FLIGHT SAFETY FOUNDATION

A Practical Guide for Improving Flight Path Monitoring

FINAL REPORT OF THE ACTIVE PILOT MONITORING WORKING GROUP

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Table of Contents

List of Figures

List of Tables

Acknowledgments

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Steven Dempsey
Co-Chair (Delta Air Lines)

Helena Reidemar
Co-Chair (Air Line Pilots Association, International)

Working Group Members

The WG membership consisted of representatives from industry, government and labor organizations.

Name	Organization
Kathy Abbott	U.S. Federal Aviation Administration
Rich Boll	U.S. National Business Aviation Association
Barbara Burian	U.S. National Aeronautics and Space Administration (NASA) Ames Research Center
Rudy Canto	Airbus
Doug Carr	U.S. National Business Aviation Association
Steve Dempsey	Delta Air Lines (Co-Chair)
Key Dismukes	NASA Ames Research Center (Retired)
Mark Draper	American Airlines
Mike Hayes	Delta Air Lines
Scott Foose	Regional Airline Association
Jim Gorman	FedEx (Retired)
Steve Guillian	JetBlue Airways
Osman Iftikhar	Delta Air Lines
Nat Iyengar	U.S. National Business Aviation Association
James Klinect	The LOSA Collaborative
Bob Lamond	U.S. National Business Aviation Association
Dave McKenney	International Federation of Air Line Pilots' Associations
Mark Millam	Airlines for America
Jay Pellicone	American Airlines
Rudy Quevedo	Flight Safety Foundation
Chris Reed	JetBlue Airways
Helena Reidemar	Air Line Pilots Association, International (Co-Chair)
Chris Sharber	United Airlines
Robert Sumwalt	U.S. National Transportation Safety Board
Steve Swauger	Southwest Airlines Pilots' Association
Ron Thomas	USAirways/American Airlines
Brian Ward	FedEx
Donata Ziedins	United Airlines

List of Abbreviations

AC	Advisory circular
ACARS	Aircraft communications addressing and reporting system
AQP	Advanced qualification program
AFCS	Automatic flight control system
ALPA	Air Line Pilots Association, International
AOV	Areas/area of vulnerability
APM	Active pilot monitoring
ALT	Altitude
ALT HOLD	Altitude hold
ASAP	Aviation safety action program
ASRS	Aviation Safety Reporting System
ATC	Air traffic control
A/T	Auto throttles (Boeing)
A/THR	Auto thrust (Airbus)
CA	Captain
CAMI	Confirm, activate, monitor, intervene
CAWS	Caution and warning system
CDU	Control display unit
CFIT	Controlled flight into terrain
CRM	Crew resource management
EFB	Electronic flight bag
EFPM	Effective flight path monitoring
FA	Flight attendant
FAA	U.S. Federal Aviation Administration
FCU	Flight control unit
FDM	Flight data monitoring
FGP	Flight guidance panel
FltDAWG	Flight Deck Automation Working Group
FMA	Flight mode annunciator
FMC	Flight management computer (Boeing)
FMGC	Flight management guidance computer
FMGS	Flight management guidance system (Airbus)
FMS[1]	Flight management system
FO	First officer
FOQA	Flight operational quality assurance
FPM	Flight path monitoring
FSF	Flight Safety Foundation
GP	Glareshield panel
HF	Human factors
ICAO	International Civil Aviation Organization
IFALPA	International Federation of Air Line Pilots' Associations
IOE	Initial operating experience
LOSA	Line operations safety audit
MCP	Mode control panel
NASA	U.S. National Aeronautics and Space Administration
ND	Navigation display
NTSB	U.S. National Transportation Safety Board
PA	Public address
PDI	Power distance indicator
PF	Pilot flying
PFD	Primary flight display
PM	Pilot monitoring
PNF	Pilot not flying
RNAV	Area navigation
RVSM	Reduced vertical separation minima
SA	Situational awareness
SID	Standard instrument departure
SOP	Standard operating procedure
SPO	Supporting proficiency objective
STAR	Standard terminal arrival route
SWAPA	Southwest Airlines Pilots' Association
TEM	Threat and error management
TOD	Top of descent
TPO	Terminal proficiency objective
VVM	Verbalize, verify, monitor
VNAV SPD	Vertical navigation – speed
WG	Active Pilot Monitoring Working Group

1. In this report, 'FMS' refers to the Boeing FMC and the Airbus FMGC.

Foreword

"Throughout the flight, pilots are required to monitor many functions, the state of aircraft systems, aircraft configuration, flight path and the actions of the other pilot in the cockpit. Thus, the number of opportunities for error is enormous — especially on challenging flights, and many of those opportunities are associated with two safeguards themselves designed to guard against error: checklists and monitoring. The impressive safety record of airline operations in developed countries is, (in part), testament that pilots perform the vast bulk of procedures correctly, neutralizing threats and averting potential consequences of errors. However, maintaining the safety of any highly ordered system — an aircraft or the entire air transport system — is a bit like balancing on a ball; constant effort is required to counter the many forces that would disorder the system."[2]

2. Dismukes, R.K.; Berman, B. (2010). "Checklists and Monitoring in the Cockpit: Why Crucial Defenses Sometimes Fail." NASA Technical Memorandum. NASA/TM-2010-216396.

Executive Summary

Contemporary aviation operators have access to information that their predecessors did not. Data streams such as those from the line operations safety audit (LOSA), aviation safety action program (ASAP), flight operational quality assurance (FOQA)/flight data monitoring (FDM), and U.S. National Aeronautics and Space Administration Aviation Safety Reporting System (ASRS) allow many errors in different phases of flight to be carefully scrutinized, categorized and analyzed. Many organizations have a data collection and analysis system to document these anomalies. A great deal of information on the various types of errors and where they occur is now well known and documented.

One conclusion emerging from this wealth of information is the importance of effective flight path monitoring (EFPM) in a safe operation. Monitoring is something that flight crews must use to help them identify, prevent and mitigate events that may impact safety margins.

Participants at the first Human Factors Aviation Industry Roundtable meeting in 2012 were concerned that while the aviation accident/incident rates are at their historically lowest levels, too many events (for example, the crash of Colgan Air Flight 3407[3]) involved ineffective monitoring as a factor. The result of the meeting was the creation of the Active Pilot Monitoring Working Group (WG), tasked with studying the issue and creating practical guidelines intended for use by aviation managers to improve the effectiveness of monitoring. The result of this effort is this "Practical Guide for Improving Flight Path Monitoring."

"Monitoring" is a very broad term, and there are many tasks that involve monitoring. The first action of the WG was to examine the data, and the results were used to limit the scope of the effort to *monitoring of the aircraft's flight and taxi path,*[4] because it is the errors that result in deviations from these intended paths that may lead to accidents. Once the scope was defined, the group identified the following barriers to EFPM:

- Human factors limitations;
- Time pressure;
- Lack of feedback to pilots when monitoring lapses;
- Design of flight deck systems and standard operating procedures (SOPs);

3. The final report said, "… the failure of both pilots to detect this situation was the result of a significant breakdown in their monitoring responsibilities and workload management." In *Loss of Control on Approach, Colgan Air, Inc., Operating as Continental Connection Flight 3407, Bombardier DHC-8-400, N200WQ, Clarence Center, New York, February 12, 2009.* NTSB/AAR-10/01.

4. For simplicity, the term "flight path" will be used throughout this report to denote any time the aircraft is in motion, including taxiing the aircraft on the ground. Flight path also includes both the trajectory and energy state of the aircraft.

- Pilots' inadequate mental models of autoflight system modes; and,
- A corporate climate that does not support emphasis on monitoring.

The WG then set about identifying organizational philosophies, policies, procedures, practices and training that may mitigate these barriers to EFPM. This effort resulted in 20 recommendations organized into the following categories:

- Monitoring practices;
- Procedures, policies and monitoring;
- Monitoring autoflight systems; and,
- Training and evaluating monitoring skills.

The WG recognizes that organizations throughout the world are diverse in operational requirements, culture and areas of flight operations. Recommendations in this guide should be evaluated by each organization against its current policies/practices, then adopted, adopted with modification as required to suit its operation, or rejected. When evaluating these recommendations, it is important to remember the goal is to improve pilot monitoring in your operation.

Regardless of any action taken by any operator, the WG feels strongly that elevating the monitoring role on the flight deck is a significant and worthwhile operational challenge. Successful improvement in monitoring will require a commitment of time and resources from managers, comprehensive training and appropriate evaluation, and time for the operational culture to change. Many experts agree that implementation of any procedure as an SOP is most effective if the attitudes shown by managers, instructors, check airmen and pilots all reinforce the need for the procedure.[5]

Recommendations to Improve Monitoring Performance

The WG's analyses of safety data and research studies have made clear that monitoring skills of pilots are important to aviation safety. The following recommendations are based on policies, procedures and practices currently in use at some operators, and on the expertise and resources available to the WG.

Recommended Monitoring Practices

1. **Institute practices that support effective flight path monitoring.**

   List 12 commonly accepted practices that promote effective flight path monitoring and ensure both pilots' intentions are well understood.

2. **Clearly define the monitoring role of each pilot.**

   Explain that all crewmembers are responsible for monitoring as a primary task.

3. **Instill the concept that there are predictable situations during each flight when the risk of a flight path deviation is increased, heightening the importance of proper task/workload management.**

   Introduce the concept of areas of vulnerability (AOV) to flight path deviations and discuss the resultant need for improved task/workload management.

4. **Practice interventions to maintain effective monitoring or to resume effective monitoring if degraded.**

   Suggest interventions that protect situational awareness and flight path monitoring capability during high-workload situations.

5. FAA Advisory Circular 120-71A, "Standard Operating Procedures for Flight Deck Crewmembers," Feb. 27, 2003.

5. **Institute policies and practices that protect flight path management from distractions and interruptions.**

   Refine the AOV concept into policies and practices.

6. **Practice interventions to resume effective monitoring after distractions and interruptions.**

   Highlight a method of regaining situational awareness after completing non-flying tasks that routinely interrupt flight path monitoring (e.g., crew changes, referencing on-board publications, communicating with cabin crew, using the aircraft communications addressing and reporting system (ACARS).

7. **Promote policies, procedures and practices to improve monitoring of altitude changes.**

   Suggest an SOP to address these, one of the most common errors in flight.

8. **Emphasize the effect that emergency and non-normal situations have on monitoring.**

   Discuss the challenges to effective monitoring during stressful situations.

Procedures, Policies and Monitoring

9. **Review current operating procedures for conflicts with operating policy.**

   Explain how problematic design of procedures can inhibit EFPM.

10. **Review specific, monitoring-related procedures that your standards pilots are not willing or able to enforce. Consider recategorizing as *policies* any procedures that frequently allow for pilot judgment in certain circumstances. Consider recategorizing as *practices* any procedures with routinely allowed pilot variations.**

    Explain how procedures that are routinely not followed can promote normalization of deviance across all areas of operation.

11. **Analyze corporate messages — explicit and implicit — that conflict with effective flight path monitoring.**

    Describe how corporate messages to the pilot group (explicit and implicit) may be creating competing goals (e.g., on-time performance vs. safety).

12. **Institute policies/procedures/practices to ensure common understanding of air traffic control (ATC) clearances between crewmembers.**

    List SOPs that may help reduce flight management system (FMS) data entries.

Monitoring Autoflight Systems

13. **Explicitly address monitoring as part of a comprehensive flight path management policy that includes guidance on use of automated systems. Make sure the policy is compatible with the aircraft manufacturer's recommendations. In this policy, the assignment of tasks (especially monitoring and cross-verification tasks related to managing the aircraft flight path) to each pilot should be clearly identified.**

    Explain the importance of having a comprehensive flight path management policy.

    List some of the guiding principles that should be included when developing this policy.

14. **Develop and refine training to improve the monitoring of automated systems as incorporated in the flight path management policy.**

    Explain how pilots must have full technical knowledge of the automated systems and how pilots must interface with them to effectively manage the aircraft's flight path. List five areas that should be considered to develop and improve training for operational use of flight path management systems.

Training and Evaluating Monitoring Skills

15. **Train pilots about why they are vulnerable to errors and monitoring lapses.**

    Explain how pilots, thinking that they themselves are unlikely to commit errors, may underestimate their vulnerability to monitoring lapses.

16. **Reinforce the responsibility of monitoring pilots to challenge deviations.**

    Explain why one pilot may not alert the other about an observed flight path error. Monitoring is ineffective if pilots do not say anything about observed deviations.

17. **Develop and publish clearly defined monitoring tasks, training objectives and proficiency standards. Ensure that instructors and evaluators are proficient at training and evaluating these standards.**

    Explain how clearly defined monitoring tasks, standards, training objectives and instructor proficiency are all necessary to improve pilots' monitoring performance.

18. **Implement a comprehensive approach to training and evaluating use of autoflight systems and flight path monitoring.**

    Recognize that pilots will place an emphasis on items they know are going to be evaluated. Monitoring should be trained and evaluated during initial training, recurrent training and operational line checks.

19. **Incorporate monitoring training into simulator sessions or other device training.**

    Suggest methods of incorporating monitoring training into training modules and instructor guides.

20. **Place greater emphasis on monitoring in operator flight standards programs.**

    Explain how the failure of check pilots to critique monitoring during checking events will lessen the effect of, if not completely undermine, all monitoring training.

A Practical Guide for Improving Flight Path Monitoring

Section 1: Introduction

The commercial aviation system is the safest transportation system in the world, and the accident rate is the lowest it has ever been. This impressive record is due to many factors, including improvements in aircraft systems, pilot training, flight crew and air traffic control procedures, improved safety data collection and analysis, professional pilot skills and other efforts by industry and government. One of the characteristics of the aviation community that has contributed is a commitment to continuously improve safety and operations (Flight Deck Automation Working Group, 2013).

To this safety-minded aviation community, we offer this practical guide to improving flight path monitoring. Monitoring is something that flight crews must use to help them identify, prevent and mitigate events that may impact safety margins. As noted, modern data collection methods point toward ineffective monitoring of the flight path as a contributing factor in many accidents. Line operations safety audit (LOSA) data in this guide show that flight crews rated "poor" or "marginal" in monitoring and cross-checking had three times the number of mismanaged errors as crews rated "good" or "outstanding." In this light, monitoring can be considered as a core defense that flight crews use to enhance their threat and error management (TEM) performance.[1]

Human factors science can help explain why consistent, adequate monitoring is so difficult to achieve, and may be used to form recommendations for a flight operation's philosophies, policies, procedures and practices to improve monitoring performance. All of these aspects of flight path monitoring are explored in later sections of this report.

This report is intended to persuade managers who have responsibility for funding and endorsing training programs that addressing monitoring issues in their operations is a necessary and prudent investment of time and resources. It is also intended for those individuals who develop SOPs, and design and implement training programs for flight crews.

Acknowledging the limited resources available to most operations, this practical guide strives to improve flight path monitoring by offering useful, realistic changes that will have a positive impact on flight safety. Included in Appendix B is sample training material[2] to facilitate the incorporation of several of the recommendations presented.

Note: This document is intended to serve as a guide that can enhance operator programs and processes designed to improve the ability of flight crewmembers to monitor and cross-check/cross-verify the aircraft's flight path, taxi path and energy state. Users should assess the guidance for compatibility with existing programs to ensure compliance with applicable regulatory requirements and the aircraft manufacturer's recommendations.

1.1 Background

Despite the lowest accident rate in history for global commercial air transport, aviation accidents involving inadequate monitoring still occur.

1. For further information on the link between monitoring and TEM, see Appendix A, "Monitoring Link to TEM Performance" by James Klinect, The LOSA Collaborative.
2. This training material is an example of what some operators are using and should not be mistaken for or applied as industry best practices.

Accident: Asiana Airlines Flight 214, July 6, 2013

In July 2013, Asiana Airlines Flight 214 struck a seawall at San Francisco International Airport. The U.S. National Transportation Safety Board (NTSB) determined the airplane crashed when it descended below the visual glide path due to the flight crew's mismanagement of the approach and inadequate monitoring of airspeed. The NTSB also determined that the crew's insufficient monitoring of airspeed indications during the approach resulted from expectancy, increased workload, fatigue and automation reliance. Three of the 291 passengers were fatally injured; 40 passengers, eight of the 12 flight attendants, and one of the four flight crewmembers received serious injuries.

Accident: Colgan Air Flight 3407, February 12, 2009

In February 2009, Colgan Air Flight 3407 crashed into a house in Clarence Center, New York, U.S., after experiencing an aerodynamic stall. The crew failed to recognize a loss of 50 kt of airspeed in 22 seconds. All 49 people aboard were killed, along with one person in the house.

These accidents were not unique. Problems with failing to monitor an aircraft's flight path and energy state have a long history in aviation accidents.

- An NTSB study found that inadequate monitoring/challenging played a role in 84 percent of major airline accidents attributed to crew error over a 12-year period.[3] These monitoring problems failed to catch primary errors that the NTSB considered to be causal or contributing factors to the accidents.
- The International Civil Aviation Organization (ICAO) found inadequate monitoring to be a factor in 50 percent of controlled flight into terrain accidents.[4]
- Flight Safety Foundation found that 63 percent of approach and landing accidents involved inadequate monitoring and cross-checking.[5]

In the early 2000s, US Airways, the Air Line Pilots Association, International (ALPA) and U.S. National Aeronautics and Space Administration (NASA) researchers joined together to call attention to the importance of monitoring as a defense against threats and errors.[6] The result of these individual and group efforts led to the 2003 publication of U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) 120-71A, "Standard Operating Procedures for Flight Deck Crewmembers," which, in part, states:

> *Several studies of crew performance, incidents and accidents have identified inadequate flight crew monitoring and cross-checking as a problem for aviation safety.*

This AC expanded recommendations for standard operating procedures (SOPs) to include guidance on monitoring procedures. Consistent with this guidance, many operators have changed the term "pilot not flying" (PNF) to "pilot monitoring" (PM) and have revised flight operations manuals to explicitly describe at least some monitoring duties. Undoubtedly, individual operators made other changes to SOPs as a result of the AC, but data indicate that these actions have not been sufficient.

Regarding Colgan Air Flight 3407, the NTSB found "the importance of monitoring was referenced in some of Colgan's guidance to its pilots and was discussed and evaluated during simulator training and IOE [initial operating experience]. However, the company did not provide specific pilot training that emphasized the monitoring function. Further, the company's CRM (crew resource management) training did not explicitly address monitoring or provide pilots with techniques and training for improving their monitoring skills."[7]

The NTSB concluded, "The monitoring errors made by the accident flight crew demonstrate the continuing need for specific

3. NTSB (1994). "Safety Study: A Review of Flightcrew-Involved Major Accidents of U.S. Air Carriers, 1978 through 1990." NTSB/SS-94/01, PB94-917001.
4. International Civil Aviation Organization. "Safety Analysis: Human Factors and Organizational Issues in Controlled Flight Into Terrain (CFIT) Accidents, 1984–1994." Montreal, Quebec, Canada: ICAO, 1994.
5. Khatwa, R.; Helmreich, R.L. "Analysis of Critical Factors During Approach and Landing Accidents and Normal Flight." In "Killers in Aviation: FSF Task Force Presents Facts About Approach-and-Landing and Controlled-Flight-into-Terrain Accidents." *Flight Safety Digest*. November–December, 1998, January–February, 1999.
6. Sumwalt, R.L. "Enhancing Flight Crew Monitoring Skills Can Increase Flight Safety." *Flight Safety Digest*. March 1999, pp. 1-8. Sumwalt, R.L.; Thomas, R.J.; Dismukes, K. "Enhancing Flight-Crew Monitoring Skills Can Increase Flight Safety," in *Proceedings of Flight Safety Foundation, International Federation of Airworthiness and International Air Transport Association, 55th annual International Air Safety Seminar, November 4-7, 2002*. Sumwalt, R.L. III; Thomas, R.J.; Dismukes, R.K. (2003). "The new last line of defense against aviation accidents." *Aviation Week & Space Technology*, 159(8), 66.
7. NTSB (2010). Aircraft accident report: *Loss of control on approach. Colgan Air, Inc., operating as Continental Connection Flight 3407. Bombardier DHC-8-400, N200WQ. Clarence Center, New York. February 12, 2009*. NTSB Report no. NTSB/AAR-10/01.

pilot training on active monitoring skills."[8] In completing the investigation, the NTSB reiterated NTSB Safety Recommendation A-07-13, calling for "all pilot training programs [to] be modified to contain modules that teach and emphasize monitoring skills and workload management and include opportunities to practice and demonstrate proficiency in these areas." In November 2013, the FAA published a final rule[9] (applicable to Part 121 air carriers) that addresses this recommendation by requiring training on pilot monitoring to be incorporated into existing requirements for scenario-based training. It also establishes an operational requirement that flight crewmembers follow air carrier procedures regarding pilot monitoring. Compliance is required by March 12, 2019.

Much of this information was discussed at the first Human Factors Aviation Industry Roundtable, whose members were concerned that while the aviation accident/incident rates are at their historical lowest, too many events (e.g., Colgan Air Flight 3407[10]) have involved ineffective monitoring as a factor. Additionally, it was noted that the increased use of automation and the requirement to monitor automated systems (partially resulting from the move toward airspace improvements such as NextGen[11]) would only serve to increase the need for effective monitoring.

While this document was originally intended for air carrier management and those individuals who develop SOPs, and design and implement training programs for flight crews, the data presented in Section 2 strongly suggest that all operators of aircraft could benefit from the content contained in this report. Utilizing this guide will help design and train operational policies, procedures and practices that will improve the pilot's ability to detect and manage errors as they occur, regardless of the type of operation.

1.2 Defining *Monitoring*

"Monitoring" is a word used quite liberally in aviation, and it is natural that its meaning could be subject to confusion. In simple, plain language:

> *Monitoring is adequately watching, observing, keeping track of, or cross-checking.*

This is very broad. To better understand the knowledge and skills that pilots need to improve monitoring, this report differentiates how a person monitors from what a person monitors.

1. **How to monitor:** The following are some of the sub-skills/actions required to actually perform the monitoring task:
    a. **Attention management:** Procedures/techniques for directing a pilot's attention to a particular place at a particular time.
    b. **Deliberate checking:** The active, disciplined and effortful action a pilot must take to look for something rather than just look at something. At a more technical level, this involves a baseline understanding of the particular thing being checked, the context of the check and, very importantly, the devotion of adequate visual dwell time on the thing being checked (i.e,. the opposite of a "quick glance").
    c. **Cross-checking/cross-verifying:** Comparing separate, independent sources of information to confirm or refute understanding derived from the initial source. Most simply, this is "seeking a second opinion."
2. **What to monitor:** The above skills may be applied in a number of different contexts. Being clear about these contexts is critical to the purpose of this report and serves to clarify the scope of this report. For example, a pilot could be monitoring:
    a. **Flight path:** Monitoring the trajectory and energy state of the aircraft, power settings and the automated systems directly affecting flight path (e.g., autopilot, autothrottle, flight management system). (Note: ground [taxi] path is included within the scope of this term.)
    b. **Systems:** Monitoring of aircraft systems, excluding those directly affecting the flight path (e.g., fuel, hydraulics, pressurization, etc.).
    c. **Operational factors:** Monitoring other operational factors affecting the flight (e.g., dispatch release accuracy, weight and balance information, weather, etc.).
    d. **Crew/situational awareness:** Monitoring the actions/condition of the other pilot(s) and crew/situational awareness.

