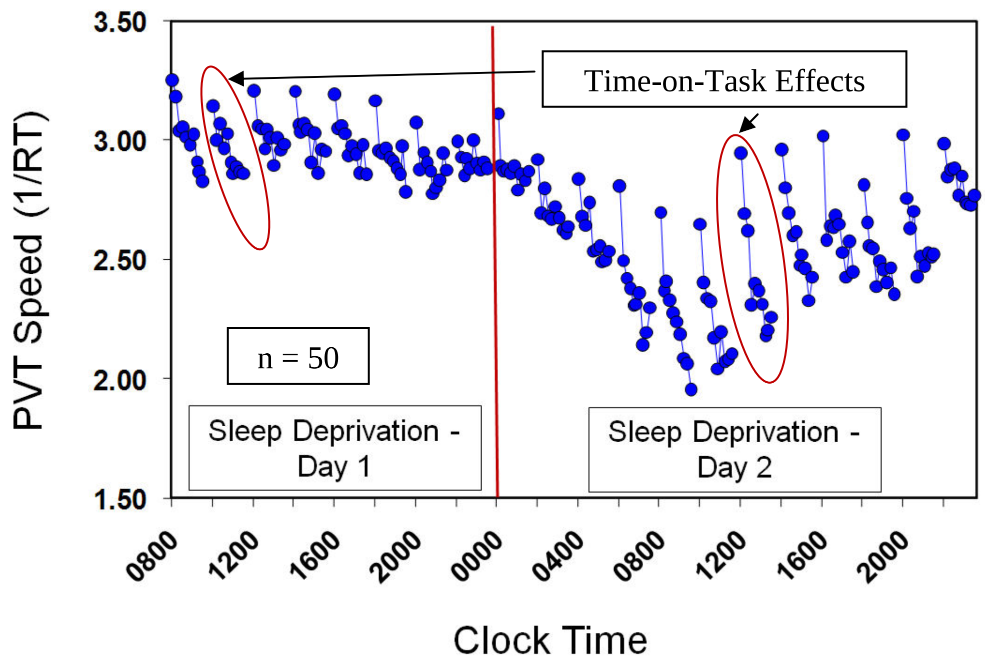

Figure 1 - Effects of time awake, time of day, and time on task on performance during 40 hours of total sleep deprivation.

In Figure 1 (adapted from Wesensten, et al., 2004) we see the effects of 40 hours of total sleep deprivation in 50 young adult subjects. Subjects' performance was tested every two hours using the ten-minute psychomotor vigilance task (PVT). The PVT is a reaction time (RT) test. In taking the PVT, subjects are required to press a button when a visual stimulus appears on a display. Their RT is the time it takes for them to respond to the stimulus with a button-push. As configured in the Wesensten et al., 2004 study, the PVT measured approximately 10 RTs per minute for a total of 100 RTs for the ten-minute test. Data for each PVT test were analyzed in successive one-minute blocks for the ten minutes of the test enabling us to visualize time on task effects (the deterioration of performance between successive one-minute blocks across the ten minutes) as well as time awake and time of day effects. Time-on-task effects were apparent within a minute or two of initiating the PVT task in both rested and sleep deprived states and accentuated in the sleep deprived state. Time-of-day effects waxed and waned in a twenty-four hour rhythm in harmony with the 24-hour circadian rhythm in temperature (see Figure 6). Time-awake effects were apparent after multiple hours awake. Time-on-task effects were reversed by a break from the task, a simple rest without sleep. Time-of-day effects were reversed by passing to a different phase of the circadian cycle. Time-awake effects were reversed only by sleep (not shown). Figure 1 illustrates clearly the interacting effects of time awake, time of day, and time on task.

Sleep/wake history (time awake)

Sleep is divided into two distinct phases – Non-Rapid-Eye-Movement (NREM) sleep and Rapid-Eye-Movement (REM) sleep. These alternate throughout the sleep period with a 90-110 minute periodicity. Despite this complex structure, it is the simple sum of total sleep time (NREM plus REM) that determines recuperation (Wesensten, Balkin, and Belenky, 1999). Sleep loss degrades performance, and sleep restores it. At the level of brain neurobiology, how sleep loss degrades performance and how sleep restores it are the focus of intense research. These questions remain fundamental mysteries in neurobiology.

Sleep loss (sleep deprivation and sleep restriction) degrade performance over time. Total sleep deprivation degrades performance by 17-25% for each successive 24-hours awake in a relatively linear fashion modulated by the circadian rhythm (Thorne et al, 1983; Thomas et al., 2000) (see Figures 2 & 3). Sleep restriction degrades performance in a sleep-dose dependent manner (Belenky, et al., 2003; Van Dongen, et al., 2003) (see Figure 4). Even mild sleep restriction (decreasing time in bed from 8 to 7 hours each night for an actual loss of 40 minutes of sleep/night) degrades performance over days (Belenky, et al., 2003) (see Figure 4). As in total sleep deprivation (see Figure 1), chronic sleep restriction enhances time-on-task effects (Belenky, et al., in preparation) (See Figure 5).

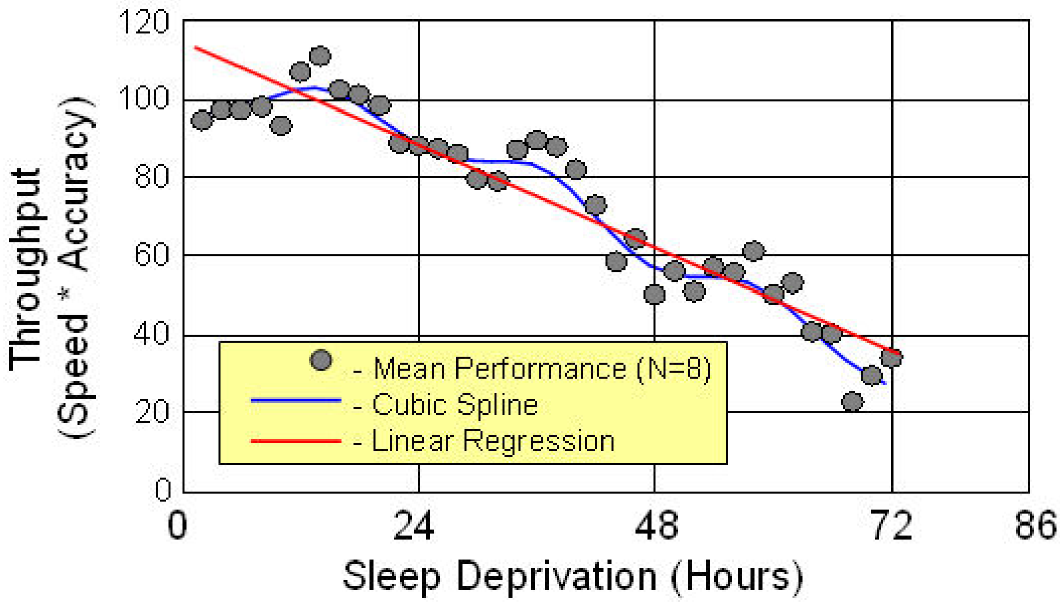

Figure 2 - Effect of 72 hours of total sleep deprivation on performance (adapted from Thorne et al., 1985).