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8. Ibid.
9. A copy of the FAA final rule (November 2013) can be found at <www.faa.gov/regulations_policies/rulemaking/recently_published/media/RIN-2120-AJ00.pdf>. Specific monitoring requirements are in Sections 121.409 and 121.544, Appendix H.
10. "The failure of both pilots to detect this situation was the result of a significant breakdown in their monitoring responsibilities and workload management." *Loss of Control on Approach, Colgan Air,* NTSB/AAR-10/01.
11. The term "NextGen" refers to the FAA's Next Generation Air Transportation System, a shift to smarter, satellite-based and digital technologies and new procedures that combine to make air travel more convenient, predictable and environmentally friendly. As demand for increasingly congested airspace continues to grow, NextGen improvements are enabling the FAA to guide and track aircraft more precisely on more direct routes. NextGen efficiency enhances safety, reduces delays, saves fuel and reduces aircraft exhaust emissions.

1.3 Scope

As “monitoring” is a very broad term, there are many flight crew tasks that involve monitoring. Among other things, pilots are required to monitor the state of aircraft systems, aircraft configuration, flight path and the actions of the other pilot on the flight deck. Often, monitoring must be performed concurrently with other tasks such as operating aircraft controls, making data entries and communicating with ATC. The working troup (WG) immediately realized that the skills involved in the broadest notion of monitoring encompass nearly the entire set of TEM skills, and that the sheer volume of what pilots monitor during every flight would make a comprehensive report on monitoring a long and arduous task.

In light of several recent monitoring-related accidents, the WG decided that a guide that addressed the most safety-critical monitoring-related threats would be most beneficial to the aviation industry. Upon examining the accident data, the WG decided that it was most valuable to focus narrowly on the most safety-critical aspect of monitoring, namely *monitoring of the aircraft's flight and taxi path,*[12] as it is the errors that result in deviations to these intended paths that have the greatest potential to lead to accidents.

Managing the flight path of the aircraft — including the energy level of the aircraft — is a basic pilot responsibility. Unfortunately, many pilots associate *managing* the flight path with simply *controlling* the flight path, either through manual control inputs (including thrust lever/throttle inputs) or manipulating various levels of an automated system. This view leaves the task cycle incomplete, as it contains no provision for feedback that the correct inputs have been made and that the correct flight path–energy level is being followed. The latter function, that the aircraft is indeed following the correct path and energy level, is at least as important as proper control inputs because, ultimately, it is the actual aircraft performance that is the issue.

To address the significant threat, this report focuses on improving pilot monitoring of the flight path so that crews are effective in discovering and correcting flight path management errors. Individual pilots achieve effective flight path monitoring by demonstrating desired monitoring skills, and by task management that allows for a level of monitoring (i.e., a “sampling rate”[13]) that is consistent with the level required by their current area of vulnerability to flight path deviations. Organizations enable effective flight path monitoring by developing, training and evaluating policies, procedures and practices that create an environment that encourages and supports effective monitoring. The bulk of this guide addresses each of these areas.

1.4 Effective Monitoring Actions

Some pilots perform better at monitoring than others. These pilots exhibit certain skills and CRM–based actions in flight that improve monitoring. These skills and actions are addressed throughout this guide and can be trained as a part of each operator's training programs.

The WG believes skills and actions that help pilots be better monitors include:

- Following SOPs consistently;
- Clearly communicating deviations to other crewmembers;
- Aggressively managing distractions;
- Remaining vigilant;
- Intervening if flight guidance modes or aircraft actions don't agree with expected actions;
- Continuously comparing known pitch/power settings to current flight path performance;
- Considering that the primary flight displays and navigation displays (PFD, ND) might be “lying” and always being on the lookout for other evidence that confirms or disconfirms what the displays are saying;
- Methodically regaining flight path situational awareness (SA) after completing non-flight-related tasks; and,
- Alerting other crewmembers when monitoring is inhibited (e.g., head down).

As a generic statement, skilled monitors understand that there are some flight segments and tasks requiring extra vigilance. Pilots who keep this in mind will avoid (defer) doing certain non-monitoring-related tasks while operating in those flight segments where they are more vulnerable to monitoring errors. They will also plan to conduct certain activities, such as briefing the approach, during the less vulnerable times.

Most pilots are good at monitoring and frequently demonstrate the actions listed above. Through effective monitoring, the vast majority of errors are undoubtedly caught and corrected. However, consistently effective monitoring during all phases of flight is surprisingly challenging to achieve, as we will see in Section 3 of this guide.

12. This view is supported with monitoring-related accident data shown in Section 2 of this report.

13. Sampling rate is the frequency with which a pilot directs his or her visual and mental attention to the various items or indicators that represent the flight path.

1.5 Working Group Makeup

In November 2012, the Human Factors Aviation Industry Roundtable established the WG to address the role of monitoring in aviation safety. The WG consisted of representatives from the aviation industry (pilots and human factors [HF] training managers from major air carriers, regional carriers and business aircraft operators), from the government (NTSB, FAA and NASA), aircraft manufacturers (Airbus and Boeing) and from organized labor — ALPA, the International Federation of Airline Pilots' Associations (IFALPA) and the Southwest Airlines Pilots' Association (SWAPA). All WG participants had expertise in incorporating HF and TEM into flight operations.

1.6 Tasking of the Working Group

With the focus on the importance of effective monitoring of the aircraft's flight path, the WG began the following tasks:

- Gathering and reviewing monitoring-related incident, accident and operations data and relevant research;
- Defining monitoring, effective flight path monitoring and monitoring roles for multi-crew flight decks;
- Developing a description of good monitoring skills that should be reinforced to enhance safety;
- Identifying HF-related "barriers" that inhibit consistent, effective monitoring;
- Developing operational guidelines for monitoring policies, procedures and practices; and,
- Developing training material to facilitate incorporation of adopted monitoring policies, procedures and practices.

The information gathered from various sources, along with the expertise and experiences of the WG members, was used to develop recommendations that address the objectives in this report. The WG saw value in expediting this material to the aviation industry, and followed an aggressive timeline for publication. Consequently, much of the HF science behind the recommendations has not been included in this report. Readers wishing to increase their subject knowledge in this area are directed to supporting research contained in *Checklists and Monitoring in the Cockpit: Why Crucial Defenses Sometimes Fail.*[14] Additional supporting information can be found at <www.caa.co.uk/application.aspx?appid=11&mode=detail&id=5447>.

14. Dismukes, R.K.; Berman, B. (2010). "Checklists and Monitoring in the Cockpit: Why Crucial Defenses Sometimes Fail." NASA Technical Memorandum (NASA TM-2010-216396). Moffett Field, California, U.S.: NASA Ames Research Center.

Section 2: Monitoring Data and Research

In this section, we provide data to show how ineffective flight path monitoring leads to undetected errors and, conversely, how effective monitoring enables flight crewmembers to detect errors that lead to enhanced safety margins. Data are presented from five different sources:

- Aircraft accident reports;
- Accident and research studies;
- Line operations safety audits (LOSA) data;
- U.S. National Aeronautics and Space Administration Aviation Safety Reporting System (ASRS) reports; and,
- Aviation Safety Action Program (ASAP) reports.

Flight path deviations are relatively common; and nearly all operators, flying different types of equipment, are beset to some degree by the following types of deviations:

- Altitude deviations;
- Airspeed deviations;
- Course deviations; and,
- Taxi errors/runway incursions.

The data that link ineffective monitoring to these and other undetected errors are shown in this section; barriers to effective monitoring and countermeasures to improve monitoring are included in subsequent sections.

2.1 Aircraft Accident Reports

Problems with monitoring on the flight deck have existed almost as long as pilots have been flying. Evidence of monitoring lapses first became apparent through accident investigations. For example, the investigation of the fatal crash of a Flanders F3 monoplane on May 13, 1912, at the Brooklands Aerodrome in England determined in part that the aircraft stalled during a turn because the pilot did not appear to "appreciate the dangerous conditions under which he was making the turn"[1] and did not correct his improper procedures. Unfortunately, ineffective monitoring also has played a role in more recent accidents.

Accident: FedEx Flight 1478, July 26, 2002

On a flight from Memphis, Tennessee, U.S., a Boeing 727 struck trees 3,650 ft (1,113 m) short of Runway 9 while on final approach to the Tallahassee (Florida) Regional Airport. The airplane descended through trees and impacted the ground about 1,000 ft (305 m) later. It slid an additional 1,100 ft (335 m) and came to rest approximately 1,000 ft from the runway, facing in the opposite direction of travel. While sliding, the airplane struck construction vehicles that were parked on the field during the night, and burn marks on the ground indicated there was a fire on the airplane for the last 1,000 ft or so of travel. The U.S. National Transportation Safety Board (NTSB) determined that the probable cause of the accident was the failure of the captain (CA) and first officer (FO) to establish and maintain a proper glide path during the night visual approach to landing. Contributing to the accident, in part, were the captain's and first officer's fatigue and the captain's and flight engineer's failure to monitor the approach.[2]

Accident: King Air 100, October 25, 2002

On a flight from St. Paul to Eveleth, Minnesota, U.S., the flight crew failed to maintain an appropriate course and speed for the approach to Eveleth-Virginia Municipal Airport. During the later stages of the approach, the flight crew failed to monitor the airplane's airspeed and allowed it to decrease to a dangerously low level (as low as about 50 kt below the operator's recommended approach speed) and to remain below the recommended approach speed for about 50 seconds. The airplane then entered a stall from which the flight crew did not

1. Royal Aero Club of the United Kingdom (June 8, 1912). Official Notices to Members. Page 1. June 8, 1912. <www.flightglobal.com/pdfarchive/view/1912/1912%20-%200513.html>.
2. NTSB (2004). Aircraft Accident Report: *Collision With Trees on Final Approach, Federal Express Flight 1478, Boeing 727-232, N497FE, Tallahassee, Florida, July 26, 2002*. NTSB/AAR-04/02, PB2004-910402. 2004.

recover. All occupants, including U.S. Senator Paul Wellstone and his family, perished.[3]

Accident: Ansett New Zealand Flight 703, June 9, 1995

At approximately 0922 local time, a de Havilland DHC-8 collided with the terrain 16 km (8.6 nm) east of Palmerston North Aerodrome in New Zealand while conducting an instrument approach. The flight attendant and three passengers were killed in the accident. During a turn to align the aircraft with the final approach course, the landing gear failed to extend, so the pilot monitoring attempted to extend the gear manually. The aircraft power settings had already been reduced to flight idle, which was normal, but the aircraft was inadvertently allowed to descend too low in relation to the rolling terrain as the flight crew focused on the malfunctioning gear. The ground-proximity warning system (GPWS) sounded only four seconds prior to impact, rather than approximately 13 seconds earlier, as it was supposed to have sounded. This accident illustrates the need for extra-vigilant monitoring and not relying too heavily on crew alerting systems during non-normal events.[4]

Case studies of other accidents involving ineffective monitoring are profiled in Appendix C. A document written by the Loss of Control Action Group of the U.K. Civil Aviation Authority entitled "Monitoring Matters: Guidance on the Development of Pilot Monitoring Skills"[5] also does an excellent job of analyzing accident reports in which monitoring performance was a causal factor.

In addition to accident investigations from the last 20 years, data regarding monitoring lapses have also been collected through studies and flight deck observations and continue to indicate that that ineffective monitoring is a causal factor in flight deck errors and (sometimes) fatal accidents.

2.2 Accident and Research Studies

Aircraft accident reports citing inadequate monitoring as a contributing factor led to independent research studies that focused on the role of monitoring in aviation safety. In addition to quantifying how inadequate monitoring leads to undetected errors, these studies identified the human factors elements of monitoring and described for the first time the forces inhibiting effective monitoring.

Safety Study: A Review of Flightcrew-Involved Major Accidents of U.S. Air Carriers, 1978 Through 1990. This study published by the NTSB in 1994,[6] found 23 percent of the 302 errors identified in the 37 accidents during this 12-year period related to inadequate monitoring/challenging. Inadequate monitoring/challenging was present in 31 of the 37 (84 percent) reviewed accidents.

Monitoring Deficiencies in CFIT and Approach and Landing Accidents. Khatwa and Roelen[7] conducted an in-depth analysis of controlled flight into terrain (CFIT) accidents involving commercial operators from a six-year period. They determined that 31 of 108 accidents (28.7 percent) involved problems with monitoring/challenging. Similarly, in a review of 24 CFIT accidents, the International Civil Aviation Organization (ICAO)[8] found that in half, the "crew did not monitor properly." Flight Safety Foundation has long been concerned about issues central to aviation safety, especially issues contributing to CFIT and approach and landing accidents. In a 1998 study, the Foundation found that 63 percent of approach and landing accidents involved inadequate monitoring and cross-checking.[9]

Checklists and Monitoring in the Cockpit: Why Crucial Defenses Sometimes Fail. Although checklists and monitoring are crucial defenses against threats and errors that might lead to accidents, these defenses sometimes fail. Dismukes and Berman[10] observed monitoring (and checklist use) on 60 flights involving six aircraft types at three large airlines and found a wide range in the number of deviations from monitoring standard operating

3. NTSB (2003). Aircraft Accident Report: *Loss of Control and Impact with Terrain, Aviation Charter, Inc. Raytheon (Beechcraft) King Air A100, N41BE, Eveleth, Minnesota, October 25, 2002*, NTSB/AAR-03/03, PB2003-910403. 2003.
4. New Zealand Transport Accident Investigation Commission. *Report 95-011, de Havilland DHC-8, AK-NEY, controlled flight into terrain near Palmerston North, 9 June 1995*. 1995.
5. CAA Loss of Control Action Group. *Monitoring Matters: Guidance on the Development of Pilot Monitoring Skills,* CAA Paper 2013/02. 2013. <www.caa.co.uk/docs/33/9323-CAA-Monitoring%20Matters%202nd%20Edition%20April%202013.pdf>.
6. NTSB. Safety Study: *A Review of Flightcrew-Involved Major Accidents of U.S. Air Carriers, 1978 Through 1990.* NTSB/SS-94/01, PB94-917001. 1994.
7. Khatwa, R.; Roelen, A.L.C. "An Analysis of Controlled-flight-into-terrain (CFIT) Accidents of Commercial Operators, 1988 Through 1994." *Flight Safety Digest* Volume 15 (April–May 1996): 1–45.
8. ICAO. *Safety Analysis: Human Factors and Organizational Issues in Controlled Flight Into Terrain (CFIT) Accidents, 1984–1994*. Montreal: ICAO, 1994.
9. Khatwa, R.; Helmreich, R. L. "Analysis of Critical Factors During Approach and Landing in Accidents and Normal Flight." In *Killers in Aviation: FSF Task Force Presents Facts About Approach-and-Landing and Controlled-Flight-into-Terrain Accidents, Flight Safety Digest* Volume 17 and 18 (November–December 1998 and January–February 1999): 1–77.
10. Dismukes, R.K.; Berman, B. *Checklists and Monitoring in the Cockpit: Why Crucial Defenses Sometimes Fail.* NASA Technical Memorandum, NASA/TM-2010-216396. 2010.

procedures (SOPs): from one to 19 per flight. Most of these deviations were fairly minor, but some could have had serious consequences. Some of these include: The first officer was head down when crossing an intersecting runway; both pilots failed to notice an incorrect heading set in the mode control panel as they prepared to take off; and the monitoring pilots failed to make required callouts during an unstabilized approach. The authors described the human factors contributing to these deviations and suggested measures to reduce vulnerability.

Pilots' Monitoring Strategies and Performance on Automated Flight Decks. Sarter, Mumaw and Wickens[11] conducted a flight simulation study that used an eye-tracking device to determine how well experienced pilots monitored automated systems during critical phases of flight. The study found that pilots failed to monitor the flight mode annunciation during about one-third of the mode changes. During climb, the experimenters caused the pitch mode annunciator to display an incorrect indication. One-third of the pilots did not gaze directly at the annunciator, and none of the pilots reported the incorrect indication, even though they had been instructed to report any anomalies. Thirty percent of the pilots did not notice a failed glideslope indication until after intercepting the localizer, and another 30 percent did not notice it at all.

These studies and accident investigations show that monitoring plays an important role in flight safety. Data collected during LOSA, and archived by The LOSA Collaborative, also show the connections between monitoring, SOPs and threat and error management (TEM).

2.3 LOSA Data

The LOSA archive continues to grow as LOSAs conducted at operators around the world are de-identified and archived by The LOSA Collaborative in Austin, Texas, U.S. LOSA involves the use of cockpit observers to collect flight crew performance data during a regularly scheduled, everyday flight. Primarily, the observers are there to capture a crew's TEM performance, including how a crew manages threats encountered or errors committed during a flight. As a secondary measurement, observers also rate various behavioral markers, such as the captain's leadership, communication environment, workload management, inquiry and monitoring/cross-checking, to list a few.

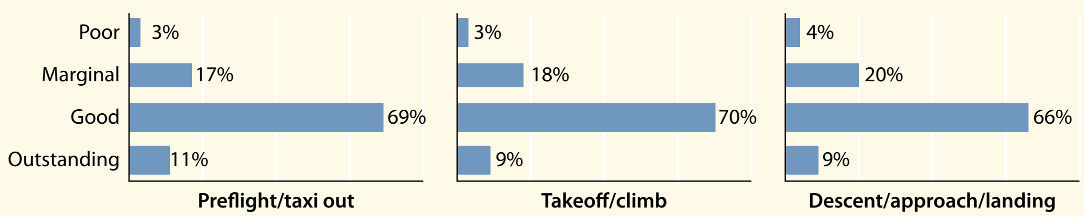
For each behavioral marker in a LOSA, observers rate the crew's performance by phase of flight (preflight/taxi out, takeoff/climb, and descent/approach/landing) using the following rating scale:

1. Poor	2. Marginal	3. Good	4. Outstanding
Observed performance had safety implications	Observed performance was adequate but needs improvement	Observed performance was effective	Observed performance was truly noteworthy

Based on the most recent 70 LOSA projects conducted over the past decade (more than 15,000 observations globally), what can the LOSA archive tell us about monitoring and cross-checking? Using the behavioral marker definition in Figure 1, monitoring/cross-checking performance is rated by LOSA observers for each phase of flight. The results show that an average of 78

MONITORING/ CROSS-CHECKING	Crewmembers actively monitored and cross-checked systems and other crewmembers. Aircraft position, settings and crew actions were verified.

Observer Ratings of Monitor/Cross-Check Performance Across Phase of Flight



Source: The LOSA Collaborative

Figure 1

11. Sarter, N.B.; Mumaw, R.J.; Wickens, C.D. "Pilots' monitoring strategies and performance on automated flight decks: An empirical study combining behavioral and eye-tracking data." *Human Factors* Volume 49 (June 2007): 347–357.

Preflight/Taxi Monitor/ Cross-Check Rating	Average Number of Mismanaged Errors	Percent of Flights With a Mismanaged Error	Average Number of Undesired Aircraft States	Percent of Flights With an Undesired Aircraft State
Poor	2.1	72	1.3	66
Marginal	1.3	57	0.9	51
Good	0.7	38	0.5	35
Outstanding	0.7	39	0.5	34

Monitor/Cross-Check Ratings During Preflight/Taxi, Correlated with Threat and Error Management Performance

Source: The LOSA Collaborative, Active Pilot Monitoring Working Group

Table 1

percent of flight crews in the LOSA archive are rated "good" or "outstanding" for monitoring/cross-checking in at least one phase of flight, while 22 percent are rated "poor" or "marginal."

Aligning these ratings with the corresponding number of observed undesired aircraft states, the working group (WG) produced Table 1.

From this chart, several correlations can be seen between monitoring/cross-checking and TEM performance. For example, based on LOSA archive data, Table 1 shows that flight crews who received a "good" or "outstanding" monitor/cross-check rating during preflight/taxi had fewer mismanaged errors and undesired aircraft states than crews with "poor" or "marginal" ratings. This same relationship held true for monitor/cross-check ratings collected during descent/approach/landing. Therefore, crews observed to be weakest in monitoring/cross-checking had *three times the number of mismanaged errors* as the crews rated "good" or "outstanding."[12] The "poor" and "marginal" crews also had two to three times the number of undesired aircraft states.[13]

From a work flow perspective, the sequence is simple: A crew that is effectively monitoring/cross-checking is more likely to detect any problems, omissions or errors than a crew that is not effectively monitoring/cross-checking. And a crew that is aware of problems, omissions or errors is more likely to manage them than a crew that remains unaware of them. As such, a positive relationship may exist between monitoring/cross-checking and TEM performance. LOSA data show that effective monitoring and cross-checking occur on flights that have fewer mismanaged errors and undesired aircraft states.

Thus, helping pilots develop more effective monitoring skills while paying due attention to the factors that can negatively affect a crew's monitoring performance should help improve their TEM performance.

2.4 ASRS Reports

Reports that pilots file with the ASRS can provide a wealth of information about a wide variety of safety issues, including flight path monitoring.

Improper flight path management, such as missing a level-off altitude, allowing the aircraft to get critically slow, or allowing an aircraft to inadvertently cross a hold short line or active runway while taxiing are some of the critical safety consequences associated with ineffective monitoring. Interruptions and distractions often contribute to or result in inadequate monitoring of aircraft flight path and flight deck automation, as illustrated in the following ASRS report.

ASRS Report 1071582: Airbus A321, March 2013

We were given clearance to descend via the area navigation (RNAV) arrival. The captain was flying. We confirmed descent altitudes and speeds on the arrival. … In the descent, [it] was noticed [that] in all probability, [we would] not make our next restriction accurately. So the captain adjusted altitude to make the restriction. He then re-engaged the vertical profile, and we believed everything was then set to descend via the altitude restrictions. We failed to notice that the airplane had fallen out of "managed descent" and entered "vertical speed" [mode]. [When] we passed an intersection [with] cross between 15,000 ft and 16,000 ft [restriction] at 14,000 ft, the captain pushed vertical speed zero to reconnect with the vertical profile. The event occurred because the captain and I did not notice the aircraft entering "vertical speed" and then further did not monitor the descent to see that we would cross at the predetermined altitude restrictions. This all happened because after the captain re-engaged "managed descent," we both were involved in a discussion which diverted us from our duties.

12. Data from The LOSA Collaborative are correlational and not causational (i.e., monitoring and error management are associated with each other, but the data cannot determine if one directly causes the other). It is easy to imagine, for example, how task overload or fatigue could be the underlying cause of both poor monitoring and increased errors.

13. Undesired aircraft states have the potential for unsafe outcomes. Undesired aircraft state management largely represents the last opportunity to avoid an unsafe outcome and thus maintain safety margins in flight operations.