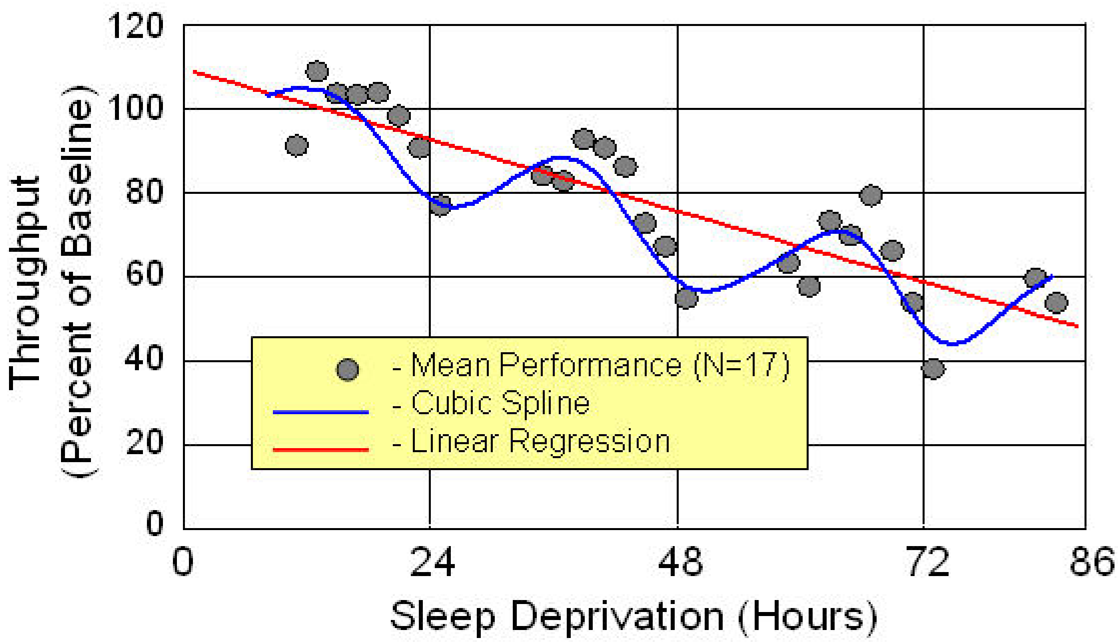

Figure 3 - Effect of 85 hours of total sleep deprivation on performance (adapted from Thomas, et al., 2000)

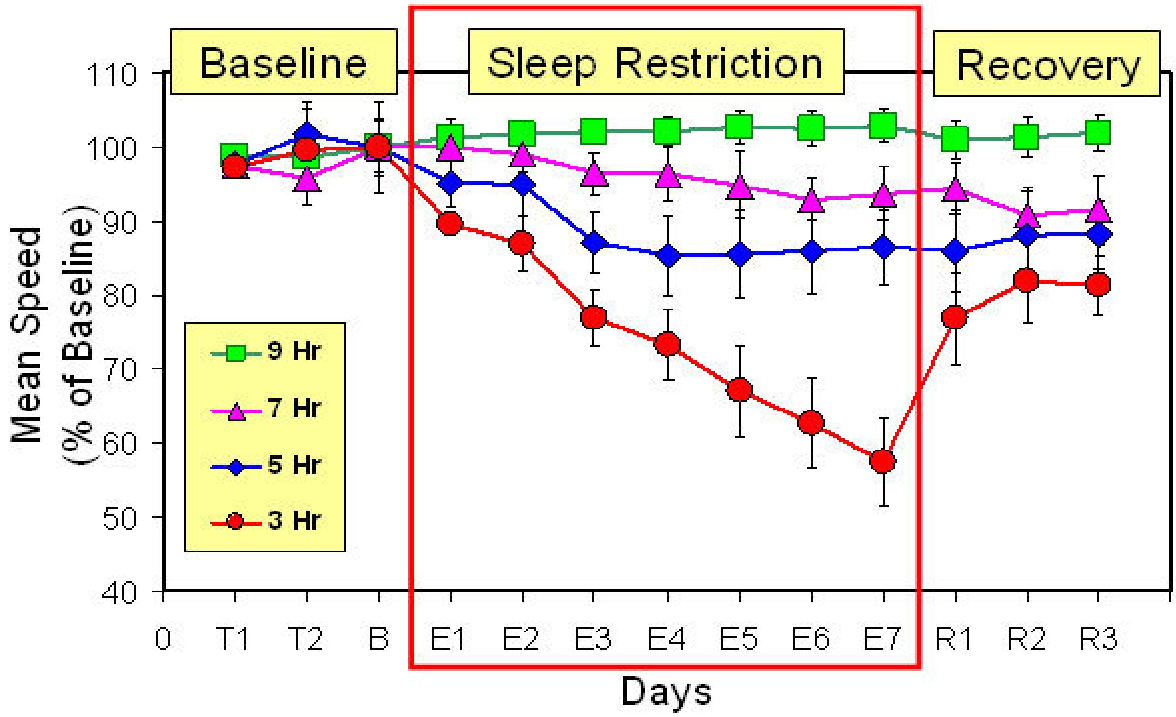

Figure 4 - Effect of mild, moderate, and severe sleep restriction (3, 5 or 7 hours vs. 9 hours time in bed each day) over 7 days on performance (adapted from Belenky, et al., 2003).

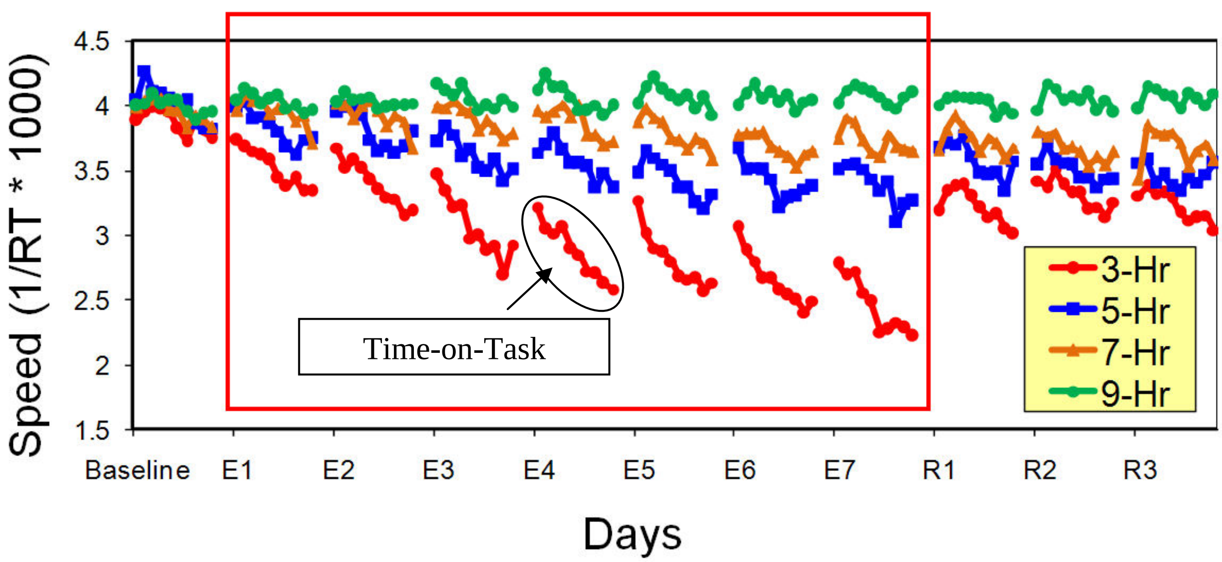

Figure 5 - Effect of mild, moderate, and severe sleep restriction (3, 5 or 7 hours vs. 9 hours time in bed) over 7 days on time-on-task effects (adapted from Belenky, et al., in preparation).