Other contributors to ineffective monitoring are poor workload management, becoming engrossed in other tasks and failing to interleave multiple concurrent tasks adequately.

ASRS Report 1071582: Wide Body Transport, March 2013

During descent, first officer [the pilot flying (PF)] decided to fly aircraft manually from about 10,000 ft. We were on vectors downwind descending to assigned altitude of 1,800 m [5,900 ft]. Approximately 1,000 to 2,000 ft above level, approach controller issued a runway change from 02R to 02L. I [captain] went head-down and changed the approach in the FMS [flight management system], then selected the new approach chart on the EFB [electronic flight bag] as we approached level-off. As I was working on the EFB, I heard the "altitude" CAWS [central aural warning system] alert, followed by the first officer verbally state "1,800 meters." My attention immediately shifted to the PFD [primary flight display], and I saw that we were below the assigned altitude, with the first officer correcting back to the assigned altitude. … The electronic charts are still new to us (my fourth leg using the system) and require more time and mental concentration than usual.

Even when SOPs are being followed and workload is being managed properly, monitoring errors can occur. One example is when cross-checking data entry appears to be occurring but is actually inadequate — something well described by the captain in the ASRS report below.

ASRS Report 1104311: Airbus A320, July 2013

First officer's report: Knowing that planned weight was near our maximum takeoff weight, I requested performance numbers. … A flex takeoff [reduced-thrust takeoff] with Flaps 3 for [Runway] 1R was entered into the FMGC [flight management guidance computer]. … The captain asked me to retrieve the performance numbers for Runway 1L. We were both surprised to see that Flaps 3 performance numbers came up for 1L [and] that TOGA [takeoff/go-round] thrust was not necessary. So I proceeded to the box and made the appropriate changes to the runway. Switched from 1R to 1L, entered the V speeds for Flaps 3 at 1L, entered the flex temperature for 1L, and somewhere in there, I mistakenly changed the current flap setting of 3 to the erroneous setting of 1. Shortly thereafter, we commenced with the "Before Takeoff" checklist. With his hand on the flap handle, captain questioned the flap setting. I glanced down behind the flap handle where the takeoff data were located and inadvertently confirmed Flaps 1. I can only assume I failed to look at the appropriate runway data.

Captain's report: Why did we take off in an undesired aircraft state? Not because the first officer made a mistake, but because at no time did I double check the takeoff data for 1L with my own eyes nor did I confirm that the data was properly loaded into the FMC [flight management computer]. I had simply watched the data being loaded, thinking that I was verifying it at the same time.

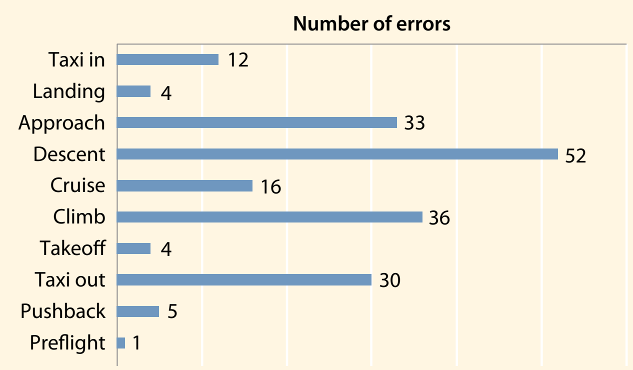
2.5 ASAP Reports

Another critical source of data that identifies specific problems during flight operations associated with ineffective monitoring is reports that are filed through the ASAPs at individual operators. To illustrate this, events in 188 reports submitted to a U.S. major airline's ASAP were analyzed by the WG in 2013. Each of the reports had been previously identified as citing pilot monitoring errors as either contributory or causal to the event described in the report. The analysis showed the following:

- There was no significant variability in the number of reports among the different aircraft fleets.
- There were a nearly equal number of monitoring errors committed by the captain and the first officer.
- In one-third of the incidents, the pilot monitoring (eventually) detected the error that resulted from ineffective monitoring; one-third of the time, air traffic control detected the error.

Of the 188 reports involving monitoring errors for this airline, the majority of monitoring errors — 66 percent — occurred while the aircraft was in a vertical phase of flight (e.g., climb, descent, approach and landing), as shown in Figure 2. In Section 4, this guide provides several recommendations to ensure

Phase of Flight Where a Monitoring Error Occurred*

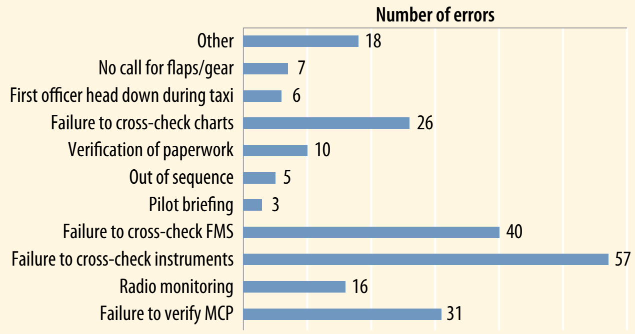


*More than one error occurred in some of the 188 reports analyzed.

Source: Active Pilot Monitoring Working Group

Figure 2

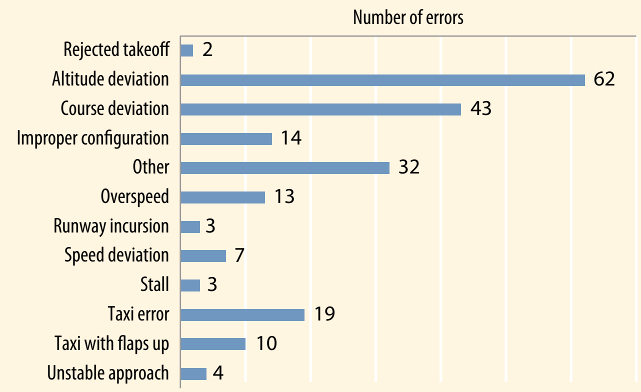
What Set the Stage for the Monitoring Error?



Source: Active Pilot Monitoring Working Group

Figure 3

Consequences of Inadequate Monitoring



Source: Active Pilot Monitoring Working Group

Figure 4

effective monitoring, particularly when the aircraft is climbing or descending.

One of the benefits of ASAP reports is that pilots are expected to describe, in detail, events and activities that were transpiring on the flight deck that set the stage for errors and undesired aircraft states to occur. Figure 3 shows that failure to cross-check and verify (FMS entries, mode control panel [MCP] annunciations, CA-FO-Standby instruments, etc.) feature prominently in contributing to performance errors on the flight deck. By understanding what led to the inadequate monitoring that allowed errors to occur, we can better devise mitigations to keep such monitoring lapses and errors from happening in the future. Information in Section 3 will also help describe why such monitoring errors occur.

Across the 188 reports, a majority of the errors that resulted from inadequate monitoring were altitude deviations, course deviations and taxi errors. Figure 4 depicts a breakdown of the errors or consequences of inadequate monitoring identified through the ASAP report analysis. Even though they occurred with far less frequency, extremely serious events associated with ineffective monitoring also were described in this sample of reports, such as runway incursions, rejected takeoffs and stalls. Any one of these events could have resulted in a catastrophic accident.

Conclusion

There is no shortage of data linking monitoring performance to safety in aviation. Investigations have shown that monitoring problems have played a significant role in individual accidents for over 100 years. Since 1994, data from focused accident and research studies have confirmed the positive contribution that effective monitoring makes in reducing error risk, and in catching errors, and the contribution that inadequate monitoring makes to serious incidents and accidents. We know from LOSA observations that crews observed to be weakest in monitoring/cross-checking had three times the number of mismanaged errors than crews rated "good" or "outstanding," and that crews that received a LOSA rating of "poor" or "marginal" also had two to three times the number of undesired aircraft states. ASRS and ASAP reports reveal specific errors associated with ineffective monitoring — from ubiquitous altitude busts (deviations) to rare, but potentially deadly, stalls and runway incursions.

Effective monitoring has been an identified safety-related topic for more than 20 years, yet significant progress in this area remains elusive. In the following section, we will examine why this problem exists and why it is so difficult to solve.

Section 3: Barriers to Effective Monitoring

Monitoring may sound like an easy part of pilots' duties, but in reality — for multiple reasons — it is often challenging and error-prone. If a flight crew deviates from an assigned altitude, it is simplistic to label them "unprofessional" or to assume they are "just not doing their job." To improve monitoring, we must first understand why it is challenging and then create ways to address the barriers to effectiveness (Table 2).[1]

The following parts of this section provide more detail about the challenges and barriers highlighted in Table 2.

3.1 Human Factors Limitations

During monitoring, pilots are expected to carry out two distinct tasks. First, they monitor highly reliable automated systems over extended periods of time (such as in cruise flight). Second, they monitor complex aircraft flight path changes and system states while simultaneously completing several other flight-related tasks (e.g., programming approaches in the flight management system [FMS] and communicating with air traffic control [ATC], cabin crew, passengers, their airline, etc.); at times, such as during approach to landing, pilots can be very busy. Even for highly skilled and conscientious professional pilots, monitoring tasks are more challenging than they seem — especially when combined with other tasks and with fatigue.

Because modern aircraft typically have advanced autoflight capabilities and are highly reliable, pilots often have little to do during cruise but monitor for occasionally unexpected flight path changes generated by the autoflight system and for system anomalies that rarely occur. Monitoring for such events on the flight deck during long periods of cruise can be compared to waiting for water to boil, watching paint dry or watching grass grow. The human brain has evolved for active engagement in individual tasks that are challenging or stimulating, yet is less effective at monitoring for events that so rarely occur.

Extensive research in cognitive science has shown that the quality of vigilant monitoring for rare events rapidly declines no matter how hard the individual tries to maintain

Challenges and Barriers to Effective Monitoring

Human factors limitations[1]

- The human brain has difficulty with sustained vigilance;
- The human brain has quite limited ability to multitask;
- Humans are vulnerable to interruptions and distractions; and,
- Humans are vulnerable to cognitive limitations that affect what they notice and do not notice.

Time pressure

- This factor exacerbates high workload and increases errors; and,
- It often leads to rushing and "looking without seeing."

Lack of feedback to pilots when monitoring lapses occur

- Pilots are often unaware that their monitoring performance has degraded.

Design of flight deck systems and standard operating procedures

- Some aspects of automated systems for flight path management are not well matched to human information processing characteristics; and,
- Standard operating procedures may fail to explicitly address monitoring tasks.

Pilots' inadequate mental models of autoflight system modes

- Pilots may not have a complete or accurate understanding of all of the functions and behaviors of the autoflight system on their aircraft.

Corporate climate that does not support emphasis on monitoring

- Inadequate training overlooks the importance of monitoring and how to do it effectively; and,
- Lack of emphasis on monitoring occurs in training and evaluation.

1. See the CAA paper *Monitoring Matters* at <www.caa.co.uk/monitoringmatters> for additional discussion of barriers to monitoring. While beyond the scope of this document, other human factors limitations also affect pilots' ability to monitor effectively (e.g., disorientation, subtle incapacitation, startle reflex, confirmation bias and fatigue). *Monitoring Matters* addresses some of these other issues, and tries to drill down to the root causes of inadequate monitoring and flesh out the factors that influence performance — physiological, psychological, personal, cultural, social factors, etc.

Source: Active Pilot Monitoring Working Group

Table 2

1. See the CAA paper *Monitoring Matters* at <www.caa.co.uk/monitoringmatters> for additional discussion of barriers to monitoring.

vigilance.[2] Also, people are vulnerable to certain attentional biases, such as not noticing one aspect of a visual scene (e.g., mode annunciations on the primary flight display) while concentrating on another aspect — a phenomenon called "inattention blindness." Likewise, when a person's perception of a visual scene is momentarily disrupted, such as when looking away, the person often subsequently fails to notice even large changes in the scene ("change blindness").[3] Also, individuals are vulnerable to thinking they see what they expect to see, a phenomenon called "expectation bias." Inattention blindness, change blindness and expectation bias are not manifestations of laziness, but simply are part of the way everyone's brain processes information.[4] Thus, it is crucial to provide pilots with practical tools to help avoid inadvertent lapses in monitoring and to design the overall human-machine system to enable monitoring with extremely high reliability.

In phases of flight other than cruise, when the flight path is changing (especially when close to the ground), a different kind of challenge is presented to pilots. Approach to landing, for example, requires pilots to complete many tasks concurrently, from controlling the aircraft and monitoring its path, to programming the FMS, responding to ATC, scanning for other aircraft and many more responsibilities — all while maintaining effective monitoring.

These tasks may involve all of the human senses, but flight deck displays put the heaviest workload, by far, on vision. Because the human visual system processes detailed information only from a cone of light about 2 degrees wide, pilots must keep their eyes moving constantly to scan inside and outside the flight deck for the sources of information relevant to the tasks being performed at a given moment.

Auditory sources of information — such as radio transmissions, speech and sounds from crewmembers, alerts, etc. — must also be monitored. The crucial point to remember is that the human ability to divide attention among tasks is quite limited, and usually is accomplished by switching attention back and forth among them, which leaves individuals vulnerable to losing track of the status of one task while engaged in another.[5] Therefore, during high-workload periods of flight, monitoring actually must be interleaved with other tasks that grab attention, pre-empting monitoring and leading to undetected errors.

Although crew resource management (CRM) classes include modules on workload management, these modules typically focus on prioritization and distribution of workload among crewmembers, which are important topics. But little guidance is provided for how to manage attention when juggling concurrent task demands.

What we end up with is a perfect storm, in which alternating periods of high-workload, multitasking demands and low-workload, sustained-vigilance demands collide with a human brain that has difficulty accomplishing either type. What we need is a system of policies, procedures, automated systems design and pilot training that better supports the way the brain processes information and helps pilots monitor effectively in all phases of flight. Implementing recommendations contained in this guide should help meet that need.

3.2 Time Pressure

Late-departing airline flights have a cascading effect on subsequent flights and can wreak havoc on any schedule. Pressure on crews to depart and arrive on time is inherent to many aviation corporate cultures as necessary for operational efficiency, and thus, corporate survival. Not surprisingly, this message is reinforced to pilots in frequent company communications and established corporate goals and policies. A "get it done" approach to flight operations is consequently nearly universal among flight crews.

Time pressure to push off from the gate, however, often compresses preflight procedures and checklists, and reduces flight crews' ability to effectively monitor the operation. In response to time pressure, pilots may develop a habit of rushing, perhaps not even realizing that they are doing so. Unfortunately, rushing makes pilots vulnerable to not noticing that the items they are checking are not correctly set, a phenomenon called "looking without seeing." Combined with numerous ground and cabin crew distractions, it is easy to see why gate operations and taxi to the runway are often hot spots for undetected errors.

Similarly, approaching a runway to land requires, among many other things, simultaneously altering the aircraft's flight path (manually or through automated systems), configuring the aircraft, completing checklists and answering radio calls. An already high workload during this period of flight is exacerbated when ATC induces additional time pressure (issuing

2. Warm, J.; Parasuraman, R.; Mathews, G. "Vigilance requires hard mental work and is stressful." *Human Factors: The Journal of the Human Factors and Ergonomics Society* Volume 50 (June 3, 2008): *433-441, doi: 10.1518/001872008X312152.*

3. O'Regan, J.K. "Change Blindness." *Encyclopedia of Cognitive Science*. <nivea.psycho.univ-paris5.fr/ECS/ECS-CB.html>. 2014.

4. Nikolic, M.I.; Orr, J.M.; Sarter, N.B. (2004). "Why Pilots Miss the Green Box: How Display Context Undermines Attention Capture." *International Journal of Aviation Psychology* Volume 4 (Issue 1): 39–52.

5. For an extended discussion of this problem, see Loukopoulos, L.D.; Dismukes, R.K.; Barshi, I. *The Multitasking Myth: Handling Complexity in Real-World Operations*. Burlington, Vermont, U.S.: Ashgate. 2009.

"Keep your speed up" instructions, a short approach, a runway change, etc.). Compromised ability to monitor in these situations leads to loss of situational awareness and can contribute to undetected errors such as unstabilized approaches.

The combination of high workload and time pressure undercuts monitoring at a time when effective monitoring is crucial.

3.3 Lack of Feedback to Pilots When Monitoring Lapses

Because the aircraft performs as expected the vast majority of the time, as noted, no feedback loop informs the pilots of most lapses in monitoring. For example, usually the aircraft levels off at the altitude that was programmed in the FMS, even though the crew may not be monitoring appropriately. Without an effective feedback loop, pilots may be unaware that their monitoring habits have become degraded or ineffective. This contrasts with active control tasks, such as flaring for landing, in which an attention lapse on the pilot's part provides immediate and forceful feedback, typically leading to immediate corrective action by the pilot. That said, proactive pilots are often able to notice subtle indications that their monitoring is faltering and to correct the situation. Among these subtle indications are missed flight path callouts; not actively looking for pitch, power or roll changes; not actively looking for mode changes; delayed recognition of terrain, traffic or weather; or performing concurrent tasks during flight path transitions.

3.4 Design of Flight Deck Systems and SOPs

Modern autoflight systems are highly sophisticated and reliable though complex. However, it is challenging to design interfaces that present information to pilots in ways well matched to how humans attend to and process that information. An indication of the magnitude of this challenge is that one of the most common errors in monitoring cockpit automation is failure to check flight mode annunciations or to fully process the meaning of these annunciations.[6]

It follows then that flight management automation and related standard operating procedures should be designed to maintain flight crew awareness of critical information. Yet some procedures are timed in ways that conflict with other duties and undercut monitoring — for example, entering last-minute weight and balance information in the FMS while taxiing.

3.5 Pilots' Inadequate Mental Models of Autoflight System Modes

Effective monitoring must be active rather than passive, and requires a correct mental model of the aircraft's operation, especially when operating in vertical navigation modes. Multiple studies have shown that many pilots poorly understand aspects of autoflight modes,[7] in part because training emphasizes correct "button pushing" over developing accurate mental models. Simply stated, it is impossible to monitor a complex system if a pilot isn't sure how to correctly operate that system or what type of aircraft performance can be expected from each autoflight mode. A pilot who has an accurate mental model of the autoflight system can then learn how to use each mode and will be able to accurately predict what the aircraft will do next in a given mode in each specific situation.

3.6 Corporate Climate Does Not Support Emphasis on Monitoring

Effective monitoring requires pilots to ascertain the aircraft's position, track and state by directing attention to flight deck indicators, the actions of the other pilot, verbal and text communications, and the outside environment. Monitoring tasks are diverse and change dynamically throughout the course of a flight. Aviation managers, pilots and instructors may not recognize the huge volume and diversity of monitoring required because it is woven into every task performed throughout the flight. Moreover, many monitoring tasks are subordinate parts of larger procedures (e.g., engine start), and other monitoring tasks are only assumed implicitly, rather than being spelled out in operating manuals.

Possibly because monitoring tasks are voluminous and historically not as explicit and well defined as flying skills, monitoring procedures have not been thoroughly trained and evaluated in the detailed fashion of other procedures. Pilots typically are told *what* to monitor, but they are given little guidance on *how* to monitor. Contributing to this problem is that instructor and evaluator training programs also do not emphasize monitoring, rendering instructors and evaluators ill-equipped to train effective monitoring skills and actions. Because monitoring techniques are not explicitly trained and evaluated, monitoring skills may vary dramatically. Airlines should ask, "How often is a pilot in our company rated as 'unsatisfactory' because of poor monitoring?"

Corporate messages also can undercut effective monitoring. A message that overemphasizes on-time arrivals and departures to speed up line operations, combined with a lack of emphasis and training on monitoring, can create a corporate culture of safety that undermines effective monitoring. The next section presents recommendations designed to enhance this culture and substantially improve monitoring, resulting in fewer undetected errors.

6. Sarter, N.B.; Mumaw, R.J.; Wickens, C.D. (2007). "Pilots' Monitoring Strategies and Performance on Automated Flight Decks: An empirical study combining behavioral and eye-tracking data." *Human Factors: The Journal of the Human Factors and Ergonomics Society* Volume 49 (June 1, 2007): 347–357.

7. Ibid.

Section 4: Recommendations to Improve Monitoring Performance

The difficulty professional pilots have in consistently achieving effective flight path monitoring (EFPM) is inextricably tied to innate human factors limitations as well as to system design, task/workload management, fatigue, distractions, complacency and other factors. Simply exhorting pilots to "do a better job monitoring" or to "pay more attention" will not work. It is necessary to understand the barriers to effective monitoring and to develop specific countermeasures to mitigate those barriers through the design of training, procedures, practices, organizational policy and aircraft systems.

The following recommendations are based on policies, procedures and practices currently in use in some organizations' flight operations, or developed with the expertise and resources available to the Active Pilot Monitoring Working Group, created in 2012 by the first Human Factors Aviation Industry Roundtable. The goal was to produce recommendations that are *practical* and *useful*, and that may improve the safety of any flight operation through increased EFPM.[1] Autoflight systems receive special attention due to their inherent connection to flight path management, and some recommendations address ways to improve training on monitoring skills. All recommendations are grouped into these four separate categories:

- Monitoring practices;
- Procedures, policies and monitoring;
- Monitoring autoflight systems; and,
- Training and evaluating monitoring skills.

Flight operations managers should evaluate each recommendation and reject or adopt/alter it, and then decide whether it fits best into their operations as a policy, procedure or company-approved practice. Any changes will require management support, consistent training, proper skill development, evaluation and *time* to become part of the organization's operating culture.

Monitoring Practices

Recommendation 1
Institute practices that support effective flight path monitoring.

Sometimes, simple practices can promote EFPM and defend against errors. Chances are that many of the following practices are currently in use by many pilots at your organization. Consider formalizing these into policies or company-approved practices and sharing them with the entire pilot group.[2]

- Brief flight path–related plans. For the pilot monitoring (PM) to effectively monitor the flight path, he/she needs to know what path the pilot flying (PF) intends to fly. When the PF shares his/her intentions, it informs the PM what to monitor. For example:
  - "I plan to descend no later than 15 nm [28 km] prior to top of descent."
  - "After crossing Runway 27, I intend to turn left on Alpha."
  - "My intention is to request a right deviation around this storm after we check in with the next ATC [air traffic control] sector."
- During this briefing, encourage the PM to call out any deviation from the briefed plan. Expanding on one of the examples above, the PF might say, "I plan to descend no later than 15 nm prior to top of descent. *Remind me to descend if it looks like I'm going to miss that target.*" Requesting and encouraging this type of deviation call can reduce any interpersonal sensitivity barriers between the pilots.
- Announce deviations from the pre-briefed plans.
- Provide positive feedback for deviation callouts. For example, say:
  - "Good catch, thanks."

1. The goal was never to produce a complete list of recommendations, as no such list exists. Recommendations found in other publications, or practices currently used by other operators may also improve flight path monitoring.

2. For a more comprehensive list of what skilled monitors do, see Appendix D.

- If the PF detects his or her own deviation, he/she should make the deviation callout. For example, say:
  - "I'm 10 kt slow, correcting."
- Maintain manual aircraft handling skills.
  - EFPM requires a well-practiced instrument scan and a thorough knowledge of pitch and power settings. Nothing reinforces this knowledge and skill more effectively than practicing and maintaining recency in manually flying the aircraft.
- Use techniques that help to direct and focus attention, particularly for items not repeatedly scanned. For example:
  - Double point[3] for all changes to the flight path. This helps to minimize looking at something without really seeing or visually processing what is being looked at.
- Manage workload to prioritize flight path monitoring. Plan (or shed) non–flight path workload to minimize the number of tasks to be performed when monitoring is particularly crucial. For example:
  - Avoid discretionary tasks (such as stowing charts, eating, public address system [PA] announcements, logbook entries, etc.) while climbing or descending.
  - Brief the approach prior to top of descent (TOD).
  - Make the last 1,000 ft before level-off a sterile period.
  - Refuse complex ATC clearances (i.e., state "Unable") or ATC clearances that compress time if not previously anticipated and prepared for by the flight crew (e.g., short approach, switch runways, clearance for immediate takeoff).
- Re-verbalize intentions during long climbs and descents.
  - This refocuses the crew on the flight path and may combat prospective memory[4] failures.
  - Maintain high vigilance during changes in flight path (e.g., approaching level-off; course changes; airspeed and pitch changes; turns during taxi).
- Alert the other pilot(s) when you will not be monitoring for any reason. For example, say:
  - "I'm going head-down to review the approach plate."
  - "I'm back with you now."
- Be particularly attentive to the flight guidance automation.
  - Ensure that the PM/PF verifies all flight management system (FMS) changes before they are executed.
  - Consider verbalizing all flight mode annunciator (FMA) changes.
- Design and implement related workload practices that support EFPM. For example:
  - The PM repeats configuration changes before actually moving the control.
  - Normally, the PM should make configuration changes.
- If the PF (usually the captain) needs to personally address a concentration-intensive or distracting flight deck task during taxi:
  - Delay completing the task until on a long, straight taxiway and transfer aircraft control (if allowed by standard operating procedures [SOPs]); or,
  - Stop the aircraft and set the parking brake (advise ATC if necessary).

Recommendation 2
Clearly define the monitoring role of each pilot.

"Crew coordination" is the crew resource management (CRM) term that idealizes a harmonious flight deck where everyone works together toward the common goal of flight safety. Crew coordination begins with defining each pilot's roles and responsibilities during flight. These roles become part of the operating culture of each flight operation.

Historically, many operators labeled pilot roles as PF and pilot not flying (PNF). This made intuitive sense, as only one pilot should be flying the aircraft at any given time, and probably contributed to the common phrases "my leg" and "your leg." However, these titles and phrases in practice could be giving pilots the wrong impression. Saying "pilot flying" and "my leg" subtly reinforces the notion that the PF is somehow more responsible for the conduct of the flight than the PNF. Additionally, the term "pilot not flying" conveys passivity — indicating only what that pilot is *not* doing.

In reality, the PF does more than just "fly" and the pilot not flying does much more than "not fly." About a decade ago, many operators recognized this deficiency in the terms and renamed the PNF role as PM. While this change represented a significant improvement, the terms "PF" and "PM" still have a deficiency in implying that the PF doesn't monitor and the PM doesn't fly, both of which are inaccurate.

To illustrate, consider the respective pilot duties during a simple task: executing an ATC-directed heading change with

3. Some organizations call this the "point and shoot" procedure, in which one pilot points to a new entry in the altitude selector, for example, and the other pilot verbally confirms the entry while also pointing to the correct display.

4. Prospective memory is a form of memory that involves remembering to perform a planned action or intention at the appropriate time. In other words, it means remembering to do a future activity.

Task Allocation Between PF and PM for Heading Change With Autopilot 'ON'

Sequence	PF Duties	PM Duties
1	Monitor radio communications	Read back clearance (with ATC)
2	Acknowledge clearance (with other pilot)	Acknowledge clearance (with other pilot)
3	Rotate heading knob to correct heading	
4	Monitor heading bug (verify correct heading set)	Monitor heading bug (verify correct heading set)
5	Select heading lateral mode	
6	Monitor FMA (verify lateral mode)	Monitor FMA (verify lateral mode)
7	**Autopilot adjusts bank and pitch to execute heading change**	
8	Monitor flight instruments to confirm execution of turn	Monitor flight instruments to confirm execution of turn

ATC = air traffic control; FMA = flight mode annunciator;
PF = pilot flying; PM = pilot monitoring

Source: Active Pilot Monitoring Working Group

Table 3

Task Allocation Between PF and PM for Heading Change With Autopilot 'OFF'

Sequence	PF Duties	PM Duties
1	Monitor radio communications	Read back clearance (with ATC)
2	Acknowledge clearance (with other pilot)	Acknowledge clearance (with other pilot)
3		Rotate heading knob to correct heading
4	Monitor heading bug (verify correct heading set)	Monitor heading bug (verify correct heading set)
5		Select heading lateral mode
6	Monitor FMA (verify lateral mode)	Monitor FMA (verify lateral mode)
7	Adjust bank, pitch and power to execute turn	
8	Monitor flight instruments to confirm execution of turn	Monitor flight instruments to confirm execution of turn

ATC = air traffic control; FMA = flight mode annunciator;
PF = pilot flying; PM = pilot monitoring

Source: Active Pilot Monitoring Working Group

Table 4

the autopilot engaged. First, the PM acknowledges the clearance, and the PF and PM communicate about the instruction as needed (or as SOPs direct) to ensure common understanding of the clearance. The PF then turns the heading knob on the mode control panel/flight guidance panel/flight control unit (MCP/FGP/FCU), as equipped, *observes/verifies (monitors) proper response of the heading "bug,"* selects the heading lateral mode, *observes/verifies proper indications on the FMA*, and *observes/verifies that the aircraft turns to the new heading.* The PM *observes/verifies that the heading bug is set to the assigned heading, observes/verifies proper indications on the FMA,* and *observes/verifies that the aircraft turns to the new heading.*

Note that each time we use the term "observes/verifies," per the definition in Section 1.2, we could just as easily substitute the term "monitors."

This illustration is illuminating because it shows that each pilot accomplishes very similar monitoring tasks. Next, consider the same task flown with the autopilot "OFF," and note that the flight guidance actions (turning the heading knob and selecting the lateral mode) are accomplished by the PM. The tables below compare pilot duties while executing a heading change with and without the autopilot.

This comparison exercise also illustrates that the respective duties of the pilot roles have a more significant similarity and overlap in monitoring tasks than the titles PF and PM would suggest, and that *both pilots have a primary responsibility to monitor the aircraft's flight path.* This is true regardless of whose leg it is. If we are to begin improving monitoring performance by flight crews, each pilot must understand his/her responsibility for monitoring and the importance of the monitoring task. To accomplish this, we must be careful how we label and define these crew roles and joint responsibilities for every flight.

In response to the reasonable suggestion that new terms are needed, working group members realized quickly that choosing more appropriate alternatives was a challenging task. Non-descriptive, generic role labels such as *pilot A* and *pilot B,* or *first pilot* and *second pilot* convey no information about responsibilities and still may inadvertently imply that one role is more important than the other. Other suggestions, such as *pilot controlling flight path* and *pilot not controlling flight* path — though perhaps more accurate — had similar failings in addition to being too complex. Ultimately, this discussion led the working group to simply acknowledge that current terms/labels may be imperfect, and may inadvertently convey the idea that monitoring is the sole responsibility of the PM. The conclusion of the working group was that improved terms/labels for these roles would emerge from further industry efforts and would be published at a later date.

What can be accomplished meanwhile is a review of how operators currently define and implement the roles labeled "PF" and "PM." Here is an example from one major airline:

Pilot flying. The PF's primary responsibility is to fly the aircraft in a safe manner, compliant with regulations, ATC instructions and company policy. The PF should not allow anything to distract him/her from executing this primary responsibility.

Pilot monitoring. The PM's primary responsibility is to ensure that the PF flies the aircraft in a safe and compliant manner. If the PM believes, or is unsure about whether, the aircraft is being operated in a safe and compliant manner, the PM will immediately bring any concern to the PF's attention. The PM should not allow anything to distract him or her from executing this primary responsibility.

Notice how neither definition mentions flight path monitoring as a primary responsibility, however. Perhaps, more appropriate definitions of each role would be similar to these:

Pilot flying. The PF's primary responsibility is to control and monitor the aircraft's flight path (including monitoring the flight guidance automated systems, if engaged). The PF is secondarily responsible for monitoring non–flight path actions (radio communications, aircraft systems, other crewmembers and other operational activities) but he/she must never allow this to interfere with his or her primary responsibility, controlling and monitoring the flight path.

Pilot monitoring. The PM's primary responsibility is to monitor the aircraft's flight path (including autoflight systems, if engaged) and to immediately bring any concern to the PF's attention. The PM is secondarily responsible for accomplishing non–flight path actions (radio communications, aircraft systems, other operational activities, etc.) but he/she must never allow this to interfere with his/her primary responsibility, monitoring the flight path.

Permanently establishing these role definitions in a source document sets the foundation for training effective monitoring skills and begins the culture-transforming mental shift away from "your leg/my leg" to "our leg," a paradigm in which both pilots understand that their primary responsibility is to ensure the safe flight path of the aircraft.

Recommendation 3

Establish among pilots the concept that there are certain, predictable areas during each flight where the risk of a flight path deviation increases, heightening the importance of proper task/workload management.

A study funded by the U.S. Federal Aviation Administration (FAA) to evaluate the training needs of junior first officers (FOs) found that in approximately one-third of the U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) reports reviewed, pilots failed to monitor adequately, "often because they had planned their own workload poorly and were doing something else at a critical time."[5] Furthermore, a 1998 NASA research project concerning flight deck interruptions and distractions reviewed 107 ASRS reports to determine the types of tasks that crews typically neglected at critical moments while attending to other tasks. "Sixty-nine percent of the neglected tasks involved either failure to monitor the current status or position of the aircraft, or failure to monitor the actions of the pilot flying or taxiing," said the NASA report. To avoid such problems, the study suggested that crews "schedule/reschedule activities to minimize conflicts, especially during critical junctions."[6]

Those task/workload management findings can be used to develop strategies to improve monitoring. If pilots could recognize the flight phases when they are most vulnerable to flight path deviations — or little time exists to correct deviations — they could strategically plan workload and manage distractions to maximize monitoring during those areas of vulnerability (AOV). Similarly, if pilots could recognize the flight phases when they are least vulnerable to flight path deviations — or have sufficient time to recover from deviations — they could relax monitoring to some degree and complete tasks that are not flight path–related. This suggests something new: Monitoring requirements vary depending on phase-of-flight circumstances (activity, period and/or area).

Areas of Vulnerability

To perform EFPM during periods of high workload and increased vulnerability to flight path deviations, it's imperative that pilots predict when and where these periods will occur and prepare for them. By "vulnerability," the working group means either the potentially increased likelihood of a flight path deviation or the increased severity of potential consequences if such a deviation occurs. Table 5 (p. 19)

5. Jentsch, F.; Martin, L.; Bowers, C. *Identifying Critical Training Needs for Junior First Officers*. A special technical report prepared at the request of the U.S. Federal Aviation Administration and the U.S. Naval Air Warfare Center Training Systems. May 1997.

6. Dismukes, K.; Young, G.; Sumwalt, R. "Cockpit Interruptions and Distractions: Effective Management Requires a Careful Balancing Act." *ASRS Directline*. December 1998.

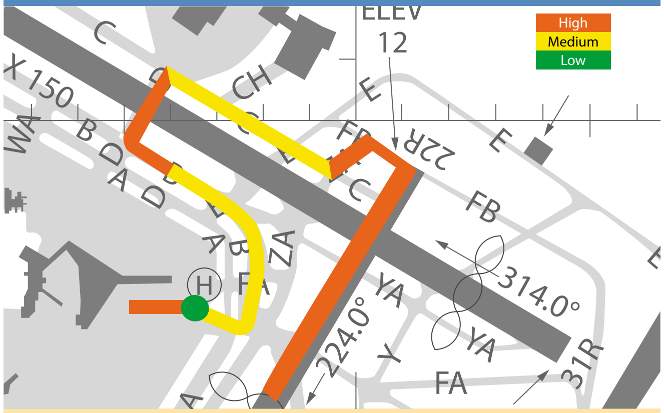
Vulnerability During Flight Path Deviation

Flight Activity (Period)	Level of Vulnerability to a Path Deviation
Taxiing near or crossing a runway	High
Stopped on a taxiway with brakes set	Low
Straight-and-level cruise flight above 10,000 ft	Low
Final approach	High
Climbs and descents	Medium
Within 1,000 ft of level-off while climbing or descending	High
Initiating a course change	High
Initiating a speed change	High
Initiating an altitude change	High
Flight below 10,000 ft (if not already in a high-vulnerability activity/period)	Medium

Source: Active Pilot Monitoring Working Group

Table 5

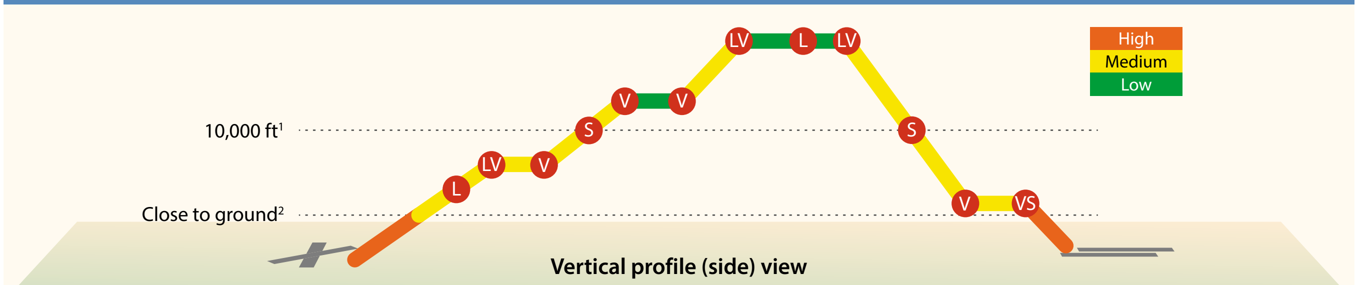
Areas of Vulnerability (AOV) to Flight Path Deviation, Ground Profile Examples



Source: Active Pilot Monitoring Working Group

Figure 5

Areas of Vulnerability (AOV) to Flight Path Deviation, In-Flight Profile Examples



L Lateral trajectory change V Vertical trajectory change S Speed change

Notes:

1. 10,000 ft is used in the United States as the boundary altitude for sterile cockpit rules and for the 250 KIAS speed restriction (both required below 10,000 ft). For the purpose of the AOV model, an altitude of other than 10,000 ft may be chosen, but it is suggested that this boundary match the use of sterile cockpit rules for your operator (or nation/state) for ease of operational applicability by flight crews
2. "Close to ground" may be defined by the operator, but it is suggested that this be an altitude no less than (a) 1,500 ft AGL or (b) the altitude of the surrounding terrain (if terrain threats exist within 5 nm [9 km] of the flight path), whichever is higher.

Source: Active Pilot Monitoring Working Group

Figure 6

shows some examples. For training purposes, the working group diagrammed examples of areas where these flight activities/periods might occur along the flight path during a normal flight. By depicting in red the areas of highest flight path–deviation vulnerability, using yellow to indicate areas of medium vulnerability, and using green to indicate areas of reduced vulnerability,[7] graphical representation examples (Figure 5 and Figure 6) quickly can bring these points to life.

Low AOVs. In this diagram, the green zones depict areas of lowest vulnerability to aircraft path deviations. These are segments where the air/ground path is stable, and where ample time exists to detect and correct possible deviations.

7. Regarding the use of color in figures, the working group's use of green, yellow and red was intended only to create a very simple, easy-to-understand representation of low-, medium- and high-vulnerability areas. The AOV chart (in this report) and this use of colors are for training purposes only, and your organization may want to consider alternate colors (or no colors at all) when training the AOV concept. Regulations govern the use of green, yellow and red for alerts on the flight deck. For additional information on the color-coding requirements used in designing flight deck displays in the United States, see U.S. Federal Aviation Regulations, Part 25, Section 25.1322.

- Low AOVs exist on the ground when the aircraft is stationary and the parking brakes are set. (On the ground, crews can create a green zone any time by simply setting the brakes.)
- Low AOVs exist in stable, straight-and-level cruise flight.

Medium AOVs. The yellow zones in the diagram depict areas of medium vulnerability to aircraft path deviations. These are segments where the time available to detect and correct an air/ground deviation is reduced.

- Medium AOVs exist on the ground during taxi segments that do not involve approaching, crossing, entering or exiting an active runway.
- Medium AOVs exist in flight during climbs and descents.
- Medium AOVs exist in some conditions in flight below 10,000 ft.

High AOVs. The red zones in the diagram depict areas of highest vulnerability to aircraft path deviations. These are segments where the path is changing or when the consequences of a path deviation are most immediate and severe. In high AOVs, the time available to detect and correct a deviation is short.

- High AOVs exist on the ground when approaching, crossing, entering or exiting active runways, and when taxiing in confined spaces or close to obstacles.
- High AOVs exist in flight when initiating climbs/descents and within 1,000 ft of level-offs, or when turning, or when changing speed or configuration.
- High AOVs exist in flight when close to the ground and/or below the level of surrounding terrain.

Armed with awareness of these AOVs, pilots can be taught to recognize when they are entering each of these zones. Now the question is "What should crews do (and not do) in each of these AOVs?" There are two categories of action: The first involves the "sampling rate" of flight path monitoring; the second involves workload management.

Flight Path Monitoring "Sampling Rate"

To monitor the flight path, a pilot must consciously look at many distinct indicators, such as the attitude indicator, airspeed indicator, altimeter, horizontal situation indicator (HSI), FMA, etc. (Often the term "instrument scan" is used as a simplified description of this fairly complex activity.) The specific items to be scanned during flight path monitoring depend on the situational context. In flight, the items to be scanned certainly include the flight instruments and associated flight guidance automation. In visual meteorological conditions, the scene and objects "outside the windshield" must be incorporated into the pilot's scan. When taxiing, the scan must include items such as the situation outside the windshield, the groundspeed readout and the airport diagram for this phase.

Regardless of what is being scanned by the pilot, it is important in training to highlight "sampling rate," the frequency with which a pilot directs his/her gaze and attention to the external situation and flight deck indicators. The appropriate sampling rate is AOV-dependent — meaning that the higher the level of vulnerability to flight path deviation, the higher the required sampling rate. Although no quantitative guidance is available to tell pilots exactly how frequently they must sample their indicators and surroundings, a useful rule of thumb is that the sampling rate must be high enough that pilots would notice an indication of a deviation quickly enough to prevent a problem from getting out of hand.

No objective numeric scale exists to define what scanning frequency constitutes a "high" sampling rate versus a "low" or "normal" sampling rate. For the purposes of this document, simplified working definitions of flight path monitoring (FPM) sampling rates are as follows:

- A *normal sampling rate* is the equivalent of the scanning frequency required of a pilot when hand-flying an aircraft in straight-and-level flight. This implies a rate sufficient to reliably detect changes, to recognize factors that may affect the flight path, and to anticipate the need to shift to a higher sampling rate.
- An *elevated sampling rate* is the scanning frequency required of a pilot when hand-flying an aircraft approaching an imminent change in trajectory or energy (e.g., approaching a turn point, or a descent point, or a configuration-change point).
- A *high sampling rate* is the scanning frequency required of a pilot when hand-flying an aircraft through the execution of a significant change of trajectory or energy.

The appropriate sampling rate for each pilot is also influenced by the division of workload between/among flight deck crewmembers. For example, if the PF has diverted his or her attention to a non–flight path task, then the sampling rate of the PM must increase, or vice versa. Some organizations have instituted procedures to support this concept. For example, if something requires the FO to go "heads down" or "eyes inside" during taxi operations (for example, to reprogram the FMS), good practice would require that the FO announce "I'm heads down." This alerts the captain that he/she is solely responsible for monitoring "outside" and therefore should increase his/her FPM sampling rate.

Task/Workload Management in an AOV

Paying attention to something is a limited-capacity human capability. Monitoring the flight path therefore requires some portion of the pilot's limited available mental capacity. Doing other non–flight path tasks also requires some portion of the total capacity. Attempting to simultaneously perform many tasks (erroneously known as "multitasking") may exceed total available mental capacity (task saturation) and increase the risk that the monitoring task will be omitted.

Because AOVs require more attention (a higher sampling rate) for flight path monitoring, less attention is available for non–flight path tasks. To ensure adequate attention is available for FPM in all AOVs, task management of non–flight path tasks is critical.

Recommended Non–Flight Path Task Management in AOVs

Matching the sampling rate appropriate for the flight crew's FPM with each AOV could help achieve effective flight path monitoring.

High AOVs, as noted, require a high sampling rate. Allocating this level of attention to the flight path requires that other, non–flight path tasks be avoided (or curtailed to the maximum possible extent).

In high AOVs:

- Both pilots must be fully engaged in FPM and have high sampling rates.
- Tasks not related to the flight path (even if those tasks are very important) should be avoided, if possible, until out of the high AOV.
- When essential, time-critical tasks cannot be avoided, flight crews should ensure that those tasks are accomplished by the PM, allowing the PF to maintain a high sampling rate.

Appropriate tasks:

In a high AOV, there is little time to detect and correct flight path deviations. All non–flight path tasks should be considered inappropriate and avoided, if possible, until out of the high AOV.

Medium AOVs, as noted, require an elevated sampling rate. This rate permits some amount of crew attention to be devoted to non–flight path tasks.

In medium AOVs:

- Both pilots must be engaged in FPM at an elevated sampling rate.
- Essential tasks (not related to the flight path) may be accomplished by the PM.
- Neither pilot should engage in any nonessential tasks.

Appropriate tasks:

In a medium AOV, there is more time to detect and correct flight path deviations. This time gives the crew an opportunity to do some short mission tasks. These tasks are usually accomplished by the PM, unless the task is *very* short. Moreover, the appropriateness of doing even short mission tasks is a function of the complexity of the airspace and the complexity of the climb or descent. Examples of short mission tasks include: modifying the FMS route, reprogramming a changed instrument arrival procedure and briefing a new landing runway approach procedure.

- While performing such short mission tasks, the PF retains the responsibility to monitor the actual flight path and ensure that it matches the intended path.
- Only the PM performs non–flight path tasks (e.g., tuning radios, getting out unanticipated charts, talking to flight attendants and ATC).
- Both pilots should endeavor to avoid nonessential tasks.
- While minor changes to the FMS may be entered by the PF, significant changes should be entered by the PM.

Low AOVs allow for a normal sampling rate. By definition, as noted, the aircraft's path on the ground or in cruise flight is unchanging, so the proportion of attention required to be focused on monitoring the path of the aircraft is lower than for medium and high AOVs. Nonessential tasks may be accomplished. At least one pilot must maintain FPM focus — but at a *normal* sampling rate.