Circadian phase (time of day)

Time of day (circadian rhythm) modulates core body temperature, sleep propensity, and performance in a sine-wave shaped, approximately 24-hour, rhythm (Kryger, Roth, and Dement, 2005) (See Figure 6). The circadian rhythm is set by light exposure. This is mediated by the light sensitive ganglion cells in the retina and the suprachiasmatic nucleus deep in the brain. Core body temperature peaks at approximately 2000 hrs. It then begins to fall reaching its minimum between 0400 hrs and 0600 hrs. It then begins to rise across the day, peaking again in mid-evening. Sleep propensity follows body temperature. Sleep propensity decreases as body temperature increases and increases as body temperature decreases. Thus sleep propensity is highest between 0400 hrs and 0600 hrs and lowest in the early to mid-evening. There is a small increase in sleep propensity in the late afternoon making this a favorable time for a nap. The time during which body temperature increases and peaks in the early to mid-evening has been described as a forbidden zone for sleep (Lavie, 1986). Performance follows core body temperature with an approximately two-hour lag. Thus performance is lowest between 0600 and 0800 hrs and peaks at approximately 2200 hrs. Performance and sleep propensity are thus near-mirror opposites. Just as performance peaks in the early to mid-evening, it is very difficult for an adult to fall asleep then. For a person synchronized to the local time zone, it is almost impossible to fall asleep before approximately 2200 hrs unless suffering from moderate to severe sleep loss.

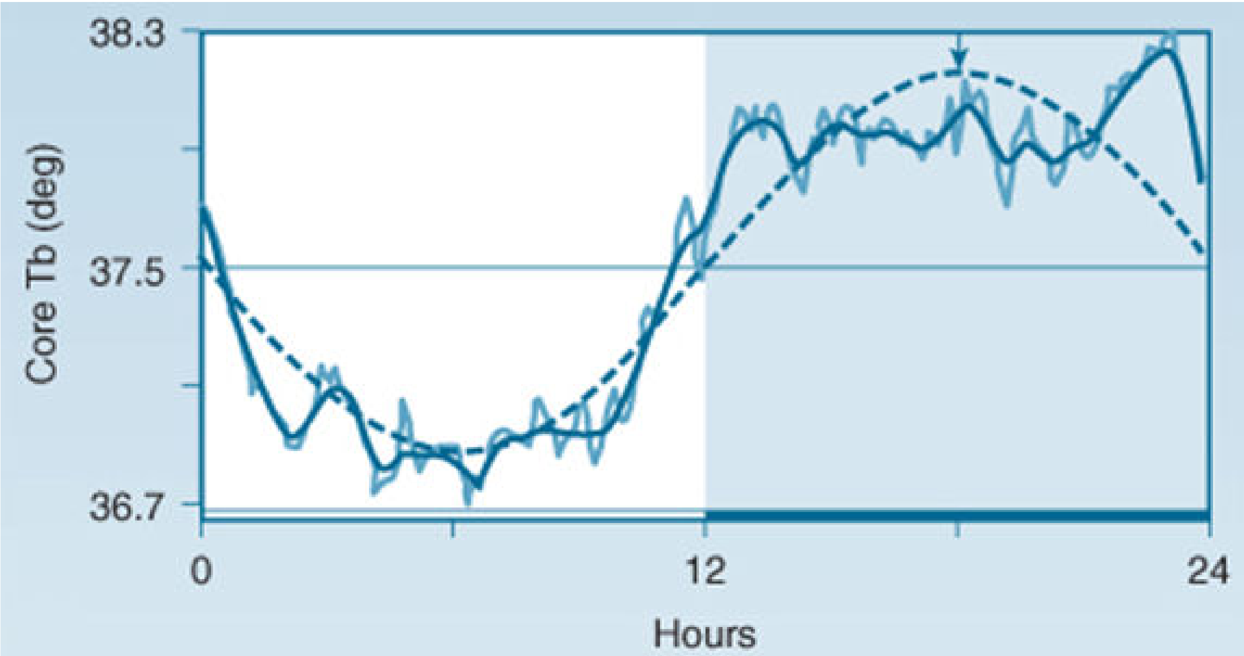

Figure 6 - The 24-hour circadian rhythm in body temperature (taken from Kryger, Roth, and Dement, 2005).

Time spent performing the same task (time on task)

Beginning in the 1930s, time-on-task effects have been well-studied in the context of manufacturing and office work (e.g., Bills, 1937). Only recently have time-on-task effects been studied in the context of sleep loss and circadian phase (e.g., Wesensten, et al., 2004) (see Figure 1 and attendant textual explanation). From Figure 1, we can see that accumulating total sleep deprivation modulated by the circadian rhythm progressively increased time-on-task effects. It is tempting to speculate that sleep loss degrades performance by increasing sensitivity to time on task.

Fatigue and complex performance

Sleep loss (total sleep deprivation and sleep restriction) degrades performance across the board from simple reaction time to complex cognitive performance (Harrison and Horne, 1998; Durmer and Dinges, 2005; Wesensten, Belenky, and Balkin, 2005; Kilgore et al., 2006). In total sleep deprivation and chronic sleep restriction, complex cognitive task performance, to include accurate, dynamically changing situational awareness and avoidance of "plan continuation" (Dekker, 2006), appears to degrade more than simple task performance (Harrison and Horne, 1998; Wesensten, Belenky, and Balkin, 2005). In military operations, this is the source of at least some friendly fire incidents as in sleep loss the ability to put cross hairs on the target (simple task) is preserved while the ability to distinguish friend from foe under the ambiguous, rapidly changing conditions of a firefight is lost (complex task) (Wesensten, Belenky, and Balkin, 2005). Avoiding "plan continuation" requires being able to perceive in real-time when reality is diverging from plan. Complex cognitive operations including avoiding "plan continuation" are based in discrete brain areas including the prefrontal cortex and parietal association areas (Thomas, et al., 2000). The sleep loss-related increase in propensity to "plan continuation" appears to be correlated with decreased brain energy metabolism as twenty-four hours of total sleep deprivation decreases brain energy metabolism by 6% globally and by 12-14% in the prefrontal cortex and parietal association areas (Thomas et al, 2000) (see Figure 7).

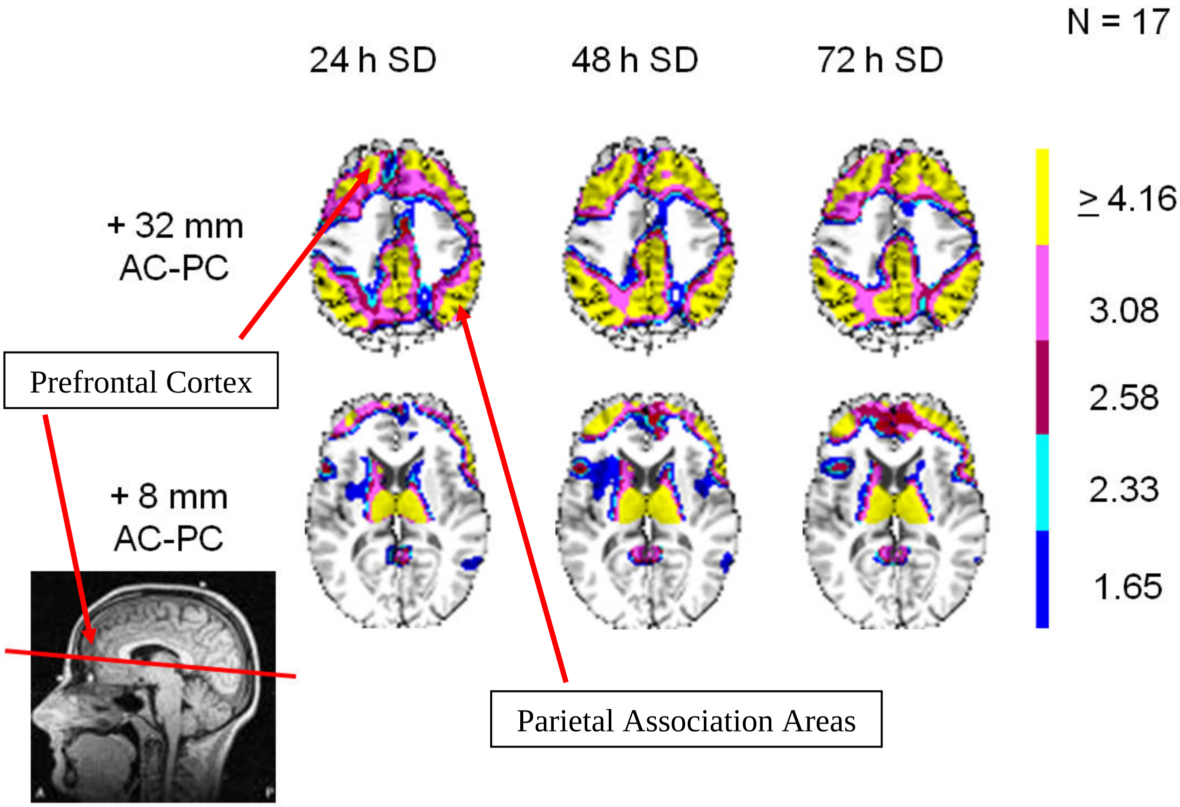

Figure 7 - Effect of 24 hours of sleep deprivation on brain energy metabolism during complex task performance (color scale indicates decrease from rested condition) (adapted from Thomas, et al., 2000).