- *Both* pilots are engaged in FPM, but at a normal sampling rate. (As described above, this should never drop below a rate at which the flight crew will detect indications of faulty monitoring.)
- Both pilots may accomplish other (non–flight path) tasks — but not at the same time — as long as an adequate sampling rate for FPM is maintained. Non–flight path tasks should be accomplished by the PM whenever possible.
- Pilots should focus on completing anticipatable, non-flight path–related tasks in low AOVs to proactively reduce their task loading during expected medium and high AOVs.

Appropriate tasks:

- Since the required sampling rate is low, pilots may use the additional available time to prepare for higher AOVs. This is also an opportunity to engage in normal, nonessential tasks, including normal conversations and eating. Low AOVs offer excellent opportunities to organize maps and charts, review future routes and destinations, check weather and brief upcoming procedures.

Table 6 (p. 22) shows an example summary of the AOV concept in chart form. Training organizations may wish to combine

Continued on p. 23

Example AOV Chart of Desired FPM Behaviors

Level of Vulnerability	Definition: In Flight	Definition: On Ground	Desired FPM Behaviors: PF/PM	Desired FPM Behaviors: FPM Attention and Sampling Rate	Desired FPM Behaviors: Workload Management Strategy
High (red areas)	All changes of: Lateral trajectory Vertical trajectory Speed within 1,000 ft of level-off while climbing or descending All flight close to the ground	Approaching, crossing or entering a runway or tight space	Crew (general)	Both pilots maintain total focus on flight path scan at a high sampling rate	Avoid any task not related to flight path Unavoidable (especially pop-up) tasks must be delayed until exiting high AOV, or accomplished by PM
			PF	Undivided attention to flight path	Avoid all tasks not related to flight path
			PM	Undivided attention to flight path, if possible	Avoid all tasks that are not essential Avoid all tasks not related to flight path Essential and time-critical tasks (not related to flight path) completed if both brief and unavoidable, but focus must be returned to flight path as soon as possible
Medium (yellow areas)	Climbs and descents Flight below 10,000 ft if not already in a high area	All other ground movement	Crew (general)	At least one pilot maintains focus on flight path scan at an elevated sampling rate	Avoid any task that is nonessential Essential tasks may be performed by PM; keep PF focused on flight path
			PF	Undivided attention to flight path, if possible	Avoid all nonessential tasks Avoid tasks not related to flight path, if possible Essential, unavoidable tasks requiring PF involvement may consume only very brief periods of attention — return focus to flight path immediately
			PM	Flight path is primary, but attention may be divided between flight path and essential tasks	Avoid nonessential tasks Essential, non-time-critical tasks (not related to flight path) may be performed but return focus to flight path at frequent intervals
Low (green areas)	Straight and level cruise above 10,000 ft	Stopped with parking brake set	Crew (general)	At least one pilot keeps flight path as top priority, but at a normal sampling rate	Proactively accomplish known tasks to reduce future workload in anticipation of upcoming medium and high AOVs Tasks not related to flight path preferably done by PM; keep PF focused on flight path
			PF	Flight path is primary, but some division of attention to complete other tasks is permitted	Minimize task not related to flight path Ensure frequent return of attention to flight path
			PM	Flight path is primary, but some division of attention to complete other tasks is permitted	Minimize task not related to flight path Ensure frequent return of attention to flight path

AOV = areas/area of vulnerability; FPM = flight path monitoring; PF = pilot flying; PM = pilot monitoring

Source: Active Pilot Monitoring Working Group

Table 6

this chart with the examples of AOV profiles, previously shown, to create a training aid for use in simulator briefing rooms. An example of what this combined chart might look like, with suggested training slides, is included in Appendix B.

Use scenario-based training to instruct flight crews in the use of the AOV concept as a task-management tool.

To briefly summarize, the AOV concept enables application of a dynamic task-management tool that reminds flight crews about the importance of scheduling non-flight path–related tasks during the portions of the flight anticipated to be the least vulnerable to the risk of flight path deviations. Completing non-flight path–related tasks during low AOVs enables crews to utilize a high or elevated sampling rate during the higher AOVs, which increases effective flight path monitoring.

One method of incorporating the AOV concept is to enlist the PF to draw a color-coded AOV flight profile for a planned line-oriented flight training (LOFT) scenario on a white board prior to each simulator LOFT session. Having a sample AOV chart (and flight profile as shown in Recommendation 3) posted in the simulator briefing room will facilitate this training. The AOV profiles posted will differ, however, based on the requirements for each LOFT scenario.

A brief discussion between the pilots achieves crew coordination for scheduling the completion of non-flight path–related tasks, and sensitizes the crew to the areas where a high sampling rate is required in FPM. This exercise is a critical first step in threat and error management (TEM) by simulating a dialogue, which helps the flight crew create a shared mental model of the intended flight to achieve the following four responses: *anticipate* threats when possible, *identify* pop-up threats when they occur, *detect* crew errors and *recognize* undesired aircraft states. The premise is that the better a crew's monitoring performance, the more likely the crew will be in position to apply one of these four responses to effectively manage a threat, error and/or undesired aircraft state.[8]

As noted, an AOV profile drawn by a pilot for a specific flight may differ greatly from the example AOV profile in this report. For instance, it is possible on a short flight that never gets above a few thousand feet that the majority of the flight profile would be in a "red" AOV zone. In this instance, crews should proactively consider one or more of the following actions:

- Use sterile flight deck procedures for the entire flight;
- Pre-position the approach plates before engine start/taxi;
- Check destination weather before engine start/taxi;
- Delay the stowing of any charts (including departure charts) until after taxi in/shutdown; and,
- Coordinate for reduced communication between the flight deck and the cabin (if applicable).

Anticipating and briefing AOVs improves EFPM and is a core defense that enhances overall TEM performance.

The goal of this training, and other training recommendations that follow, is to apply the AOV concept during actual flights to increase EFPM. Operators can encourage this by procedurally including AOVs in pre-departure briefings or implementing them as a company-identified best practice.

Recommendation 4

Practice interventions to maintain effective monitoring or to resume effective monitoring if degraded.

At times, flight crews will find themselves in high-workload situations that can negatively affect situational awareness (SA) and flight path monitoring. Pilots usually describe these periods as being "behind the aircraft." Often, there are indicators of both degraded SA and degraded FMP. An example is missing the "1,000 ft to level-off" altitude callout. Frequently missing this callout suggests that the pilot is not effectively monitoring.

Specific skills can be employed by the crew to avoid becoming overloaded and to protect SA and FPM. With clearly defined standards and properly trained instructors and check pilots, these skills can be taught and evaluated in the simulator. In Table 7, p. 24, and Table 8, p. 25, the working group recommends interventions to protect SA and FPM capabilities.

Recommendation 5

Implement policies and practices that protect flight path management from distractions and interruptions.

Distractions and interruptions degrade flight path monitoring. According to a 2012 IATA STEADES study[9] of FMS data-entry errors, common route changes at critical times of flight were cited as the top contributor to FMS data-entry errors because they "potentially add(ed) an unnecessary distraction and increase in the workload." The second most common contributor to FMS data-entry errors was crew distraction resulting from operationally related threats such as aircraft

8. For further information on the link between monitoring and TEM, see Appendix A, "Monitoring Link to TEM Performance" by The LOSA Collaborative.

9. International Air Transport Association. STEADES: Safety Trend Evaluation, Analysis and Data Exchange System. "FMS Data Entry Errors," 2012, Issue 4.

General Threats to EFPM and Intervention Examples

General Threats to EFPM	Intervention Examples
Anticipatable high task loading in flight (any area of vulnerability)	Anticipate the potential for high workload. Give yourself more time to complete tasks by, for example: Reducing airspeed, slowing descent rate; and/or, Requesting vectors or a turn in holding.
Unanticipated task loading in medium AOVs In flight: Reroute Runway change Non-normal situation On the ground: Complex reroute	The captain should designate one pilot to fly the airplane and one pilot to complete the task. Verbalize relevant tasks before and after the PM goes head down to work on the task and/or exit the medium AOV by "creating" time (slow down, request vector or enter holding).
Unanticipated task-loading in high AOVs; for example: Bleed air temperature–controller trips off after takeoff Non-normal situation on final approach Reroute during course change Call from cabin on the ground	Either: Defer the task until out of the high AOV (e.g., for the bleed-air trip or reroute). Or: Exit the high AOV (e.g., for the non-normal task on final approach–go-around).
PM preoccupied with a non-flying task	If in a high AOV: Defer the task. If in a medium AOV: Announce "head-down" to alert the other crewmember. Verbalize any flight path constraints or restrictions to reinforce short-term memory.
PF preoccupied with a non-flying task	Transfer control or transfer the task.
Rapid or large airplane energy changes (with potential for sensory overload and/or sudden reversion to hand-flying). For example: Go-around Wind shear Terrain escape maneuver Large deviation from intended aircraft state	When surprised, fly the airplane. Use pitch and power as primary references.
High workload at low altitude (potential for overload or disorientation at low altitude)	This can be very dangerous. Preventive strategies include: Identifying precursors to flight crew overload or disorientation at low altitude (see Table 8). Including the "Enhanced Monitoring Briefing" as part of the approach briefing (see Table 8). Going around if targets are missed or there are indications of flight crew overload.

AOV =areas/area of vulnerability; EFPM = effective flight path monitoring; PF = pilot flying; PM = pilot monitoring

Source: Active Pilot Monitoring Working Group

Table 7

malfunction and cabin and ground events. As noted in the threat section of this study, cabin crew and ground crew–initiated distractions have also played a role in flight crew omissions of cross-verification (monitoring).

One way to accomplish EFPM, therefore, is to prevent distractions from diverting the pilot's focus from flight path management during high-workload periods of flight. Flight operations management should implement sound policies and SOPs to help pilots manage these distractions. Humans make errors, and pilots are no exception. The best defense to keep these errors from causing an undesired aircraft state may be two focused pilots who are not distracted by other duties.

Precursors to Overload and Intervention Examples

Precursors to Overload or Disorientation at Low Altitude	Intervention Examples
Clearance that reduces time in flight; for example: Short approach Late runway change	If not planned and previously briefed, refuse the clearance (tell ATC "Unable").
Challenging approaches Marginal conditions/potential for deteriorating conditions; for example: Some combination of short runway, marginal braking action, tail wind, crosswind Mission/goal fixation	**Enhanced Monitoring Briefing** Review the overall plan carefully Identify areas where teamwork can help Agree not to accept last-minute changes and expedited approaches ("Unable") Stress the importance of timely and specific deviation callouts Stress that the PM monitor basic instruments Set altitude targets on approach Set configuration targets Set bottom lines Land "true to plan" Discuss the potential for goal fixation Stress the need to go around, consistent with SOP, at the first sign the crew is behind

ATC = air traffic control; PM = pilot monitoring; SOP = standard operating procedure

Source: Active Pilot Monitoring Working Group

Table 8

Recommendation 3 said that the AOV concept should be an established part of training so that pilots remain aware of the need to manage workload during every flight, commensurate with the fluctuating criticality levels in monitoring the flight path. Ideally, flight crews should be able to recognize AOVs involving anticipatable high workload and when they have been thrust into an unanticipated AOV involving high workload (e.g., non-normal situations, complex clearances, etc.). They should be able to schedule nonessential tasks during known periods of low workload and to shed nonessential tasks when they are thrust unexpectedly into a high AOV. These efforts will allow crews to minimize distractions and to consistently achieve EFPM.

Flight operations managers can encourage this behavior and improve pilots' monitoring by creating policies that list the appropriate tasks to be completed in each AOV. Due to the fluid nature of AOVs, a policy works better than a procedure because a policy increases awareness of the importance of task management during high AOVs, yet allows the flexibility that crews need to complete all tasks in a dynamic environment.

Sample Wording of Policy for Each AOV

To improve flight path monitoring and reduce the risk of flight path deviations in all phases of flight, flight crews should endeavor to schedule and complete nonessential and non-flight path–related tasks during periods of operation in lower AOVs. Examples of allocation of nonessential and non-flight path–related tasks (from Recommendation 3) for each AOV level by pilot role are listed below.

High AOV

- PF — Flight path management–related tasks only.
- PM — Flight path management–related tasks only.

Medium AOV

- PF — Flight path management–related tasks only.
- PM — Non-flight path management–related tasks as necessary (updating weather, briefing runway changes, etc.).

Low AOV

- PF — Non-flight path management–related tasks as necessary (updating weather, briefing runway changes, etc.); nonessential tasks (eating, casual conversation, filling out forms, communicating with company, informational PA announcements) as long as one pilot is monitoring the flight path.
- PM — Non-flight path management–related tasks as necessary (updating weather, briefing runway changes, etc.); nonessential tasks (eating, casual conversation, filling out forms, communicating with company, informational PA announcements) as long as one pilot is monitoring the flight path.

Individual operators can be as specific or as general as they desire about specifying the tasks. The point is that potentially distracting tasks, such as casually conversing with a jump seat occupant, eating or filling out customs forms are inappropriate during times requiring heightened monitoring. Having a policy in place that reflects the appropriateness of these tasks gives instructors and evaluators a tool to critique — and to discourage — this type of behavior.

Additional policies that promote effective monitoring include:

- Encouraging (not requiring) the PM (instead of the PF) to make FMS data entries during high AOVs;
- Instituting sterile flight deck procedures not only during all flight below 10,000 ft but also during all high AOVs, including within 1,000 ft of an altitude restriction;
- Encouraging sterile flight deck procedures during periods of hand-flying (unless the aircraft type is always hand-flown);
- Ensuring that one pilot stays fully engaged in monitoring the flight path when the crew is distracted or during interruptions to normal crew duties; and,
- Prohibiting the completion of checklists or starting engines during taxi in high AOVs (in taxi hot spots, during low visibility or when crossing active runways).[10]

Recommendation 6

Practice interventions to resume effective monitoring after distractions and interruptions.

Although the AOV concept and associated policies are designed to reduce the number of times crews are distracted during high-workload periods, certain legitimate flying and non-flying tasks will inhibit EFPM. These include, but are not limited to:

- Scheduled rest periods on international flights;
- Restroom breaks;
- Looking down to organize charts; and,
- Communicating with the cabin crew, company, etc.

Upon returning to monitoring duties, the pilot should:

- Confirm pitch and power settings;
- Restate altitude constraints or clearance limits; and,
- Share/verify new ATC clearances.

Operators may be able to identify a memory-jogger acronym or a standardized scan pattern to help flight crews remember the action items necessary to regain SA. The working group recommends that the returning pilot verbalize these actions to alert the other crewmember(s) that monitoring has been resumed.

Recommendation 7

Promote policies, procedures and practices to improve monitoring of altitude changes.

> *The most common monitoring deviation was omitting a callout or making it late. By far, the most common example of this subcategory (137 of ... 211 instances) was omitting the "1,000 ft to go" callout before altitude level-off, or making this call only after prompting by the automatic chime.*

This statement, quoted from a 2010 study by Dismukes and Berman,[11] clearly reveals that the common SOP of crews calling out an impending altitude restriction is not, by itself, sufficient. To prevent altitude deviations, SOPs that support altitude awareness must be strengthened. For example:

- Adopt a policy and associated task management that allow one pilot to monitor the flight path during all climbs and descents;
- Adopt a policy to include the last 1,000 ft before a level-off as a sterile flight deck period, allowing both pilots to focus on the last segment of altitude capture;
- Both pilots should point to and confirm that a new altitude has been set in the altitude-select window;
- The PF (or the PM, if hand-flying) should select pitch mode on the MCP/FGP/FCU;
- The PF, as the primary flight path manager/monitor during climbs and descents, should point to each FMA pitch mode change and verbalize the correct mode; for example, "Out of 10,000 for 13,000, VNAV SPD [vertical navigation speed]";
- The PF makes the 1,000-ft callout. The PF includes the *anticipated* FMA pitch mode at level-off; for example, "1,000 to go, expect ALT HOLD [altitude hold]";
- The PM calls out what he/she sees; for example, "Out of 12 for 13,000"; and,
- The PF calls out the pitch mode at altitude capture, for example, "ALT HOLD."

10. Refer to FAA Advisory Circular 120-71A, "Standard Operating Procedures for Flight Deck Crewmembers," for additional examples of how to improve monitoring during taxi.
11. Dismukes, R.K.; Berman, B. (2010). "Checklists and Monitoring in the Cockpit: Why Crucial Defenses Sometimes Fail." NASA Technical Memorandum. NASA/TM-2010-216396.

Recommendation 8

Emphasize the effects that emergency and non-normal situations have on monitoring.

High AOVs are defined, predictable areas of flight that are particularly vulnerable to flight path deviations, but there are also specific *situations* in which crews may be susceptible to lapses in flight path monitoring. This section describes one of those situations: monitoring during emergency/non-normal situations.

Emergency/non-normal situations may increase flight crew workload and stress as follows:

Workload Effects. When an emergency or non-normal situation occurs, the crew must not only continue to manage the tasks normally associated with their current phase of flight (and factors affecting the flight such as weather, traffic, terrain, etc.) but must also concurrently manage a host of additional tasks, including:

- Interpreting the indications of a non-normal situation and selecting the appropriate non-normal procedure;
- Executing the non-normal procedure;
- Determining the effect of the non-normal situation on the mission and choosing a course of action (continue as before, descend, divert, etc.); and,
- Communicating/coordinating with additional stakeholders affected by the situation (ATC, company, cabin crew, passengers).

As discussed earlier, flight path monitoring requires a portion of each pilot's available attention and, as task loading increases, it is essential to preserve sufficient attention for effective flight path monitoring.

Stress Effects. When under stress, a pilot's attention narrows (this is also called "tunneling").[12] As defined in a 2005 NASA study, "Tunneling restricts scanning the full range of environmental cues, causing the individual to focus narrowly on what are perceived to be the most salient or threatening cues. Thus, under stress, a pilot may focus on a single flight deck indicator and not notice other indications also relevant to [the] situation."[13] Recognizing the normal human susceptibility to this effect points to the importance of intentionally prioritizing flight path monitoring during a non-normal situation.

Monitoring During Emergency and Non-Normal Situations

The increased workload and tunneling effects caused by the onset of an emergency/non-normal situation reduce flight path monitoring ability. According to a NASA review of incident reports submitted to NASA's ASRS, one of the biggest hazards of non-normal situations is becoming distracted from other flight deck duties.[14]

ASRS Report 124063

"We had just leveled off at 33,000 ft going direct to [Palmdale VOR]. We received a call from the flight attendants that a water leak in the right aft lavatory had developed. Water was running and could not be turned off. The FO was flying the airplane. I asked him to look up in the operating manual how to shut the water off. He was reading the book to me and we were discussing with the flight attendants how to shut the water off. At this time, we flew over [Palmdale VOR] where we were supposed to make a 60-degree left turn to intercept J6. We then realized we missed our turn and turned to get back on course. We went 15–20 [nm (28–37 km)] off course from J6. No doubt flying the airplane is the most important thing. We paid too much attention to a problem with the airplane and forgot the most important thing — fly the airplane.[15]… One [pilot] flies the airplane at all times, while the other crewmember solves the problem."

This report illustrates that flight path deviations can occur due to failure to monitor — even when an aircraft is in a low AOV. In this case, the aircraft was in level cruise flight at the onset of the non-normal situation, yet the crew allowed its attention to be "tunneled" toward resolving a relatively minor aircraft malfunction. As the flight approached a fix where a course change was required (a high AOV due to change of lateral trajectory), no one was monitoring the flight path, resulting in a 15–20 nm course deviation.

Workload and stress increase during emergencies and non-normal situations and, because of that, pilots need to increase the priority of flight path monitoring during these events. This should be considered when developing SOPs and training curricula for EFPM.

The stress and the extra tasks that must be completed during emergency and non-normal situations can make it difficult

12. Burian, B.K.; Barshi, I.; Dismukes, K. (2005). "The Challenge of Aviation Emergency and Abnormal Situations." NASA Technical Memorandum (NASA/TM-2005-213462). Retrieved from <ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20060023295_2006008691.pdf>.
13. Ibid, p. 5.
14. Dismukes, K.; Young, G.; Sumwalt, R. (1998). "Cockpit Interruptions and Distractions." *ASRS Directline*, Issue 10, pp. 4-9. Retrieved from <asrs.arc.nasa.gov/docs/dl/DL10.pdf>.
15. The working group believes that the captain's use of the term "fly the airplane" included both making proper control inputs and monitoring that those inputs had the desired effect on the aircraft's flight path.

to take the time, or have the mental "bandwidth" available, to effectively monitor the flight path. Furthermore, the way that workload between two crewmembers is typically divided during these events — one flies the airplane and handles the radios while the other completes non-normal checklists — can make it more difficult for each pilot to cross-check the actions of the other. The working group makes the following recommendations:

- At the onset of any emergency/non-normal situation, *ensure the PF role is clear* and *make EFPM a specific priority for the PF*. This recommendation is not new — most operators have for decades had a policy stating that, in the event of a non-normal situation, "fly the airplane"[16] is always the first step. However, practitioners have been saying this for so long, and the commercial air transport industry's track record is so notably imperfect, that a reemphasis of this point seems warranted.
- In the event of an emergency/non-normal situation, *reduce the AOV level if possible.* If the non-normal situation occurs in a high AOV, try to put yourself in a medium or low AOV. If in a medium AOV, try to put yourself in a low AOV. If in a low AOV, try to stay there. As described earlier, the lower the AOV, the lower the criticality of FPM. Since non-normal situations limit each pilot's capacity for FPM, it is wise to lower the AOV-related demand for attention.
- For example, if a non-normal situation occurs on approach (high AOV), go around and, if possible, climb to a safe altitude and level off (moving to a medium or a low AOV). Also, if a non-normal situation occurs while taxiing, stop, advise ATC and set the brake, which puts you in a low AOV.

Procedures, Policies and Monitoring

Recommendation 9
Review current operating procedures for conflicts with operating policy.

During the dynamic line operations of air carriers, conflicts sometimes occur between policies and procedures although they work well during idealized "linear" training scenarios. Here are a few examples where the problematic design of procedures inhibited effective flight path monitoring and contributed to error vulnerability during line operations.[17]

Procedures That Have Inhibited EFPM

- Prescribing that the reconciliation of final weight and balance numbers and FMS entries be done just after pushback. This usually has resulted in this task being performed at times of increased risk during pushback, engine start and initial taxi-out on a congested ramp.
- An approach checklist that required suspending the checklist until an appropriate time occurred to advise the flight attendants to be seated on final approach. (The airline revised this checklist to correct the problem during the course of the study.)
- Requiring the PM to make all FMS data entries (even minor ones), overloading this pilot during descent and approach, when he/she was busy with other tasks.