Thus, we see greater degradation of complex task performance in sleep loss coupled with larger decreases in brain energy metabolism in brain areas enabling complex task performance and avoidance of "plan continuation." From the studies cited above and the example given below, we can see that sleep loss effects on performance are not restricted to simple tasks and interruptions in task performance from overtly falling asleep. Rather, we see clear evidence - both experimental and anecdotal - of sleep loss causing failures in complex cognitive operations in people who are awake, even wide-awake, and striving to perform well. In this situation, persevering (adaptive performance, trying multiple alternative solutions until met with success) transitions into perseveration (repeating the same failed performance over and over). Subjectively, in both perseverance and perseveration people feel that they are exerting effort and trying to solve the problem presented.

An anecdotal example of this is the crash at Guantanamo Bay, Cuba of American International Airways Flight 808 on 18 August 1993 (NTSB, 1994). In this accident, all three of the flight crew – accident captain (CPT), first officer (FO), and engineer – had been without sleep for at least 24 hours. They decided to try the difficult approach to Guantanamo for the experience. The accident CPT, despite clear and increasingly direct warnings from the accident FO and engineer, perseverated in trying to find a navigation beacon (the strobe light marking the border of U.S. and Cuban airspace), neglected to aviate, and stalled the aircraft. This perseveration on an irrelevant problem is typical of fatigue-related "plan continuation" and consistent with findings from brain imaging studies (described above) that sleep loss selectively deactivates brain areas subserving complex cognitive tasks. The CVR recording clearly shows this perseveration (see Table 1).

Table 1 - CVR recording from American International Airways Flight 808.

Engineer:	*Slow, Airspeed*
Co-Pilot:	*Check the turn.*
Captain:	***Where's the strobe?***
Co-Pilot:	*Right over here.*
Captain:	***Where?***
Co-Pilot:	*Right inside there, right inside there.*
Engineer:	*You know, we're not getting' our airspeed back there.*
Captain:	***Where is the strobe?***
Co-Pilot:	*Right down there.*
Captain:	***I still don't see it.***
Engineer:	*#, we're never goin' to make this.*
Captain:	***Where do you see a strobe light?***
Co-Pilot:	*Right over here.*
Captain:	*Gear, gear down, spoilers armed.*
Engineer:	*Gear down, three green spoilers, flaps, checklist*
???:	*There you go, right there, lookin' good.*
Captain:	***Where's the strobe?***
Co-Pilot:	*Do you think you are going to make this?*
Captain:	***Yeah… if I can catch the strobe light.***
Co-Pilot:	*500, you're in good shape.*
Engineer:	*Watch the, keep your airspeed up.*
Co-Pilot:	*140. [sound of stall warning]*
???:	*Don't – stall warning.*
Captain:	***I got it.***
Co-Pilot:	*Stall warning.*
Engineer:	*Stall Warning*
Captain:	***I got it, back off.***
???:	*Max power!*
???:	*There it goes, there it goes!*
???:	*Oh no!*

Fatigue risk management

Fatigue risk management seeks to develop a multi-layer, defense-in-depth against fatigue-related error, incident, and accident (Reason, 1997). Through this multi-layered defense-in-depth it seeks to minimize the impact on performance of time awake, time of day, and time on task (Dawson and McCulloch, 2005).

In its basic form, fatigue risk management has three layers of defense (Dawson and McCulloch, 2005). The first layer of defense evaluates shift timing and duration to determine if there is adequate opportunity for sleep both in terms of duration of time off and in terms of placement of time off at a sleep-conducive circadian phase. The second layer determines to what degree scheduled-personnel take advantage of the opportunity and get sleep. The third layer determines, given sleep opportunity and sleep-obtained, how well personnel are performing while on-duty and whether or not they show fatigue-related behaviors and performance impairment. Below, we analyze the performance and behavior of the accident CPT, FO, and ATC with respect to these three layers of fatigue risk management.

Fatigue Analysis of Comair 5191

Personnel with Clear Chances to Avoid the Accident

There were three people on the morning of 27 August who had clear chances to prevent the accident. These were the accident Captain (CPT), First Officer (FO), and Air Traffic Controller (ATC). At various times from the point that the flight crew boarded the aircraft to just before the accident, singly and collectively, the accident CPT, FO, and ATC could have developed a more accurate understanding of the aircraft's true position and projected path. This would have given them the opportunity to take corrective action and prevent the flight from taking off from the wrong runway. There was a similar incident in 1993 in which an aircraft held short of runway 26 instead of runway 22 (the active runway). In that incident both the CPT and the FO and the ATC realized the mistake prior to the take off roll.

Sleep/Work Schedules for the 96 Hours Prior to the Accident

We estimated sleep/work schedules for the 96 hours prior to the accident for the accident from the data contained in the NTSB factual reports. These estimates are displayed in Table 2.

Captain	Wednesday 23rd	Thursday 24th	Friday 25th	Saturday 26th	Sunday 27th
Beginning location	Eastern time zone	Eastern time zone	Eastern time zone	Central time zone	Eastern time zone
Awoke	Around 0800 EDT	Around 0630 EDT	Around 0615 EDT	Around 0500 CDT (0600 EDT)	Around 0430 EDT
Started work	Off work, at home	Off work, at home	Reported 0800 EDT	Reported 0530 CDT (0630 EDT)	Reported 0500 EDT
Ended work	Off work, at home	Off work, at home	Released 1926 CDT (2026 EDT)	Released 1546 EDT	ACCIDENT @ 0606 EDT
Ending location	Eastern time zone	Eastern time zone	Central time zone	Eastern time zone	-
Bedtime	Assumed 2300 EDT	Assumed 2300 EDT	Assumed 2230 CDT (2330 EDT)	Assumed 2230 CDT (2330 EDT)	-

First Officer	All Times EDT Wednesday 23rd	Thursday 24th	Friday 25th	Saturday 26th	Sunday 27th
Beginning location	Eastern time zone	Eastern time zone	Eastern time zone	Eastern time zone	Eastern time zone
Awoke	Assumed 0700	Assumed 0700	Assumed 0500 Possible nap 0830 to 0930	Assumed 1000	Around 0430
Started work	Off work, at home	Off work, at home	Reported 1150	Off work, at hotel	Reported 0500
Ended work	Off work, at home	Off work, at home	Released 0200	Off work, at hotel	ACCIDENT @ 0606
Ending location	Eastern time zone	Eastern time zone	Eastern time zone	Eastern time zone	-
Bedtime	Assumed 2300	Assumed 2300	Assumed 0230	Around 2230 Interupted at 0100 for short phone call	-

Air Traffic Controller	All Times EDT Wednesday 23rd	Thursday 24th	Friday 25th	Saturday 26th	Sunday 27th
Awoke	Assumed 0800	Assumed 1000	Assumed 0700	0540	-
Started work	1700	1500	0800	0630	-
Ended work	0100	2200	1600	1430 Nap from 1530 to 1730	ACCIDENT @ 0606
Bedtime	Assumed 0200	Assumed 2300	Assumed 2200	Reported 2330	-

Table 2 - Estimated sleep schedules for the accident CPT, FO, and ATC.

Qualitative Effects of Sleep/Work Schedules on Performance

From our reconstruction of the sleep/work schedules of the accident CPT, FO, and ATC, it appears all three were both sleep restricted and at the low point in their circadian rhythm in performance at the time of the accident. Both would impair overall performance and in particular the ability to be proactive in developing, correcting, and communicating an accurate situational awareness and would foster plan continuation, that is impair the ability to abandon erroneous courses of action.

From our sleep/work history reconstruction, we estimate that the accident CPT went to bed at approximately 2230 hrs EDT on Saturday, 26 August and awoke at 0430 EDT on Sunday, 27 August, the morning of the accident. This yields a maximum sleep opportunity of 6 hours of which we would expect that he actually slept about 5.5 hours. This is a less than optimal amount of sleep, and, by any definition, the CPT was sleep restricted at the time of the accident. Such sleep-truncation is not uncommon for personnel working early morning shifts. As the accident CPT's circadian rhythm was synchronized to EDT, his body temperature would not have begun falling until after 2200 EDT the night before, making sleep before 2200 hours unlikely. Continuing this circadian rhythm analysis, his low point in body temperature would have been between 0400 hrs EDT and 0600 hrs EDT and his low point in performance would have been between 0600 hrs EDT and 0800 hrs EDT. Thus, at the time of the accident and for the 30 minutes preceding, the accident CPT's performance would likely be impaired as a result of sleep restriction and adverse circadian phase.

Applying a similar analysis to the accident FO, it appears reasonable that his sleep schedule was approximately the same at the accident CPT's the night before the accident. Thus, at the time of the accident and for the 30 minutes preceding, the accident FO's performance would likely be impaired as a result of sleep restriction and adverse circadian phase.

The accident ATC was at end of a shift schedule that involved two afternoon-shifts, two day-shifts, and one night shift, all within a consecutive 5-day period. This is called a 2-2-1 rotation. There is research indicating that the 2-2-1 rotation disrupts the sleep/wake cycle and degrades performance during the latter part of the single night shift (studies reviewed by Koenig, 1997). On Saturday, 26 August, the day before the accident, the accident ATC worked the second of his day shifts. This was an early day shift (0630 hrs EDT to 1430 hrs EDT). We estimate that the accident ATC went to bed at 2200 hrs EDT the night before (Friday) and we know that he awoke up the following morning at 0540 hrs EDT. He had a sleep opportunity of 7 hours and 40 minutes of which we estimate that he slept 7 hours and 10 minutes. This represents mild sleep restriction. The accident ATC went on duty at 0630 hours EDT and worked until 1430 hours EDT at which time he began a 9-hour off-duty period. The accident ATC reported being able to nap during that period for approximately 2 hours from 1530 hrs EDT to 1730 hrs EDT. To obtain this nap, the accident ATC took advantage of the small increase in circadian sleep propensity that occurs in the late afternoon. From his self-report, he slept until physiologically his body temperature resumed its rise toward peak levels at which point he awoke spontaneously and would be very unlikely to fall back asleep as he was entering the period in the early to mid-evening that has been termed the forbidden zone for sleep (Lavie, 1986). The accident ATC went back on duty at 2330 hrs EDT and worked through to the accident at 0606 hrs EDT. He worked this shift moderately sleep-restricted and worked through his circadian low in temperature and into his circadian low in performance. Thus, at the time of the accident and for the 30 minutes preceding, the accident ATC's performance would likely be impaired as a result of sleep restriction and adverse circadian phase. Given the placement of the accident ATC's 9-hours off with respect to circadian phase (overlapping as it did the circadian forbidden zone for sleep), it is probable that the 2-hour nap the accident ATC obtained was near the maximum possible during the 9-hours he had of off-duty. Thus the accident ATC made good, conscientious use of his off duty time to get what sleep was possible.

Because of incomplete data, we were not always able to determine the exact timing of sleep and wakefulness of the accident CPT, FO, and ATC. Where sleep/wake times were unknown, we made reasonable estimates, leaning in the direction of best case. It is worth noting that the accident CPT, FO, and ATC all obtained close to the maximum sleep possible given the sleep opportunities available. Bear in mind that because of adverse circadian phase, their sleep opportunities were limited in the evening by the circadian peak in temperature and in the morning by the early start time.

With respect to time on task effects, the accident CPT, FO, and ATC were subject to moderate-to-high workloads during the 30 minutes preceding the accident. The CPT was immersed in checklists and taxiing, the FO in check lists and then the take off roll, and the ATC in controlling aircraft. Since time on task effects can emerge in less than 10 minutes of continuous work and are amplified by sleep deprivation and sleep restriction and adverse circadian phase (Wesensten, et al., 2004) (see Figure 1), it is likely that time-on-task effects contributed to the failure of all three to trap the runway error. Independent of time on task effects, the high workload, in itself, left them little time to realize their error.

To summarize, during the 30 minutes preceding the accident, the accident CPT, FO, and ATC were all sleep-restricted and working near their circadian low in performance. They were working at moderate to high tempo during this period and thus it is likely that time on task effects were operative as well. The erroneous situational awareness that persisted well into the take off roll was likely enabled by multiple factors including the effects of time awake, time of day, and time on task.

Effects of Sleep/Work Schedules on Performance Estimated using Mathematical Models Predicting Performance

Of the available mathematical models using sleep wake history and estimated circadian phase to predict performance, the Sleep, Activity, Fatigue, and Task Effectiveness Model / Fatigue Avoidance Scheduling Tool (SAFTE™/ FAST™) appears to be one of the better validated ones (Van Dongen, 2004; Hursh et al., 2004a; 2004b; 2006). Using SAFTE/FAST, we obtained performance predictions based on the 96-hour estimated sleep/wake history and circadian phase for the 30 minutes preceding the accident for the accident CPT, FO, and ATC. It is worth noting that neither SAFTE/FAST nor other extant commercially available models takes into account time on task effects. The model yielded numerical predictions of performance for the accident CPT, FO, and ATC. The predictions for each are depicted graphically in Figures 8, 9, and 10. The SAFTE/FAST model overlays green, yellow, and red bands across its performance predictions to indicate safe, questionable, and unsafe levels of performance. Blue bars at the bottom of each plot indicate sleep periods, red bars indicate on duty periods. As can be seen from the figure, the accident CPT, FO, and ATC were all in the yellow (questionable) zone of performance at the time of the accident. The accident CPT and FO were in the upper portion of the yellow (questionable) performance band and the ATC was in the lower part of the yellow (questionable) performance band. The ATC was almost in the red performance band. Thus, using a validated mathematical model (SAFTE/FAST) predicting performance, we found that for the accident CPT, FO, and ATC we would expect their performance to be mildly to moderately impaired by sleep loss and adverse circadian phase at the time of the accident. For reference, an effectiveness level of 70% is equivalent of a blood alcohol level of 0.08 g/100mL or 21 hours of continuous wakefulness (Hursh, et al., 2006).