Some aircraft operators (including major airlines) have performed an analysis of their actual operational environment to look for error "hot spots" that could indicate a checklist or procedure conflict with the operating policy. These analyses have suggested ways to improve the timing and structure of checklists to reduce competing task demands and distractions (see Loukopoulos et al., 2009).[18]

As you begin to review your operation, look for places where you have higher occurrences of errors, because undetected errors may represent a failure to monitor. Use flight operations data and safety data to identify specific places in the normal operation where pilots frequently become rushed in performing particular procedures. You may discover that there are many operational tasks that you have added or altered over time. They may seem to have served your operational goals, but inadvertently have increased the flight crew's vulnerability to reduced monitoring or have increased their incentive to rush.

For example, does your policy allow flight crews to make cabin PAs during descent for approach and landing? Does your policy allow crews to start an engine while taxiing across an active runway? Does your policy allow engine starts in complex taxi environments or while taxiing in low visibility? Do you have specific procedures that have unintended consequences, such as motivating pilots to set the flaps for takeoff while approaching taxi hot spots? Are there particular airports or time periods where undetected errors occur relatively frequently?

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16. Again, the working group believes the term "fly the airplane" includes both making proper control inputs and monitoring that those inputs have the desired effect on the aircraft's flight path. This distinction should be made clearer in some operators' related SOPs.

17. Dismukes, R.K.; Berman, B. "Checklists and Monitoring in the Cockpit: Why Crucial Defenses Sometimes Fail." NASA Technical Memorandum NASA/TM-2010-216396, 2010.

18. Loukopoulos, L.D.; Dismukes, R.K.; Barshi, I. (2009). *The Multitasking Myth: Handling Complexity in Real-World Operations.* Burlington, Vermont: Ashgate, 2009.

While evaluating problematic procedures for FPM vulnerabilities, analyze them to see if any of the following could be contributing factors:

- Procedures that do not specifically define what is to be verified;
- Procedures that combine multiple verifications into a single checklist item, making it easy to omit one or more verifications;
- Procedures that encourage the human tendency to "look without seeing" when performing a routine repetitive task; and,
- Periods in flight operations when pilots reduce or cease their monitoring duties to complete operationally convenient tasks (passenger PAs, calls to station coordinators, going off-frequency to coordinate passenger connection information, etc.).

Successful analyses performed for large flight operations have used the following process:

1. List all operational procedures or demands that are typically scheduled at each phase of flight. Divide these for analysis by pilot position.
2. Annotate the related events, tasks and prerequisite information that positively or negatively affect the completion of each task.
3. Using operational and safety data, along with subjective experience, list the errors committed while completing each task.
4. Categorize each error by causes and contributing factors.
5. Collect examples of recommended practices that pilots can use to complete each task and to avoid committing errors.
6. Evaluate proposed changes of procedures that eliminate or mitigate errors and conflicts while incorporating effective recommended practices.
7. Evaluate proposed changes through flight simulator testing and controlled, line operations–testing environments.
8. Institute the new procedures. Share the background and reasoning behind each change with the line crews to improve their understanding and gain their support.
9. When developing checklists, minimize their length and complexity to decrease the risk of introducing monitoring errors.[19]

What you may discover is that many operational tasks can be moved or omitted to preserve the most focused and effective FPM practices. Following are two practical examples of recommended practices that have been successfully incorporated in flight operations to improve monitoring and reduce errors:

- Procedures such as *double pointing* focus both pilots' attention on the task performed and reduce vulnerability to the "looking without seeing" error. In this procedure, one pilot points to a new entry in the altitude selector (for example) and the other pilot verbally confirms the entry and — in some operations — also points to the display. This procedure illustrates a general principle that is especially important for checklist use: Execution should always be deliberate and not rushed, so that the executive function of the brain is able to track and oversee the largely automatic operation of highly practiced actions. An important feature of pointing to and verifying the FMA is to confirm that the aircraft has entered the correct mode, not just that the value has been set or the light is on.
- *Explicitly defined callouts* make it easier to know when and how to alert the PF. In a 1995 research report, Besco[20] advocated escalating callouts to alert the flying pilot to deviations: probing, alerting, challenging and — if all else fails — verbalizing an emergency warning.

Recommendation 10
Review the specific monitoring-related procedures that standards pilots are not willing or able to enforce.

Consider re-categorizing as *policies* any procedures that frequently allow for pilot judgment in certain circumstances. Consider re-categorizing as *practices* any procedures with routinely allowed variations by pilots. The working group estimated that the "1,000 ft to go" callout was missed around one-third of the time, which raises the question of the effectiveness of this callout and whether it should be revised in some way.[21]

Pilots notice what is being evaluated by their companies during check rides and line checks, and what is not. If proper checklist use or unstabilized approach callouts are not strongly emphasized, pilots could perceive these to be less important than "getting the airplane on the ground on time."

19. Degani A.; Wiener, E. "Human Factors of Flight-Deck Checklists: The Normal Checklist." NASA Ames Research Center, May 1990.

20. Besco, R.O. "Releasing the hook on the copilot's catch 22 (crewmembers' decision making)." In *Proceedings of the 39th Annual Meeting of the Human Factors and Ergonomics Society*, pp. 20-24, San Diego, California, 1995.

21. Dismukes,R.K.; Berman, B. (2010). "Checklists and Monitoring in the Cockpit: Why Crucial Defenses Sometimes Fail." NASA Technical Memorandum NASA/TM-2010-216396, 2010.

Operators should evaluate how realistic their official, bottom-line requirements are (e.g., executing a missed approach if the aircraft is not stabilized at a specified altitude on approach) in actual line operations. If the official requirements are too idealistic or too conservative to be applied realistically and consistently during line operations, they should be modified. If the operator truly requires the prescribed actions without exception, these actions must be strongly reinforced in all training and evaluations, and the reasons why exceptions cannot be made must be explained clearly. The worst of situations is when a bottom-line requirement is routinely violated for whatever reason. This promotes the normalization of deviance across all areas of flight operations.

In other situations, the PM's decision may be more reasoned. For example, at the point at which a go-around from an unstabilized approach is prescribed by SOP (typically 500 to 1,000 ft above ground level), the PF may have managed to get the aircraft properly configured for landing, on glideslope and localizer, with airspeed and descent rate on target, but not yet have the engines spooled up as required.

Technically, the PM at this point (according to some operators' SOPs) should call "unstable, go-around." He/she might choose not to do so, however, seeing that the PF recognized the situation and was about to advance the throttles. This example illustrates a difficult tension between writing SOPs to cover critical situations and allowing pilots to exercise reasonable judgment.

On the one hand, if the SOP only *recommends* — instead of *mandates* — going around at this point, some pilots may use the latitude to continue unstabilized approaches far too close to the ground. On the other hand, if operators officially state that pilots are not to deviate at all from unstable approach criteria — but at the same time strongly encourage them to aggressively pursue on-time performance — then conflicting goals exist. If company leadership does not provide realistic guidance on how to resolve these competing objectives, pilots are likely to conclude that SOPs may be safely ignored. This "wink and nod"[22] stance may lead to widespread deviation from all SOPs for pilot convenience or company profit.

Thus, if companies intend that their bottom-line requirements be adhered to without even small variations, this intention must be strongly emphasized in all training and evaluations. If pilots are allowed to exercise judgment and to deviate from a policy or procedure in specific situations, the limits of deviation should be discussed explicitly. Consider re-categorizing as *policies* those procedures that frequently allow for pilot judgment in certain circumstances. To reiterate, consider re-categorizing as *practices* those procedures with routinely allowed variations. In any event, it is crucial that flight crews know which deviations are allowed and which are not, and that management, instructors, check pilots and line pilots apply these standards evenly.

Recommendation 11
Analyze corporate messages — whether explicit or implicit — that conflict with emphasizing good monitoring.

Operators should systematically analyze their entire body of explicit and implicit messages — as understood by their pilot group — to balance/correct perceptions of competing safety and business goals. Consciously or unconsciously, pilots may allow their concern with on-time performance to rush their execution of checklists and to short-change monitoring. Management may, deliberately or not, be encouraging this behavior by over-emphasizing on-time performance.

Because rushing substantially increases pilots' error rates, company leadership should carefully examine the trade-offs of policies such as reducing the time allowed for turns (the time between landing and pushing back for the next leg of the trip). Also, because of adverse economic conditions, many companies now strongly emphasize reducing fuel use and/or fuel upload, and this can influence pilots' decision making in unintended ways. For example, flights with minimum reserve fuel on arrival may require crews to expedite executing non-normal checklists, which in turn can distract from effective flight path monitoring.

Operational and safety data provide information that reflects how well checklists and monitoring are being performed. Feedback to the pilot group from all these sources of data should include a realistic discussion of company expectations on balancing competing goals.

Recommendation 12
Institute policies/procedures/practices to ensure common understanding among crewmembers of ATC clearances.

Receiving, reading back and executing ATC clearances is an important task on any flight deck. Special attention to improving monitoring of this task is warranted because undetected errors in complying with ATC instructions generally result in a flight path deviation. Combining the following elements into SOPs can improve pilots' ability to accurately monitor and comply with ATC clearances:

22. This commonly used phrase suggests that while one thing might be publicly stated or formally printed, what is actually intended or what will be enforced may be something rather different.

- Educate flight crews that communicating with ATC is an important task;
- Require both pilots to listen to ATC clearances;
- Always use the standard phraseology for the theater of operation;
- Share the latest ATC clearance when a pilot completes a "head-down" task;
- Encourage the PM to write down complex taxi or flight clearances (for prospective-memory protection);
- Require the captain to verbally repeat all taxi clearances after the FO reads back the clearance to ATC; and,
- Encourage clearance verification if redundancy is lost or if there is any doubt.

Monitoring Autoflight Systems

Monitoring autoflight systems for flight path management already has been highlighted as it pertained to the scope of the report. In Section 1, the working group said, "The first action of the working group was to limit the scope of this document to *monitoring of the aircraft's flight path* because errors that result in deviations to the intended flight path ultimately lead to accidents."

Flight crews' increased use of autoflight systems to control the flight path has led to the identification of "new tasks and errors." Use of automated systems has been a factor in flight path deviations that resulted in accidents (almost 20 percent of accidents reviewed) and major incidents (approximately one-third of major incidents reviewed).[23] These tasks and errors were related to the operation and the monitoring of these systems. For example, the following statement came from the NTSB's final report findings for the Asiana Airlines Flight 214 accident:

> *As a result of complexities in the [Boeing] 777 AFCS [automatic flight control system] and nadequacies in related training and documentation, the pilot flying had an inaccurate understanding of how the autopilot flight director system and autothrottle interacted to control airspeed, which led to his inadvertent deactivation of automatic airspeed control.*[24]

Factors associated with errors in using and monitoring automated systems are many, including:

- Systems are complex. Training for routine operations is relatively easy, but training extensive knowledge is time consuming and expensive.
- Training is usually for "canned" scenarios that may not reflect the dynamics of actual line operations.
- Data entry–verification procedures may be poorly designed, not always followed, vulnerable to task saturation/workload management, and vulnerable to flight crew distractions.
- The large number of FMS manufacturers creates complexity.
- Different versions of software are installed, each with its own vulnerabilities.
- Incorrect entry of data into the FMS keyboard occurs.
- Systems will accept incorrect entries if they meet specified criteria.
- Automation policies, developed without reference to details of the aircraft manufacturer's automation philosophy, may not clearly spell out automation priorities.
- Ineffective SOPs are used.
- Ineffective training of crews on monitoring strategies occurs.

Furthermore, the FAA's ongoing modernization of the National Airspace System — known as the Next Generation Air Transportation System (NextGen) — and other generic airspace improvements are expected to increase monitoring requirements for pilots, including:

- An increased emphasis on sensor input;
- Additional tasks for pilots within the NextGen environment;
- New tasks involving electronic flight bags and portable electronic devices; and,
- Expectations of increased flight path precision.

The list of causal factors associated with monitoring errors involving automated systems already includes many events involving training or operation of these systems. This is because effective monitoring of autoflight systems requires a pilot to have a thorough understanding of how the automated systems work, how to interface with them, how to interpret the output from the systems and how to project what the automated systems will do in the future. Training to this highly functional mental model[25] of the FMS and related autoflight systems is a necessary precursor to FPM of any modern aircraft.

23. FAA. *Operational Use of Flight Path Management Systems: Final Report of the Performance-Based Operations Aviation Rulemaking Committee/ Commercial Aviation Safety Team Flight Deck Automation Working Group (FltDAWG)*. Sept. 5, 2013.
24. NTSB. "Crash of Asiana Flight 214." Accident Report Summary, June 24, 2014.
25. The term "mental model" is described in detail later in the report.

Because training and monitoring of autoflight systems are intrinsically connected, the working group's following recommendations for flight operations management and training programs were designed to be used to strengthen the focus on monitoring automated systems for EFPM.

Recommendation 13

Explicitly address monitoring as part of a comprehensive flight path management policy that includes guidance on use of automated systems.

Make sure the operator's FPM policy is compatible with the aircraft manufacturer's recommendations. In this policy, the assignment of tasks (especially monitoring and cross-verification tasks related to managing the aircraft flight path) to each pilot should be clearly identified. As one report on this subject said:

> *Every airline should have a policy on flight path management that emphasizes a human-centric approach to flight operations, allowing the pilot to decide how and when to use manual handling or autoflight systems to control and manage the aircraft's flight path and energy. Effective monitoring of both aircraft state and the manual/automated systems used for control and guidance to manage the aircraft is critical to safe flight.*[26]

The Flight Deck Automation Working Group (FltDAWG) report[27] identified gaps in flight crew understanding of how to use the aircraft's autoflight systems to manage the flight path, and in their ability to manually control the aircraft when required to do so. Therefore, flight path management policy and expectations must be clear.

According to the FltDAWG report, the following items represent some of the guiding principles that should be included when developing guidance for operational policy for flight path management:

- The policy should highlight and stress that the responsibility for flight path management remains with the pilots at all times. Focus the policy on the broader view of flight path management, rather than simply on automated systems.
- The policy should state that automated systems must be viewed as important tools (among other tools) to support the flight path management tasks.
- The policy should include the guidance for manual flight operations contained in the FltDAWG report and the FAA Safety Alert for Operators (SAFO) 13002, "Manual Flight Operations."[28] The manual flight operations guidance should include SOPs for using manual handling skills, cognitive skills and automated systems for flight path management, and maintaining currency in all aspects of manual flight operations.
- The operator's policy should provide guidance on the operational use of automated systems, including the following information (based on the 1996 FAA report recommendation titled "Automation-Mgt-2"):[29]
  - Examples of circumstances in which the autopilot should be engaged, disengaged or used in a higher or lower authority mode;
  - The conditions under which the autopilot or autothrottle will or will not engage, will disengage or will revert to another mode; and,
  - Appropriate combinations of automatic and manual flight path control (e.g., autothrottle engaged with the autopilot off or in accordance with aircraft-specific original equipment manufacturer [OEM] instructions).
- The policy should make a clear distinction between guidance and control. The elements of flight path guidance (selection of the information used to drive the flight path) should be clearly distinguished from who/what is controlling the aircraft (consideration for autopilot and autothrust engagement status).
- The policy should be consistent with the aircraft manufacturer's recommendation for the use of automated systems. However, simply adopting the manufacturer's recommended policies may not meet the operator's own requirements or reflect its own philosophy of operations. The policy should reflect the operator's own circumstances, operating environment, culture and expectations of the flight crew.30
- The policy should be dynamic and may need to be adapted as the operator's circumstances and operational challenges

26. Flight Deck Automation Working Group. *Operational Use of Flight Path Management Systems: Final Report of the Performance-Based Operations Aviation Rulemaking Committee/Commercial Aviation Safety Team Flight Deck Automation Working Group (FltDAWG)*, Sept. 5, 2013.
27. Ibid.
28. FAA. SAFO 13002, "Manual Flight Operations." Jan 1, 2013.
29. FAA. "Human Factors Team Report on the Interfaces Between Flightcrews and Modern Flight Deck Systems," 1996.
30. See <www.skybrary.aero/index.php/Automated_Cockpit_Guidelines_(OGHFA_BN)> for an example of a set of guidelines for the use of automated systems.

change — e.g., new equipment, routes, changing flight crew demographics.

- The operator should regularly review feedback from training, line experience, and incident and accident data when considering changes.

After developing a comprehensive flight path management policy, the operator should promote compliance with this policy as one of the main responsibilities of each crewmember. Develop training programs to underscore this policy in all training curricula. Suggestions on how to integrate automated and manual flight path management policies into training are discussed in Recommendation 14.

Recommendation 14

Develop and enhance training to improve the monitoring of automated systems as incorporated into the flight path management policy.

Automated systems were introduced in civil aviation to reduce risk and increase operational reliability. These systems provide the flight crew with a large number of functions and options for carrying out given tasks under different circumstances. However, this capability results in new tasks and increased workload-management requirements for pilots. The pilot must enter data and/or select the mode best suited for a particular situation, as well as monitor the automated system to ensure it accomplishes its intended task. These new tasks require increased knowledge of the full functionality of automated systems to competently manage (control and monitor) the aircraft through dynamic flight path situations.

However, as noted in Section 3 of this report, multiple studies have shown that many pilots poorly understand aspects of autoflight modes, in part because training emphasizes "button-pushing" over developing accurate mental models. In addition, the FltDAWG report found that training programs (i.e., their content and structure) may not completely prepare pilots for their flight path management and monitoring tasks due to the following reasons:

- **Syllabus requirements.** Traditional regulatory requirements tend to focus on performing discrete maneuvers correctly rather than handling real-world issues affecting the flight path management task. Advanced qualification programs (AQPs) are commonly implemented at some training organizations. These programs are objective-based and data-driven, as opposed to training programs that are defined by regulation and are hours-based. Ideally, AQPs allow these organizations to tailor training programs to match their pilot populations and unique needs and objectives. However, even with the ability to tailor these programs, the working group's data showed that many training programs, including some AQPs, may not cover all the knowledge and skill sets now considered essential for pilots.

- **Variation in practices.** There is wide variation in the training practices applied to establish the skills associated with FPM, and this may result in inconsistent pilot performance.

- **Limited training.** Many training programs provide limited training in flight path management and energy management during simulator and ground training. Training is also limited on how to handle known "automation surprises" and unknown situations.

- **Unstructured training.** Many training programs train pilots in how to interface with the control display unit (CDU) but may not address the full use of on-board systems for flight path and energy management until after pilots are conducting line operations. This includes the understanding of flight path management system behavior and partial failures. Given that non-normal situations during line operations cannot be controlled, the training received is necessarily less structured and more variable than training that would be presented in a training center. In many cases, the pilots train themselves on the full use of automated systems during unsupervised line operations.

- **Deviation and off-path management.** The working group found that training programs typically did not explicitly address the management of deviations or off-path operations.

- **Expertise of data analysts.** Some data analysts may not have sufficient line operational knowledge and expertise to properly analyze safety and training data with the operational context needed to provide appropriate feedback for improving FPM training and addressing current operational threats and errors.

- **Content of training.** Training may not cover all the relevant topics at the depth necessary.

If the commercial air transport industry is to address the noted "new tasks and errors" related to the use of automated systems for managing the flight path, improved training in the use and monitoring of these systems is required. Some considerations when developing new training are:

- Train pilots to a deeper understanding of how automated systems affect flight path management;

- Develop procedures and training for automated system degradations and failures;

- Develop realistic training that highlights real-world occurrences; and,

- Strengthen FMS training and procedures to enhance the monitoring of FMS operations.

Train pilots to have a deeper understanding of how automated systems affect flight path management. Most training departments discuss FMS data entry, modes, mode changes and how to accomplish normal tasks on the line (extending centerlines, etc.) in a canned and scripted manner. An enhancement is training in interpreting the FMAs and autoflight systems relative to aircraft state and knowing what to expect based on current programming, configuration and aircraft state.

This requires training on a conceptual picture of automation functioning and use, as opposed to "buttonology/switchology" (training to press certain buttons in a certain sequence to have a desired result). Training to this conceptual level provides the pilot a deep and highly functional "mental model" of the FMS and related autoflight systems, equipping the pilot with the ability to use and monitor the FMS and autoflight systems to their full functionality during line operations.

Training to an accurate and functional mental model can be accomplished in flight simulation training devices by:

- Degrading automated systems periodically to demonstrate moving between modes and autoflight configurations/levels;
- Demonstrating predictive situation awareness by requiring pilots to verbalize the *next* mode of expected behavior of the autoflight system rather than simply verbalizing what they see in the FMA window. (This is a good predictor of whether a pilot has a complete mental model of the system.);
- Eliminating predictable training scenarios and replacing them with realistic scenarios that mimic the dynamics (surprises) of line operations;
- Avoiding teaching simply pressing automation-related buttons (buttonology/switchology). This includes ensuring that pilots understand what the buttons represent and do;
- Including the time element in scenarios to induce stress in the pilot and determine his/her depth of system knowledge; and,
- Training pilots in strategies to communicate with the other pilot(s) on the flight deck the current and projected state of the flight path in order to develop a common mental model.

To move beyond the buttonology/switchology level of automation knowledge, autoflight systems training should provide an in-depth understanding of *how* autoflight systems work and integrate with one another. Pilots need to have a thorough understanding of the overall intent and methodology designed into automation systems. Training should teach what the autoflight systems will be attempting to do, such as:

- What goals, objectives and priorities (airspeeds, pitch control modes, altitude/vertical targets, etc.) are designed into the system in different phases of operation;
- How the autoflight systems will attempt to achieve those goals; and,
- How the autoflight systems will communicate with the pilots.