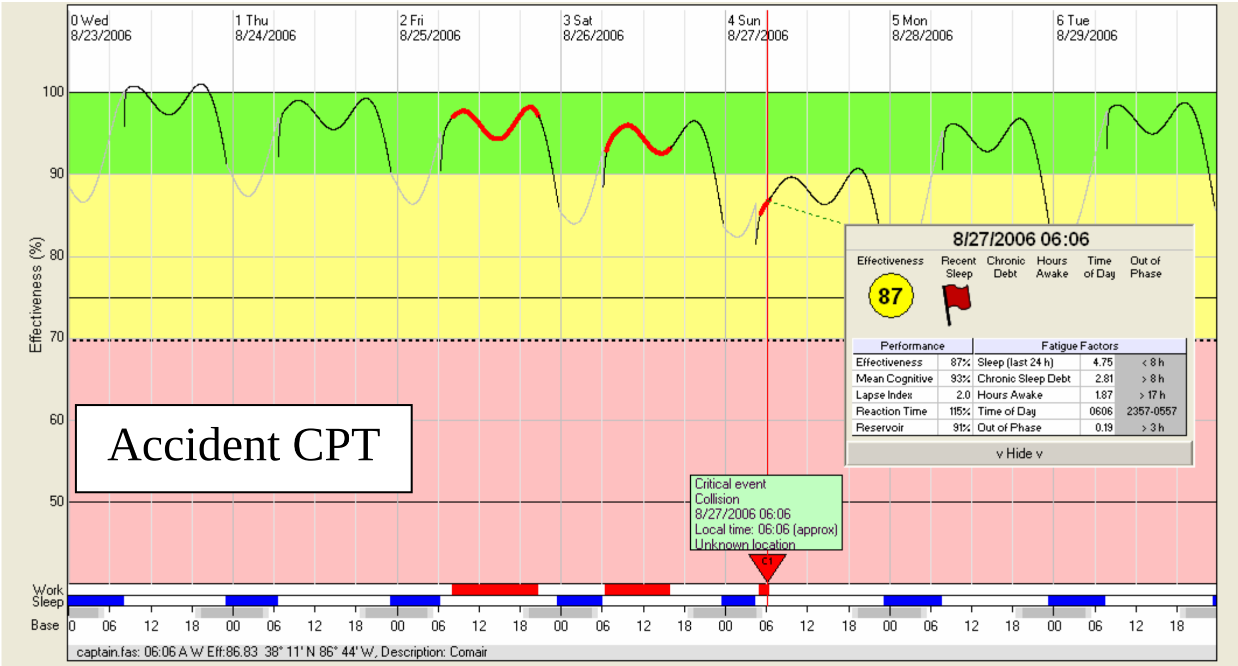

Figure 8 - Performance prediction for accident CPT based on estimated sleep/wake schedule and circadian phase using the SAFTE/FAST model (courtesy of S.R. Hursh)

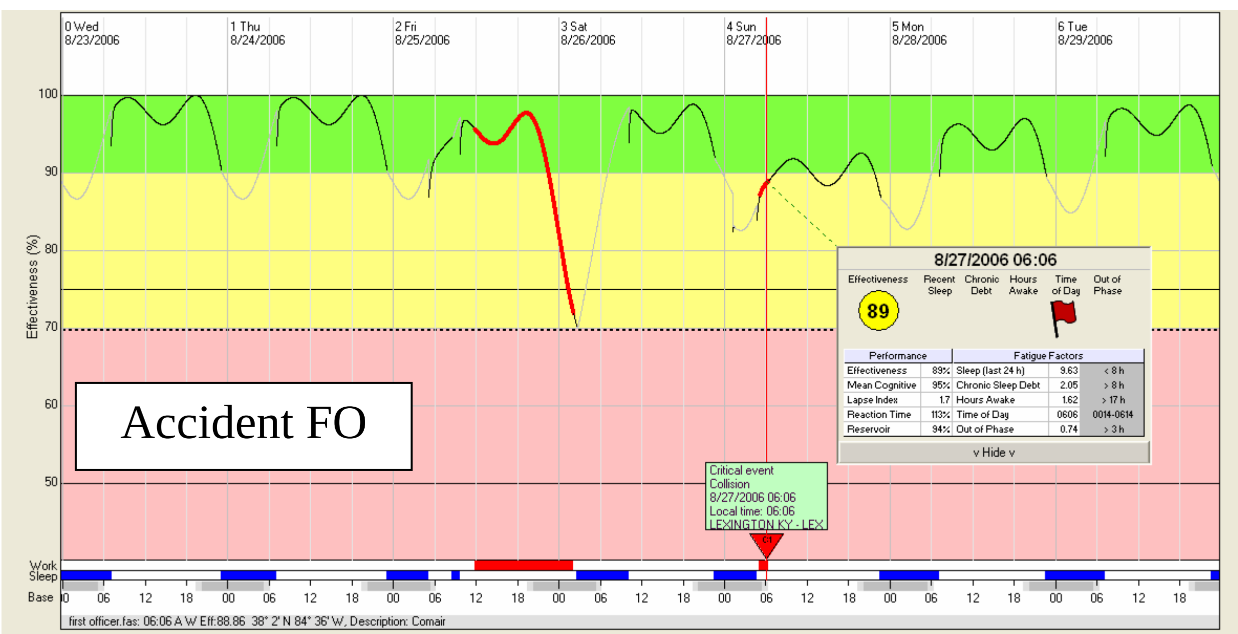

Figure 9 - Performance prediction for accident FO based on estimated sleep/wake schedule and circadian phase using the SAFTE/FAST model (courtesy of S.R. Hursh).

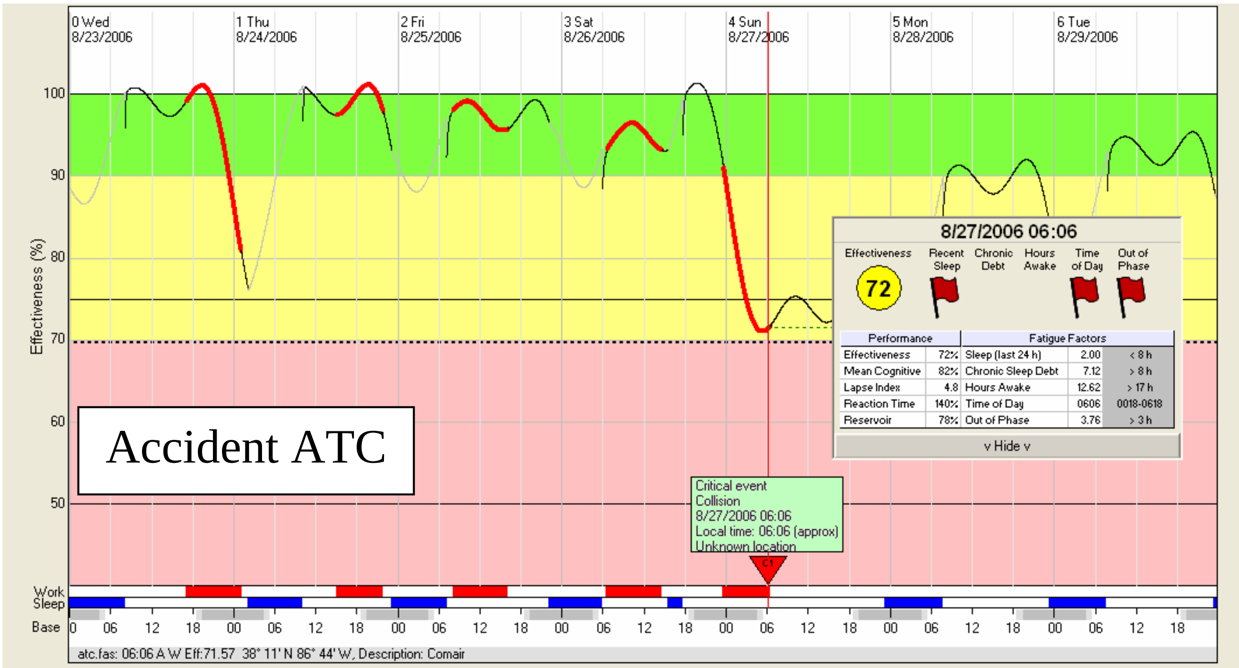

Figure 10 - Performance prediction for accident ATC based on estimated sleep/wake schedule and circadian phase using the SAFTE/FAST model (courtesy of S.R. Hursh).

Evidence of Fatigue-Related Behaviors from the CVR and Interviews of Accident-Relevant Personnel

We found evidence of fatigue-related errors and fatigue-related behaviors for the accident CPT and FO in the CVR transcript and in the NTSB factual summaries. Table 3 list the errors identified during the 30 minutes preceding the accident for both the accident CPT and FO.

Time	Errors	Crewmember	Category of Error	Crew Response
05:20:00	Crews initially powers up wrong aircraft	Crew	Procedural	Trapped error
05:38:04	Checklist item read incorrectly	Captain	Procedural	Failed to respond
05:45:44	Checklist item read incorrectly	Captain	Procedural	Failed to respond
05:50:06	Missed part of ATC clearance	First Officer	Communication	Trapped error
05:51:29	Alternate is incorrectly declared acceptable	Captain	Procedural	Failed to respond
05:53:27	Cockpit PA switch left on	Captain	Procedural	Trapped error
05:56:14	Crew briefing to first officer incomplete	Captain	Procedural	Failed to respond
05:56:25	Reduced thrust briefed, normal thrust set	Crew	Procedural	Failed to respond
05:56:34	Takeoff briefing to captain incomplete	First Officer	Procedural	Failed to respond
05:57:23	First Officer provides taxi briefing	First Officer	Intentional non-compliance	Failed to respond
05:57:23	Taxi briefing to captain incomplete	First Officer	Procedural	Failed to respond
05:57:39	Captain calls item on checklist complete before it was done	Captain	Procedural	Trapped error
05:57:40	Checklist item read incorrectly	First Officer	Procedural	Failed to respond
05:57:50	Flight attendant doesn't receive a briefing until requesting	Captain	Procedural	Failed to respond
05:57:50	Crew briefing to flight attendant incomplete	Captain	Procedural	Failed to respond
05:58:12	Crew misses checklist item	Crew	Procedural	Failed to respond
05:58:12	Crew never calls checklist complete	Crew	Procedural	Failed to respond
05:58:17	Wrong checklist begun	First Officer	Communication	Trapped error
06:01:50	Checklist item read incorrectly	First Officer	Procedural	Trapped error
06:02:00	Wrong checklist read complete	First Officer	Procedural	Failed to respond
06:02:28	Radar briefed off but is turned on	First Officer	Procedural	Failed to respond
06:03:12	Non-standard call for checklist	Captain	Procedural	Failed to respond
06:03:16	Violation of sterile cockpit	First Officer	Intentional non-compliance	Failed to respond
06:03:29	Violation of sterile cockpit	First Officer	Intentional non-compliance	Failed to respond
06:03:35	Violation of sterile cockpit	First Officer	Intentional non-compliance	Failed to respond
06:03:37	Violation of sterile cockpit	First Officer	Intentional non-compliance	Failed to respond
06:03:49	Violation of sterile cockpit	First Officer	Intentional non-compliance	Failed to respond
06:03:54	Violation of sterile cockpit	Captain	Intentional non-compliance	Failed to respond
06:04:05	Checklist item read incorrectly	First Officer	Procedural	Failed to respond
06:04:13	Checklist item read incorrectly	First Officer	Procedural	Failed to respond
06:04:59	Unknown error with extra CAS item	Unknown	Procedural	Trapped
06:05:15	Wrong flight number used	First Officer	Communication	Failed to respond
06:05:46	Checklist item read incorrectly	First Officer	Procedural	Failed to respond
06:06:16	Violation of sterile cockpit	First Officer	Intentional non-compliance	Failed to respond

Table 3 - Fatigue-related errors and behaviors in the accident CPT and FO.

The accident CPT and FO initially boarded the wrong aircraft and had powered it up when they were notified by the ground crew of their error. Once on-board the correct aircraft, the accident CPT and FO made a number of procedural errors. Examples of these include omissions of checklist items, incorrect reading of checklists, and incomplete briefings. Although most of these errors probably did not contribute directly to the accident, one of these errors that could have contributed was the inadequate, incomplete taxi briefing. This briefing normally done by the CPT was for reasons that were not apparent done by the accident FO and was both non-specific and incomplete. For example, the accident FO limited his description of the taxi route to "taxi instructions with ATC" and "Alpha 22's a short taxi" and in addition did not brief the runway to be crossed. Choosing the incorrect runway is at the heart of this accident. It is reasonable to think that the non-specific and incomplete taxi briefing contributed to this. With respect to fatigue-related behaviors, the accident FO yawned twice (both just after 0603 hrs EDT) and breached sterile cockpit procedures on five occasions (between 0603 and 0604 hrs EDT) and the accident CPT breached sterile cockpit procedures on one occasion (06:03:54). Though with the possible exception of the taxi briefing these fatigue-related errors and behaviors did not contribute directly to the accident, they are indicators of fatigue in both the accident CPT and FO. In our opinion, they signal the integrated toll on performance taken by time awake, time of day, and time on task on performance during the 30 minutes preceding the accident.

We found evidence of fatigue-related errors and fatigue-related behaviors for the accident ATC in the NTSB ATC factual summary. Table 4 list the errors identified during the 30 minutes preceding the accident for the accident ATC.

Event	Category
Failed to include local NOTAM A-1682 to ATISs Alpha and Bravo.	Procedural Error
Waited until known high workload period to perform administrative task.	Less-than-optimal response
Failed to notice aircraft had stopped at hold short for runway 26.	Less-than-optimal response
Failed to notice aircraft was holding at runway 26 when they requested takeoff clearance.	Less-than-optimal response
Failed to notice aircraft taking runway 26 after receiving takeoff clearance.	Less-than-optimal response
After hearing explosion, delay of 40-45 seconds before alerting ARFF.	Less-than-optimal response
Played no role in assisting ARFF with crash site location.	Less-than-optimal response

Table 4 - Errors and behavioral indicators of fatigue for the air traffic controller

When the accident ATC recorded the ATIS at 0455 EDT and 0555 EDT, he neglected to include the local NOTAM A-1682 describing the closed portion of Taxiway "A" north of runway 26. Other controllers in the days prior to the accident did include NOTAM A-1682 in their ATIS recording per policy. We note that accident ATC cleared Comair 5191 for takeoff while it was holding short of runway 26, the accident runway. In the process of clearing Comair 5191 for takeoff, the accident ATC did verify that runway 22 (the active runway) was clear as required but failed to observe that Comair 5191 was not holding short of runway 22 but rather was holding short of runway 26. After clearing Comair 5191 for takeoff, the accident ATC turned his attention first to another aircraft and then to his traffic counts, a time-insensitive administrative task. He continued doing his counts until he heard the explosion of the crash. Had he not turned his attention to doing traffic counts, he might have detected the runway error. Once he heard the crash, it took the accident ATC 40-45 seconds to telephone airport rescue and firefighting (ARFF). Once he notified ARFF, he turned to administrative tasks related to crash notification rather than assist in guiding the ARFF vehicles to the crash site. Such errors of omission, failure to proactively manage work-load, slowed response times, and inappropriate responses are typical fatigue-related behaviors (Banderet, et al., 1981).

Discussion

We collected information to enable us to analyze the crash of Comair 5191 within the context of fatigue risk management. Taking the first three layers of fatigue risk management as articulated by Dawson and McCulloch (2005), we ask three fatigue-related questions. First, did the accident CPT, FO, and ATC have adequate opportunity for sleep? Second, did they make use of the opportunities they had? Third, given the opportunities and the use they made of them, did they show evidence of fatigue-related errors and other fatigue-related behaviors during the 30 minutes preceding the accident?