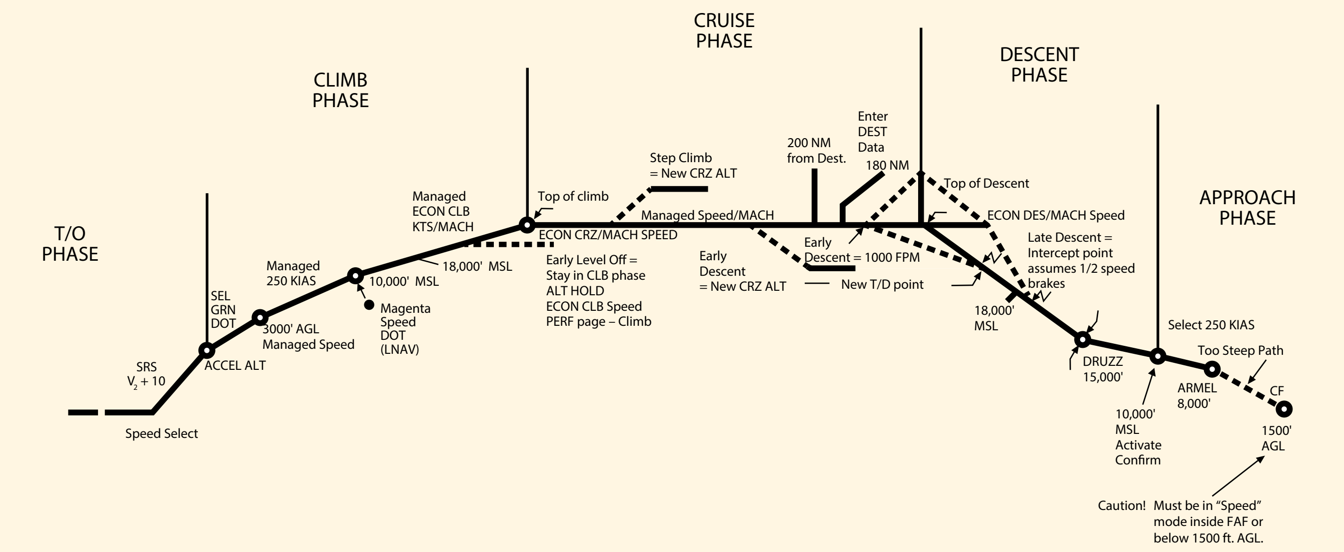
Pilots who have a deep understanding of the big picture will be less prone to confusion about what the system is doing, and will be able to accurately predict what it should be doing next. They will be better able to detect undesired modes, deviations from desired path, etc. Pilots should possess a thorough understanding of:

- What vertical profile/speed the FMS is trying to achieve (and why) during various phases of flight — takeoff, climb, cruise, descent, approach, go-around, etc.;
- How the FMS interfaces with the flight directors, autopilot and autothrust to achieve that profile;
- The assumptions built into, and inputs considered by, the FMS, such as:
  - How it calculates the TOD point and subsequent vertical paths from point to point;
  - The impact of drag devices, winds, speed intervention, etc.; and,
  - The FMAs and display symbology that indicate what the system is doing now, where it should change, and what it should change to next;
- How the vertical/lateral profiles may be affected by ATC vectoring, speed changes or other ATC changes that affect the lateral/vertical profile during all phases of flight; and,
- Various ways to monitor and re-capture the planned vertical and lateral profiles after ATC-induced (or other causes of) departures from the programmed lateral/vertical profile.

Training practices incorporated at one airline are offered below as an example of how this mental model (Figure 7, p. 35) can be developed:

- Pilots are provided with a graphic that depicts a vertical-view flight profile from taxi-out through takeoff and landing.
- The graphic is divided from left to right into specific phases of flight that correlate to FMS phases (takeoff, climb, cruise, descent, approach, go-around, etc.).
- For each phase of flight, the graphic depicts the vertical and lateral FMS modes, the speeds that will be commanded, the associated FMAs that will be displayed, how descent points

Example of an Autoflight 'Mental Model'



Source: Active Pilot Monitoring Working Group

Figure 7

are calculated and what assumptions are made about them, and the events that will trigger a change to the next phase or mode.

- The graphic includes symbology from the navigation and primary flight displays that relate to vertical or speed changes.
- Excerpts are displayed from specific FMS pages that correspond to that phase of flight and indicate the FMS entries that determine the commanded speed/altitude/lateral modes, etc.
- This all-in-one training graphic allows pilots to visualize in a chronological order the relationship between FMS entries, lateral and vertical navigation modes, autothrottle modes, commanded speeds, FMAs and display symbology.
- The graphic also is used in self-study and briefings to help develop the desired big picture or mental model of the interrelationship and function of the various automation systems.
- This pre-acquired mental model greatly enhances comprehension and understanding when training device and full flight simulator training introduce and demonstrate all of those functions/displays and transitions.
- These autoflight relationships (phase of flight, FMAs, vertical modes, lateral modes, autothrottle and speed commands, etc.) are continually reinforced and demonstrated as training progresses.

Develop procedures and training for degradation and failures of automated systems. Current autoflight systems provide highly reliable operations and information that may lead flight crews into a high level of trust and reliance on the systems. This level of reliability presents a few problems:

- The rarity of failures causes crews to become desensitized to the possibility of failure, which could lead to complacency.
- When systems do fail or provide unexpected or conflicting information, crews can experience a significant level of confusion.
- This can result in the inability to correctly analyze the situation, and creates the potential for inappropriate corrective responses.

A good method to reduce pilot confusion when systems fail is to expose crews to these failures during training. Operators and training providers should design scenarios with various subtle, unannounced failures that can and should be detected by FPM skills. These failures should be discussed in the debriefing process, highlighting if and how they were detected, or why they were not. Some examples could be:

- Failure to capture set altitude;
- Failure to engage desired lateral mode; and,
- Insidious autothrottle failure/failure to maintain desired speed.

This training should reinforce the reality that although automated systems are highly reliable, failures *can and do* occur, and pilots should guard against complacency and any bias that automated systems always work perfectly.

Exposing pilots to system failures and partial failures will condition them to have an appropriate level of skepticism regarding automated systems, and to continuously monitor status and performance of automated systems. However, care should be taken to strike a proper balance and not to overdo these failure scenarios, and thereby inadvertently instill an inappropriate mistrust of the automation systems.

Furthermore, training the use of automated systems for flight path management should include the recognition and handling of unexpected events, such as:

- Uncommanded autopilot disconnect or pitch up;
- Autothrottle/autothrust disconnect;
- Electrical failures;
- Air data and/or computer failures;
- Partial failures of automated systems;
- Off-path deviations and how to recover;
- Alternative methods and techniques to meet clearances/ requirements if a system fails; and,
- How and where to scan to resolve conflicting information.

Finally, training should include manual flight operations (including both the motor skills for hand-flying and the knowledge and cognitive skills), and techniques to revert to manual flight operations in the event of a failure. Training should provide the proper techniques to transition/revert along the spectrum from managing the flight path with full automation to fully manual flight path management and back again, including:

- How to properly disengage the autoflight systems and resume hand-flying;
- If the autoflight system disconnects or is disengaged, how to re-engage it in the desired mode; and,
- Recommending "bottom line" decisions regarding when the use of the automated modes should be abandoned in favor of the manual methods.

All facets of training should provide crews with OEM-approved procedures and a cross-check methodology that highlights other sources of information that can be used to corroborate or discredit/disregard conflicting information from the automated systems with regard to vertical path, lateral position, speed, etc.

Develop realistic training that highlights real-world occurrences. Any autoflight system may have unique characteristics or operating details that could result in common flight crew errors or misunderstandings — creating a high likelihood of pilot mismanagement of the system. Using information obtained from operational and safety data, training and checking events, etc., training departments should use a risk-based approach to develop realistic training that highlights real-world events and known problems/errors when using automated systems. Training also:

- Should place a particular emphasis on these known pitfalls;
- Can be in the form of written bulletins, highlighted in the flight manual, trained and practiced in scenarios developed for the simulator, etc. as appropriate; and,
- Should emphasize how the system should work, what factors can result in the undesired outcome, how to recognize an undesired aircraft state/outcome and how to correct it.

Strengthen FMS training and procedures to enhance monitoring of FMS operations. As part of realistic training:

- Consider requiring verification of the effect of FMS entries on the flight path;
- Consider requiring verbalizing (not simply verifying) all FMA modes upon change; and,
- Consider requiring verbalizing (not simply verifying) all FMA modes expected to occur.

To provide a standardized framework, reduce variability and increase efficiency, an FMS data–entry policy that requires that the PM perform all FMS data entries below Flight Level 180 (approximately 18,000 ft) is the most conservative approach. Making FMS data entries the same way every time and having the effect of the entry verified by the PF may reduce variability, which is of particular importance in high vulnerability/high risk portions of flight. Altitude deviations and course deviations are the most common FPM errors, and these generally result from data-entry errors. As most pilots recognize, the FMS draws attention away from the actual task of flying the aircraft. To mitigate this tendency, the PM should make all FMS data entries (except, as appropriate, very small ones), thereby allowing the PF to manage the aircraft.

Training and Evaluating Monitoring Skills

Assigning expanded monitoring responsibilities to each flight crewmember will have only a minimal effect on improving FPM performance if these skills are not *trained and evaluated* alongside flying skills. This section contains five specific actions that training and standards departments can use to improve a pilot's ability to monitor and correct errors.

Recommendation 15

Train pilots about why they are vulnerable to errors and monitoring lapses.

Although pilots are often exhorted to follow procedures as written, training typically does little to help them understand the reasons they are vulnerable to making errors and to failing to detect these errors through effective monitoring. This is a critical oversight, because individuals are better motivated and better prepared to deal with error-prone situations if they understand the nature of these vulnerabilities and the circumstances in which they occur. Thinking of themselves as highly unlikely to commit errors, pilots may underestimate their vulnerability.

Initial (new-hire) training and transition to new aircraft–type training focus primarily on teaching pilots aircraft-specific and company-specific operating procedures. Instructors should facilitate a discussion of operational pressures that work against the deliberately paced execution of procedures, and, in particular, pressure for on-time completion of flights and the distracting effects of interruptions and concurrent task demands. Pilots can then discuss how best to deal with these pressures without compromising safety. Objectives for this module of training should include:

- Identifying the barriers to effective pilot monitoring as listed earlier in this report.
- Explaining that the slow, deliberate approach to monitoring is crucial, even though it goes against the pilot's "natural grain," which is for highly practiced actions to become fast, fluid and automatic, with little if any conscious oversight.
- Demonstrating that the slow, deliberate approach to monitoring requires practice and vigilance to become a habit during line operations. The few extra seconds required to perform a monitoring task or a checklist deliberately are well worth the slight time cost.
- Recognizing how reduced monitoring capability due to poor task management (so-called "multitasking") can increase errors.[31]
- Explaining that "looking without seeing" is inadvertent, and that pilots are often completely unaware that their performance has eroded.
- Explaining the workload and stress effects caused by the onset of emergencies/non-normal situations, and their impact on flight path monitoring.

Once pilots understand why they are susceptible to monitoring lapses, they can be taught to identify indications that their FPM is not effective, including if:

- You miss a flight path callout;
- You see a pitch, power or roll change *that you were not actively looking for*;
- You see a mode change *that you were not actively looking for*;
- You recognize terrain, traffic or weather, but *in an untimely fashion*;
- You notice yourself doing a non–flight path–related task *during high AOV*;
- You notice yourself doing a nonessential task *during a medium AOV*; and,
- You accept a workload-intensive task when you have control of the aircraft *during a medium AOV*.

Pilots should be trained to specifically look for these indications, and to increase their sampling rate when triggered by the above indications. Illustrating these indications in training through aviation safety action program/accident reports is a powerful way to teach this concept. However, to effect lasting change in pilot performance on the line, all of the academic training discussed in this report must be reinforced in initial and recurrent simulator training and during line evaluations.

Recommendation 16

Reinforce the responsibility of monitoring pilots to challenge deviations.

If we take another look at the PF/PM role definition from Recommendation 2, the first line states:

> *The PM's primary responsibility is to monitor the aircraft's flight path (including flight guidance automation, if engaged) and to immediately bring any concern to the PF's attention.*

Simply stated, monitoring is ineffective if the PM does not say anything about observed deviations. Yet there are many reasons that one pilot will not alert another about an observed error. One common reason has been identified as the *power distance index* (PDI) that exists between captains and FOs.

The concept and measurement of PDI was developed by Dutch sociologist Geert Hofstede and assesses the distribution of power between those with power and those without power. In aviation, there is typically power distance between the captain and subordinate crewmembers. A high PDI is a

31. Loukopoulos, L.D.; Dismukes, R.K.; Barshi, I. (2009). *The Multitasking Myth: Handling Complexity in Real-World Operations.* Burlington, Vermont: Ashgate, 2009.

strong inhibitor for the FO to speak up against a perceived powerful captain.

In general, PDI measurements are higher in national/regional cultures with a more authoritarian hierarchy and lower in cultures where authority figures work more closely with those not in authority. But even a lower PDI does not mean that it can be ignored, as demonstrated in this excerpt from a U.S. study:[32]

> Captains in the monitoring pilot role were more than twice as likely to trap deviations made by the flying pilot than first officers in the monitoring pilot role (27.9 percent vs. 12.1 percent). This is consistent with flight simulation research showing that captains were more likely to challenge first officers flying the aircraft than vice versa (Orasanu, McDonnell and Davidson, 1999; Fischer and Orasanu, 2000) and is also consistent with the 1994 NTSB study of accidents attributed to crew error. The simulation studies also revealed that captains were more likely to use commands and first officers to use hints to call the flying pilot's attention to errors, high risk errors were more likely to be challenged than low risk errors, and first officers were less likely to challenge an error if the error involved a loss of "face" for the captain.
>
> [Thus,] even when pilots monitor appropriately, challenging deviations by the pilot flying often does not occur. ... Our findings ... reveal that first officers are less likely to challenge a captain flying than vice versa; thus, the airlines need ways to support challenging when appropriate — simply telling first officers to challenge is not sufficient to counter their hesitation. Both initial and recurrent training should address the issue realistically, which requires frank discussion of the reasons challenging is sometimes difficult. Pilots — especially first officers — must balance the need to challenge with maintaining a positive cockpit environment. An outstanding technique used by some captains during the initial briefing to a first officer goes something like: "I expect I will make errors on this flight — it is your job to catch them and point them out." Not only does this approach give the first officer permission to speak up, it establishes an atmosphere in which either pilot can challenge the other without causing him or her to lose face, and it establishes the standard that monitoring is an essential cockpit procedure.

The PDI will never be higher than it is for new-hire first officers who will be hesitant to say anything at the beginning of their careers. Training to urge these FOs to challenge captains must begin at indoctrination training for their first assignment and continue throughout their careers.

Recommendation 17

Develop and publish clearly defined monitoring tasks, training objectives and proficiency standards. Ensure instructors and evaluators are proficient at training and evaluating these standards.

Having included monitoring responsibilities as a primary task for each crewmember, individual maneuver tasks and training objectives (supporting proficiency objectives [SPOs]/terminal proficiency objectives [TPOs] for AQP air carriers) must be developed to reflect these responsibilities if the industry is to train and evaluate them accordingly. In the opinion of the working group, failure to train and evaluate monitoring skills severely undermines the likelihood that monitoring performance will improve.

Care should be taken to ensure flying skills and monitoring skills are equally represented in standards documents because, traditionally, standards have been defined best for flying skills and less well defined for monitoring skills. Monitoring standards must be defined as well as flying standards to provide pilots with knowledge of what EFPM is and to give them tangible goals to work toward in achieving those standards.

In addition, flight instructors need the monitoring standards to effectively and consistently train monitoring skills. The first step in this process is to clearly define the monitoring tasks required of each pilot for each maneuver. Sample monitoring tasks (shown in this example using the TPO/SPO hierarchical numbering from one carrier's AQP Task Analysis) for the takeoff maneuver are:

- 2.1.3 Perform rotation and liftoff procedures
- 2.1.3.2 [Pilot monitoring] observes barometric/air data computer/primary flight display altimeter increase [K][33]
- 2.1.3.3 [Pilot monitoring] calls out positive rate [C]
- 2.1.3.7 [Pilot monitoring] raises landing gear lever [MS]
- 2.1.4.3 [Pilot monitoring] contacts departure control as directed [K]

32. Dismukes, R.K.; Berman, B. "Checklists and Monitoring in the Cockpit: Why Crucial Defenses Sometimes Fail." NASA Technical Memorandum NASA/TM-2010-216396, 2010.

33. In AQP, K = Knowledge, C = CRM, and MS = Motor Skills.

2.1.4.4 [Pilot monitoring] effectively monitors management and conduct of flight path when not occupied with other flying duties [MS]

2.1.4.5 [Pilot monitoring] calls out observed deviations to flight path [C]

Once published, these tasks may be broken down into training objectives (with SPOs in AQP terminology), and they should be incorporated into every phase of crewmember training. As monitoring skills share many of the qualities of traditional CRM skills, organizations may find it easier to assimilate FPM training objectives into existing CRM training objectives. The following (see "Supporting Proficiency Objective: Situation Awareness") is an example of how one air carrier incorporated FPM objectives into training objectives for the CRM skill "situation awareness."

To achieve these learning objectives, instructors and evaluators themselves must be trained on the human factors related to monitoring, the importance of monitoring and the company-approved practices that achieve EFPM. Ultimately, they should be as comfortable and as standardized in training and evaluating FPM skills as they are with traditional flying skills.

Recommendation 18
Implement a comprehensive approach to training and evaluating autoflight and flight path monitoring.

As mentioned in Recommendation 10, pilots focus on subjects that they know will be checked. Therefore, embedding improved monitoring of the flight path into flight deck culture requires comprehensive training *and* evaluation.

Autoflight and flight path monitoring SOPs should be emphasized and highlighted from Day 1 of training, continue throughout the curriculum, and end with an assessment of monitoring skills/SOP compliance during simulator and operational line checks. Highlighting monitoring requires development of:

- Instructional briefings and simulator scenarios for training events; and,
- Event sets for the line/initial operations experience and evaluation check ride that emphasize autoflight and flight path monitoring skills.

As with any cultural shift, instructors and evaluators must lead the way by agreeing to the importance of monitoring and placing as much emphasis on monitoring skills as they do on flying skills. A PM who fails to comply with a critical monitoring duty should be held as accountable as a PF who fails to properly execute a flight maneuver or procedure. This level of emphasis will reinforce to pilots the importance of automation monitoring and raise the awareness that both pilots are equally responsible for management of the flight path and autoflight systems.

Supporting Proficiency Objective: Situation Awareness

Crew Duty Position: Captain (Pilot Flying/Pilot Monitoring)
First Officer (Pilot Flying/Pilot Monitoring)

Situation Awareness Procedures

All pilots will:

- Maintain an awareness of physical location of the aircraft;
- Maintain an awareness of the automation systems and modes selected by the crew or automatically initiated by the flight management computer (mode awareness) to effectively monitor flight path;
- Maintain an awareness of the capabilities available in engaged automation modes (mode confusion);
- Effectively monitor systems and selected modes to ascertain that the aircraft is on the desired flight path;
- Recognize if making automation inputs is becoming a detriment to situation awareness and select an appropriate level of automation;
- Ensure that distractions do not degrade overall crew situation awareness;
- Alert crew/team when added vigilance or attention may be necessary;
- Recognize and inform other crewmembers when individual awareness is low; and,
- Maintain an awareness of other crew/team member's capabilities.

Captains will:

- Monitor or assign duties per operational requirements;
- Divide awareness tasks to enhance effective monitoring of the flight path; and,
- Brief and initiate strategies for handling distractions that degrade monitoring.

First officers will:

- Suggest attention priorities when recognizing situation awareness is low;
- Contribute information to enhance the crew and the captain's situation awareness.

Recommendation 19
Incorporate monitoring training into simulator or other device training.

Utilizing published training objectives, instructors will now be able to incorporate monitoring instruction into device

Including Monitoring in Instructor Guides

B777 INSTRUCTOR GUIDE

CMV1/MAN 3U

1301

2) Med Emer, ATB, CAT III, Autoland, CAT II GA (PF : CA) (Planned 0:30/1:00)	
	HF Topics: • Pilot Monitoring during Precision Approaches • FOM 2.37 Flight Deck Autjority • Crew Communication and Planning • Automation Management/ModeAwareness
	Condition: • METAR: KSLC 25015KTS 1/4SM R16L34R 1000FT FZFG OVC001 M2/M2 A2982 • RVR 500/500/500
On climb out	**SLC DEPT (126.25)**

Source: Active Pilot Monitoring Working Group

Figure 8

training along with the more traditionally emphasized flight instruction. As an example, a traditional simulator pre-brief for the takeoff task might sound like this: "PF, talk me through the takeoff procedure."

Instructors should now include the PM, saying: "PM, walk me through the same procedure." The PM should then recount the takeoff-monitoring tasks listed in Recommendation 17.

Similarly, monitoring performance should be included in the simulator itself. Monitoring objectives should be emphasized along with flying objectives in the instructor guide used to conduct the simulator training. Figure 8 is one example of how that might look for a simulator LOFT session.

Instructor guides should also emphasize the importance of monitoring by elevating the role of PM in debriefing modules. Figure 9 (p. 41) is an example.

Including EFPM as a primary responsibility — and treating it as such in all training and flight operations — will heighten pilot awareness of the importance of this function. However, in the opinion of the working group, pilots will pay little attention to the additional training if it is not emphasized in the evaluation environment.

Recommendation 20
Place greater emphasis on monitoring in operator flight standards programs.

It is readily apparent to pilots which tasks and maneuvers are emphasized during validations and evaluations. Failure of check pilots to critique FPM during evaluation events will lessen, if not completely undermine, the effect of all of the training.

There is no current research on the relative emphasis that check pilots give to diverse aspects of the pilot's performance. Check pilots should evaluate and critique flying performance and monitoring performance because controlling the flight path and monitoring the flight path are interrelated, equally important and required duties for both the PF and PM.

Recall from Section 3 that a barrier to effective monitoring is that, because the aircraft performs as expected the vast majority of the time, there is little feedback to inform the pilot of a lapse in monitoring. The check airman's debriefing of the crew should coach and critique the practices that support flight path monitoring as listed in Recommendation 1. Check airmen should debrief the observed task-management issues that affected monitoring, especially if the AOV concept has

Continued on p. 42

Elevation of Role of Pilot Monitoring During Debriefing

B777 INSTRUCTOR GUIDE

CMV1/MAN 3U

1301

Prior to FAF	Instructor Action: • Take Snapshot
At FAF	**<u>Tower 119.050</u>** *"Runway 16L/34R (as appropriate), 500/500/500, cleared to land, Winds 235/15kts."* Instructor Action: • Validate Autolanding

Safe Taxi Speed	Facilitated Debrief
	• Ask the PF:
	  • "What did you do well?"
	  • "What would you improve?"
	• Ask the PM:
	  • "What did you do well?"
	  • "What would you improve or do differently?"

	• Flight Freeze • RVR • Reposition to FAF snapshot forCAT II ILS and Go-Around

Passing 5000 MSL	Facilitated Debrief
	• Ask the PF:
	  • "What did you do well?"
	  • "What would you improve?"
	• Ask the PM:
	  • "What did you do well?"
	  • "What would you improve or do differently?"

Source: Active Pilot Monitoring Working Group

Figure 9

been adopted and trained by the operator or training provider. Each debriefing should include both a critique and positive reinforcement (where applicable) of effective monitoring.

As noted, there are several indications to an observer (e.g., other pilot, instructor or check airman) of faulty monitoring, including:

- Either pilot misses a required flight path callout;
- Either pilot recognizes terrain, traffic or weather *in an untimely fashion*;
- The PF is doing a non-flight path–related task *during a high AOV*;
- The PM is doing a non-flight path–related task (i.e., that isn't critical) *during a high AOV*;
- The PF is doing a non-flight path–related task *during a medium AOV*;
- The PM is doing a nonessential task *during a medium AOV*;
- Either pilot accepts a workload-intensive task *during a high AOV*; and,
- The PF accepts a workload-intensive task *during a medium AOV*.

For grading purposes, the decision to assess or evaluate monitoring must be carefully considered. Despite standardizing monitoring skills in learning objectives (or, in the United States, the AQP TPOs), there will be more subjectivity in determining if a pilot is monitoring properly versus whether he or she is controlling airspeed properly. One suggestion is to treat the assessment/evaluation of monitoring in a manner consistent with how the operator currently assesses/evaluates CRM skills.