It seems clear that the accident CPT, FO, and ATC had less than adequate opportunity for sleep the night before the accident. For both the accident CPT and FO sleep opportunity was truncated at both ends – by the circadian rise in core body temperature in early to mid-evening preventing sleep much before 2200 hours and by the early start the next morning. For the accident ATC, sleep opportunity was limited to 1-3 hours in the late afternoon again as the circadian rise in core body temperature in the early to mid-evening prevented him from extending his nap beyond the late afternoon. Once he went on duty at 2330, he remained awake until the accident at 0606 hours. It is also clear that all three made nearly maximal use of the sleep opportunity they did have. The accident CPT and FO probably slept from a bit after 2200 hours until they woke up around 0430 hrs. The accident ATC was able to obtain a 2-hour nap during the mini-circadian low in the late afternoon. It also seems clear both from the mathematical modeling and from our analysis of the CVR transcript and the NTSB factual summaries that all three were by the modeling likely to be impaired and by the CVR transcript and factual summaries made fatigue-related errors and showed fatigue-related behaviors during the 30 minutes preceding the accident. Thus, our analysis within the fatigue risk management framework suggests that for the accident CPT, FO, and ATC: 1) they did not have adequate opportunity for sleep; 2) they made maximum use of this the less-than-optimum opportunity they had; and 3) despite making maximum use of this less-than-optimum opportunity, they showed evidence of fatigue in the 30 minutes prior to the accident. We note also that with the short taxi, task load for the accident CPT and FO from checklists during the taxi was high. The information gathered in the investigation seems to indicate that "plan continuation" a consequence of sleep loss possibly mediated by decreases in regional brain energy metabolism and brain activation played a significant role in this event.

Conclusion

Fatigue resulting from time awake, time of day, and time on task likely played a role in the crash of Comair 5191. It is worth noting that all three of the personnel discussed in this analysis, the accident CPT, FO, and ATC, made nearly optimal use of the sleep opportunities given to them. The fact that their sleep opportunities were inadequate is a function of the mismatch between the schedules they were asked to work and the imperatives of human physiology.

References

Banderet, L.E., Stokes, J.W., Francesconi, R., Kowal, D.M., Naitoh, P. (1981) Artillery teams in simulated sustained combat: Performance and other measures. pp. 581-604 in DHHS (Department of Health and Human Services) *NIOSH (National Institute for Occupational Safety and Health) Report 81-127: The Twenty-Four Hour Workday: Proceedings of a Symposium on Variations in Work-Sleep Schedules,* L.C. Johnson, D.I. Tepas, W.P. Colquhon & M.J. Colligan, eds. Washington, DC: Government Printing Office

Belenky, G., Wesensten, N.J., Thorne, D.R., Thomas, M.L., Sing, H.C., Redmond, D.P., Russo, B.M., Balkin, T.J. (2003) Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. *J. Sleep Res.*, 12, 1-13.

Belenky, G., Wesensten, N.J., Van Dongen, H.P.A., & Balkin, T.J. (in preparation) Time-on-task effects in chronic sleep restriction.

Bills, A.J. (1937). Fatigue in mental work. *Physiological Reviews*, 17, 3, 436-54.

Dawson, D. & McCulloch, K. (2005) Managing fatigue: Its about sleep. *Sleep Med Rev*, 9, 5, 365-80.

Durmer, J.S. & Dinges, D.F. (2005) Neurocognitive consequences of sleep deprivation. *Semin Neurol*, 25, 117-29.

Harrison, Y. & Horne, J.A. (2000) The impact of sleep deprivation on decision making: A review. *J Exp Psychol Appl*, 6, 3, 236-49.

Kilgore, W.D., Balkin, T.J., Wesensten, N.J. (2006) Impaired decision making following 49h of sleep deprivation. *J Sleep Res*, 14, 3, 255-66.

National Transportation Safety Board (NTSB). (1993). *Aircraft accident report—uncontrolled collision with terrain, American International Airways flight 808, Douglas DC-8-61, N814CK, U.S. Naval Air Station, Guantanamo Bay, Cuba, August 18, 1993.* NTSB/AAR-94/04. Washington, DC: Author.

Mistleberger, R.E. & Rusak, B. (2005) Circadian rhythms in mammals: Formal properties and environmental influences. In M. Kryger, T. Roth, and W.C. Dement (Eds.), *Principles and practice of sleep medicine* (4th ed.), Philadelphia, PA: Elsevier Saunders.

Reason, J. (1997). *Managing the risks of organizational accidents*. Aldershot, England: Ashgate Publishing Ltd.

Dekker, S. (2006) *The Field Guide to Understanding Human Error.* Aldershot, England: Ashgate Publishing Ltd.

Koenig, R.L. (1997) Air traffic control counterclockwise rotating shift schedule appears to affect performance only on night shift. *Flight Safety Foundation: Airport Operations*, 23, 2, 1-7.

Hursh, S.R., Raslear, T.G., Kaye, A.S., and Fanzone, J.F. (2006) Validation and Calibration of a Fatigue Assessment Tool for Railroad Work Schedules, Summary Report, *U.S. Department of Transportation,* *Federal Railroad Administration, Office of Research and Development,* Washington, DC, Agency Report Number: DOT/FRA/ORD-06/21.

Hursh S.R., Balkin, T.J., Miller, J.C., & Eddy, D.R. (2004a) The fatigue avoidance scheduling tool: Modeling to minimize the effects of fatigue on cognitive performance. *SAE Transactions*, 113, 1, 111-119.

Hursh, S.R., Redmond, D.P., Johnson, M.L., Thorne, D.R., Belenky, G., Balkin, T.J., Storm, W.F., Miller, J.C., Eddy, D.R. (2004b). Fatigue models for applied research in warfighting. *Aviat Space Environ Med*, 75, 3, 44-53.

Lavie, P. (1986). Ultrashort sleep-waking schedule. III. 'Gates' and 'forbidden zones' for sleep. *Electroencephalogr Clin Neurophysiol*, 63, 5, 414-25.

Rosekind, M.R., Gander, P.H., Connell, L.J., & Co, E.L. (1999) Crew factors in flight operations X: Alertness management in flight operations. *National Aeronautics and Space Administration, Ames Research Center,* Moffett Field, California, Agency Report Number: NASA/TM-1999-208780.

Thomas, M L., Sing, H.C., Belenky, G., Holcomb, H.H., Mayberg, H.S., Dannals, R.F., Wagner, Jr., H.N., Thorne, D.R. Popp, K.A., Rowland, L.M., Welsh, A.B., Balwinski, S.M. & Redmond, D.P. (2000) Neural basis of alertness and cognitive performance impairments during sleepiness. I. Effects of 24 h of sleep deprivation on waking human regional brain activity. *J. Sleep Res*, 9, 335-352.

Thorne, D.R., Genser, S., Sing, H., Hegge, F. (1983) Plumbing human performance limits during 72 hours of high task load. In *Proceedings of the 24th DRG seminar on the human as a limiting element in military systems* (pp. 17– 40) Toronto, Canada: Defence and Civil Institute of Environmental Medicine (DCIEM).

Van Dongen HPA, Maislin G, Mullington JM, Dinges DF (2003). The cumulative cost of additional wakefulness: Dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep*, 26, 117–126.

Van Dongen, H.P.A. (2004) Comparison of mathematical model predictions to experimental data of fatigue and performance. *Aviat Space Environ Med*, 75, Supplement 1, A15-36.

Wesensten, N.J., Balkin, T.J., & Belenky G.L (1999) Does sleep framentation impact recuperation? A review and reanalysis. *J Sleep Res,* 8, 237-245.

Wesensten, N.J., Belenky, G., Thorne, D.R., Kautz, M.A., & Balkin, T.J. (2004) Modafinil versus caffeine: Effects on fatigue during sleep deprivation. *Aviat Space Environ Med,* 75, 520-525.

Wesensten, N.J., Belenky, G. & Balkin, T.J. (2005) Cognitive readiness in network centric operations. *Parameters: U.S. Army War College Quarterly, 35, 1, 94-105.*