Note: Since both pilots are responsible for monitoring, it is not appropriate to simply "blame the PM" for any error that is undetected, calling it a "failure to monitor." This is unrealistic because the PM has multiple other flight-related tasks to perform in addition to flight path monitoring (see the PM role definition in Recommendation 2.) Before assessing degraded monitoring performance, check airmen must use judgment to determine if the PM was rightfully involved in other tasks when the error occurred.

Section 5: Concluding Remarks

The Active Pilot Monitoring Working Group sincerely hopes that operators and aviation managers will share our vision that successful flight path management is a keystone to mitigating future accidents. At its core, successful flight path management requires two equally critical components: proper flight path control and effective monitoring.

Traditional training and evaluation emphasize control of the aircraft over monitoring of the flight path. Where increased use of automation can lead to deteriorating flight control skills, several studies and guidance have been published to encourage renewed focus on developing and maintaining hand-flying skills. This guide is intended to focus on developing and maintaining effective monitoring skills.

Ultimately, how effectively the flight path is controlled and monitored is the product of a series of people, making a series of decisions, at different levels. Managers create the policies and procedures designed to not interfere and/or to support prioritization of flight path monitoring. Pilots make task/workload decisions that expand their ability to monitor in areas of vulnerability to flight path deviations. It is essential that they share a common vision.

Adopting a corporate philosophy that flight path monitoring is a priority demonstrates a belief in its importance. It also communicates intent and ensures continuity of that intent at different levels within the organization.

The full implementation of this philosophy has several key components:

- The philosophy should be written in operators manuals;
- Senior leaders in the organization should personally communicate their commitment to, and belief in, the importance of the philosophy to all levels of the operational structure;
- This communication should be sustained and periodically reinforced; and,
- After completing the tough work (and sacrifice) of ensuring that policies and procedures are aligned with philosophy, senior leaders can point to these decisions to emphasize the primacy of flight path management and speak to that primacy as a commonly held standard that the entire organization shares.

Improved flight path monitoring is intended to reduce the number of errors that result in flight path deviations. Despite the numerous barriers inhibiting monitoring, the adoption of recommendations in this report will improve monitoring effectiveness and substantiate the corporate investment in resources to do so.

Appendix A: Monitoring Link to TEM Performance

BY JAMES KLINECT | THE LOSA COLLABORATIVE

Why do flight crews have to monitor and cross-check? One answer is that flight crews must use these techniques to help manage events, such as threats and errors, and keep them from affecting safety margins. Line operations safety audit (LOSA) data show that flight crews rated "poor" or "marginal" in monitoring and cross-checking had three times more mismanaged errors than crews rated "good" or "outstanding." In this light, monitoring can be considered a core defense that flight crews use to enhance their threat and error management (TEM) performance.

Monitoring plays its most critical, first role in TEM by stimulating a dialogue, which helps a flight crew create a shared mental model. This model is used to *anticipate* threats when possible, *identify* pop-up threats when they occur, *detect* crew errors, and *recognize* undesired aircraft states. The premise is that the better a crew's monitoring performance, the more likely the crew will be prepared to effectively manage a threat, error and/or undesired aircraft state.

However, successful TEM performance is ultimately measured by outcome, not by the process that led to the outcome. The three optimal outcomes of TEM are mitigated threats, corrected errors and undesired aircraft states that are recovered to a desired configuration and/or flight profile. The premise is that monitoring can be trained and evaluated more effectively by focusing check pilots on the extent to which monitoring plays a role in TEM performance. This linkage allows check pilots to more quickly discuss monitoring as a core factor in flight crew performance instead of as a set of global behaviors that all crews must perform, all the time, in a vacuum.

For threat anticipation, crews are typically in an active monitoring role. This can be best measured by how crews are monitoring the environment and planning to manage threats from the earliest time the threats become known. For example, a convective weather threat en route usually can be anticipated at the planning stage by consulting significant meteorological reports (SIGMETs) and route weather charts, and formulating an initial plan that will best mitigate the threat. If the information was available yet was not used at the planning stage, regardless of the effectiveness of the subsequent threat management, an evaluator would question the crew as to why monitoring had broken down when the threat should have been anticipated.

For pop-up threats, an evaluator must consider the amount of time it took for the crew to detect the pop-up threat, how they responded and how effective the response was. The evaluator would debrief the crew using a framework based on the overall impression of the captain's leadership in setting the communication environment on the flight deck. When the threat occurred, was the crew in an active or passive monitoring role? Was there timely and effective dialogue, a clear plan, an effective inquiry where needed and a review to mitigate the threat?

If threat mitigation has failed, the next step in TEM is error detection. Error detection for takeoff, flight path and landing involves a higher level of monitoring and situation awareness than is provided through standard operating procedures (SOPs). The number of errors that are detected, undetected or not discussed, therefore, is a key indicator of effective monitoring and cross-checking.

Some key monitoring-related TEM items to be observed during pre-departure are:

- When crews perform a checklist, does the responding pilot cross-check the setting?
- Does the pilot doing the challenge back up the responding pilot?
- Is there an effective cross-verification of individual flight management system (FMS) entries?
- Do both pilots independently check the load sheet and final weight and balance figures?
- Do both pilots independently cross-check the takeoff figures?

Some key monitoring-related TEM items to be observed during flight are:

- Does the pilot monitoring (PM) call out trend instead of waiting for a deviation callout?

- Do the pilots call out transition levels, and do the pilots cross-check their altimeters?
- Do the pilots make their required cross-checks of flight guidance panel entries?
- Is a change of autopilot mode cross-verified by confirming the flight mode annunciator?
- Do pilots make the required cross-check of FMS entries?
- Do the pilots make the required altitude awareness and level-off calls?

For undesired aircraft states, the monitoring is often passive, but requires a quick response since it often involves a significant deviation from the flight path. SOP-deviation callouts are often only required on approach. An evaluator would once again debrief the crew using TEM, based on the overall impression of the captain's leadership in setting the communication environment on the flight deck. Ideally, all PMs should be unconstrained in speaking up with a trend callout that:

- Opens crew communication and a shared mental model, with the PM calling out the error/divergence in the trend as early as possible, using simple words that provide situational guidance and a cue for action.

  For example: "Are we slow?"

- Stimulates a response from the pilot flying that recognizes the error.

  For example: "Affirmative, correcting."

- Evokes management of the error by the PM calling the ongoing trend of the divergence.

  For example: "Thrust increased, speed trend positive."

- Provides better crew management of trend below minimum stabilization height to permit continuation of the approach to a successful landing.
- Produces a safe missed approach when the divergence cannot be safely managed.

In summary, linking monitoring to TEM performance can provide much-needed, substantial rationale for training monitoring, and a basis for evaluation.

Appendix B: Improving Flight Path Monitoring, A Training Aid

Powerpoint presentation (4.6 MB)

Appendix C: Selected Accidents in Which Inadequate Monitoring Was a Factor

Controlled Flight Into Terrain
Era Aviation
Sikorsky S-76A++, N579EH
Gulf of Mexico
March 23, 2004
10 fatalities

On March 23, 2004, about 1918 local time, an Era Aviation Sikorsky S-76A++ helicopter, N579EH, crashed into the Gulf of Mexico about 70 nm (130 km) south-southeast of Scholes International Airport (GLS), Galveston, Texas, U.S. The helicopter was transporting eight oil service personnel to the Transocean drilling ship *Discoverer Spirit*, which was en route to a location about 180 nm (333 km) south-southeast of GLS. The captain, copilot and eight passengers aboard the helicopter were killed, and the helicopter was destroyed by impact forces. The flight was operating under U.S. Federal Aviation Regulations (FARs) Part 135 on a visual flight rules flight plan. Night visual meteorological conditions prevailed at the time of the accident.

Originally, the helicopter was to make a fuel stop at an oil platform before continuing to the *Discoverer Spirit*, but about 30 minutes after departure, the crew radioed their dispatcher that they had enough fuel to continue nonstop to the *Discoverer Spirit*.

No radar, cockpit voice recorder (CVR) or flight data recorder information was available to help investigators reconstruct the final minutes of flight. However, based on physical indications from the wreckage, the U.S. National Transportation Safety Board (NTSB) concluded that the helicopter hit the water at a high airspeed, shallow descent angle and near-level roll attitude. In essence, somehow a slow descent was established and not detected by the flight crew. According to the NTSB's report:

> The accident occurred about four minutes after the flight crew notified the dispatcher of the change in destination. Under most conditions, a change in destination increases pilot workload, depending on the tasks that need to be completed and the flight conditions. The accident flight crew's decision to proceed directly to the reported location of the *Discoverer Spirit* required the pilots, at a minimum, to coordinate a change in course and communicate with the dispatcher to receive updated coordinates for the ship, which would have been programmed into the global positioning system (GPS) unit after the course change. It is also possible that the flight crew initiated a change in control from one pilot to the other or a change in flight control method from automatic (coupling of the autopilots and flight director) to manual flight or vice versa. Such changes require effective crew coordination, including continuous cross-checking and monitoring of instruments to ensure that the intended system inputs have correctly been made.
>
> The accident helicopter's flight control system allowed the pilot to couple the autopilots and flight director so that the helicopter would automatically carry out pilot-set flight path commands. The pilots might have intended to use this feature to automatically maintain heading and altitude while they completed some immediate manual tasks related to the change in destination. However, the pilots could have incorrectly programmed the flight director mode selector and either not have detected this situation or have misinterpreted it given the available system feedback. … One of the most critical issues associated with flight deck automation is automation misuse, that is, pilot overreliance on automation, because it can lead to deficiencies in monitoring an aircraft's performance. Pilots may become complacent if they are overconfident in automation and may fail to exercise appropriate vigilance. As a result, significant deviations in altitude or flight path, if controlled by automation, may develop without detection by the flight crew, especially when the flight crew is focused on other tasks. The only reliable way for pilots to detect such deviations is through continuous monitoring of cockpit instrumentation. Although the opportunity for successful monitoring

> would be increased with two flight crewmembers rather than an individual pilot, research indicated that an overreliance on automation and a failure to monitor were unaffected by the presence of a second pilot in the cockpit.

Although the NTSB analyzed several possible scenarios, it was unable to conclusively determine why the aircraft inadvertently descended without being detected. Notwithstanding the lack of such a determination, the NTSB said: "It is clear, however, that the flight crew should have been actively monitoring cockpit instrumentation showing the helicopter's altitude, especially because of the lack of outside visual references. The flight crew would have been presented with salient cues to detect the helicopter's descent and proximity to the water. Thus, the Safety Board concludes that the flight crew was not adequately monitoring the helicopter's altitude and missed numerous cues to indicate that the helicopter was inadvertently descending toward the water."

For more information:

NTSB. (2006). Aircraft Accident Report: *Controlled Flight Into Terrain, Era Aviation Sikorsky S-76A++, N579EH. Gulf of Mexico, About 70 Nautical Miles South-Southeast of Scholes International Airport, Galveston, Texas, March 23, 2004.* (NTSB Report No. NTSB/AAR-06/02.) Retrieved from <www.ntsb.gov/doclib/reports/2006/AAR0602.pdf>.

Stall and Loss of Control
Circuit City Stores
Cessna Citation 560, N500AT
Pueblo, Colorado, U.S.
February 16, 2005
8 fatalities

On Feb. 16, 2005, about 0913 local time, a Cessna Citation 560, N500AT, operated by Martinair for Circuit City Stores, crashed 4 nm (7 km) east of Pueblo Memorial Airport, Pueblo, Colorado, while on an instrument landing system approach to Runway 26R. The two pilots and six passengers aboard were killed, and the airplane was destroyed by impact forces and a post-crash fire. The flight was operating under FARs Part 91 on an instrument flight rules flight plan. Instrument meteorological conditions prevailed at the time of the accident.

The airplane was approaching the airport from the east and was expected to fly past the airport and to land to the east on Runway 8L. Upon contacting Pueblo Approach Control, the flight crew learned they would be landing straight in to Runway 26R. The following is extracted from the NTSB's report on this accident:

> The Safety Board examined the flight crew's actions during the approach to determine the role of the timing of the approach briefing in the accident sequence. Although the flight crew had expected to land on Runway 8L, based on the current ATIS [automatic terminal information service] information, at 0905:56, approach control issued vectors for the ILS [instrument landing system approach] to Runway 26R. According to the CVR, the flight crew noted the change in the runway assignment and immediately tuned the radios and set the inbound course. However, subsequent discussion about the details of the Runway 26R approach was not initiated until almost five minutes later, at 0910:47. During the remaining two minutes before the stall, the flight crew needed to intercept the localizer and glideslope and configure and slow the airplane for the approach. However, CVR evidence showed that, although these airplane-handling tasks were being performed, the flight crew was concurrently briefing the ILS 26R approach.
>
> Specifically, from 0912:17 to 0912:31, as the airspeed was decreasing, the flight crew briefed the missed approach procedure for Runway 26R. It was only at the end of this discussion that the first officer recognized and called for the need to run the deice boots and indicated that the airplane had slowed to V_{REF}, the reference landing speed.
>
> The Safety Board recognizes that a runway change can disrupt a flight crew's planning and may affect the pilots' ability to conduct an approach briefing during a relatively low workload phase of flight, such as the top of the descent. When the runway change occurs late in the approach, it is important for flight crews to determine how and when to conduct the briefing to ensure that the objectives of the briefing are achieved without compromising safety of flight. For the accident flight crew, the runway change occurred early enough for the briefing to have been completed before the pilots began to configure and slow the airplane for final approach. Literature on monitoring emphasizes that cockpit workload should be distributed to minimize conflicting task demands during critical phases of flight. In this case, the flight crew's delayed approach briefing served to divert the pilots' attention from handling the airplane, managing the deice boot system, and monitoring the tasks that had to be performed during that period. The Safety Board concludes that the briefing conducted late in the approach was a distraction that impeded the flight crew's ability to monitor and maintain airspeed and manage the deice system.

The NTSB determined that the probable cause of this accident was "the flight crew's failure to effectively monitor and maintain airspeed and comply with procedures for deice boot activation on the approach, which caused an aerodynamic stall from which they did not recover."

Photo: U.S. National Transportation Safety Board

For more information:

NTSB. (2007). Aircraft Accident Report: *Crash During Approach to Landing, Circuit City Stores, Inc. Cessna Citation 560, N500AT. Pueblo, Colorado, February 16, 2005.* (NTSB Report No. NTSB/AAR-07/02.) Retrieved from <www.ntsb.gov/doclib/reports/2007/AAR0702.pdf>.

Crash Due to Inadequate Monitoring During Aircraft Malfunction
Empire Airlines Flight 8284
ATR-42-320, N902FX
Lubbock, Texas, U.S.
January 27, 2009
2 injuries

On Jan. 27, 2009, about 0437 local time, an ATR 42-320, N902FX, operating as Empire Airlines Flight 8284, was on an instrument approach when it crashed short of the runway at Lubbock Preston Smith International Airport, Lubbock, Texas. The captain sustained serious injuries, and the first officer sustained minor injuries. The airplane was substantially damaged. The airplane was registered to FedEx and operated by Empire Airlines as an FARs Part 121 supplemental cargo flight. The flight departed from Fort Worth Alliance Airport, Fort Worth, Texas, about 0313. Instrument meteorological conditions prevailed, and an instrument flight rules flight plan was filed.

While flying an ILS approach in light freezing drizzle, the crew experienced a flap asymmetry. The aircraft was at approximately 1,400 ft above ground level (AGL), just outside the final approach fix, when this occurred. The first officer continued flying the approach while the captain attempted to troubleshoot the flap problem by checking circuit breakers behind the first officer's seat and repositioning the flap handle several times.

While the captain was attempting to troubleshoot the problem, airspeed decreased 35 kt, culminating in a stall warning activation. The captain told the first officer, "Yeah, don't do that. Just keep flying the airplane, okay." The autopilot disconnected when the stall warning activated and the first officer advanced power. The stall warning ceased as airspeed increased. The first officer asked, "Should I go around?" and the captain replied, "No keep descending."

The first officer was straining due to the amount of control wheel deflection caused by the flap asymmetry. The captain took over control of the aircraft as it passed through 700 ft AGL. He reduced power because the aircraft was now fast. Airspeed decreased rapidly. As the aircraft passed through approximately 150 ft AGL, the captain allowed the aircraft to stall and did not regain control. The aircraft crashed about 300 ft (92 m) north of the runway threshold, slightly right of course, and skidded along the airport surface. The NTSB's report on this accident stated:

> Previous accidents have shown that pilots can become distracted from flying duties when an emergency or abnormal situation occurs, and literature suggests that "one of the biggest hazards of 'abnormals' is becoming distracted from other cockpit duties." While flying the approach, the first officer was likely distracted from monitoring the instruments by the flap anomaly, the captain's nonstandard actions involving the circuit breakers and the control force inputs needed to maintain control of the airplane because of the flap asymmetry. Further, for the captain to check circuit breakers behind the first officer's seat, he would need to turn away from the instrument panel, a position from which monitoring the instruments was not possible. The NTSB concludes that the first officer's failure to maintain airspeed while acting as the PF [pilot flying] likely resulted from being distracted by the flap anomaly, the captain's actions in response to it, and the control force inputs needed to maintain aircraft control. Further, the NTSB concludes that the captain's failure to call out the first officer's airspeed deviations resulted directly from his preoccupation with performing an inappropriate, nonstandard procedure in response to the flap anomaly.

The NTSB determined the probable cause of the accident was "the flight crew's failure to monitor and maintain a minimum safe airspeed while executing an instrument approach in icing conditions, which resulted in an aerodynamic stall at low altitude. Contributing to the accident were 1) the flight crew's failure to follow published standard operating procedures in response to a flap anomaly, 2) the captain's decision to continue with the unstabilized approach, 3) the flight crew's poor crew resource management, and 4) fatigue due to the time of day in which the accident occurred and a cumulative sleep debt, which likely impaired the captain's performance."

Photo: U.S. National Transportation Safety Board

For more information:

NTSB. (2011). Aircraft Accident Report: *Crash During Approach to Landing, Empire Airlines Flight 8284. Avions de Transport Régional Aerospatiale Alenia ATR 42-320, N902FX*. Lubbock, Texas, January 27, 2009. (NTSB Report No. NTSB/AAR-11/02.) Retrieved from <www.ntsb.gov/doclib/reports/2011/AAR1102.pdf>.

Controlled Flight Into Terrain
Eastern Air Lines Flight 401
Lockheed L-1011, N310EA
Near Miami, Florida, U.S.
Dec. 29, 1972
99 fatalities

On approach to Miami International Airport, the crew selected the landing gear down, but did not get a green "gear down and locked" indication for the nose gear. They climbed to 2,000 ft and received vectors from air traffic control (ATC) so they could troubleshoot the problem. The crew was flying over featureless terrain (the Florida Everglades) on a dark, moonless night.

While attempting to replace a potentially inoperative light bulb, the first officer jammed the replacement bulb in the socket. While attempting to remove the lodged bulb, the NTSB concluded that one of the flight crewmembers inadvertently bumped the control column, forcing the autopilot out of the altitude hold mode and placing it into a gradual descent. The NTSB said that "the first officer became preoccupied with his attempts to remove the jammed light assembly; the captain divided his attention between attempts to help the first officer and orders to other crewmembers to try other approaches to the problem, and the flight crew devoted approximately four minutes to the distraction, with minimal regard for other flight requirements."

In short, the crew became distracted by attempting to resolve the problem and inadvertently disengaged the autopilot's altitude hold mode, allowing the airplane to descend undetected into the terrain. The NTSB found the probable cause of this accident to be "the failure of the flight crew to monitor the flight instruments during the final four minutes of flight, and to detect an unexpected descent soon enough to prevent impact with the ground. Preoccupation with a malfunction of the nose landing gear position indicating system distracted the crew's attention from the instruments and allowed the descent to go unnoticed."

For more information:

NTSB. (1973). Aircraft Accident Report: *Eastern Air Lines, Inc., L-1011, N310EA, Miami, Florida. December 29, 1072*. (NTSB Report No. NTSB/AAR-73/14.) Retrieved from <libraryonline.erau.edu/online-full-text/ntsb/aircraft-accident-reports/AAR73-14.pdf>.

Attempted Takeoff From Wrong Runway
Comair Flight 5191
Bombardier CL-600-2B19, N431CA
Lexington, Kentucky, U.S.
Aug. 27, 2006
49 fatalities

During a predawn taxi-out for departure to Runway 22 at Lexington Blue Grass Airport, the flight crew of the Bombardier Regional Jet mistakenly taxied onto Runway 26 and attempted a takeoff. The runway was 3,501 ft (1,068 m) long, not long enough to safely take off. The aircraft continued the ground run at high speed past the departure end of the runway before colliding with trees and impacting upward-sloping terrain. The aircraft burst into flames, killing everyone aboard except the first officer.

Photo: U.S. National Transportation Safety Board

The NTSB determined that the probable cause of this accident was "the flight crewmembers' failure to use available cues and aids to identify the airplane's location on the airport surface during taxi and their failure to cross-check and verify that the airplane was on the correct runway before takeoff. Contributing to the accident [was] the flight crew's non-pertinent conversation during taxi, which resulted in a loss of positional awareness."

For more information:

NTSB. (2007). Aircraft Accident Report: *Attempted Takeoff from Wrong Runway. Comair Flight 5191. Bombardier CL-600-2B19, N431CA. Lexington, Kentucky. August 27, 2006.* (NTSB Report No. NTSB/AAR-07/05.) Retrieved from <www.ntsb.gov/doclib/reports/2007/AAR0705.pdf>.

Appendix D: What Skilled Monitors Do

Some pilots perform better at monitoring than others. What are some of the characteristic traits associated with skilled monitoring? Based on the expertise available to the Active Pilot Monitoring Working Group, created in 2012 by the first Human Factors Aviation Industry Roundtable, this section outlines some of those traits to illustrate how monitoring is directed at doing (and looking for) specific actions.

In general, skilled monitors understand the importance of areas of vulnerability (AOV). They avoid (defer) doing non-monitoring–related tasks while operating in areas where they are most vulnerable to flight path errors. They also plan to conduct activities such as briefing the approach in a less vulnerable AOV.

On the Ground

Phase	Captain	First Officer
Prior to taxi	Complete all anticipatable tasks.	
During taxi — general	Avoid tasks not related to ground navigation.	
If interrupted by an unanticipated task during taxi	Monitor ground path with high-sample-rate scan. Delegate the task to PM. Consider stopping and setting brake if significant collaboration is necessary or if the taxi route is complex. Consider re-verbalizing restrictions before and after PM completes the task to reinforce working memory.	Advise head-down and complete the required task.
Taxiing in tight spaces or in proximity to runway crossing	Monitor ground path with high-sample-rate scan. Defer tasks until away from runway crossing or tight space.	

PM = pilot monitoring

In Flight

Phase	Pilot Flying	Pilot Monitoring
FMS entries	Ensure both pilots deliberately check and confirm changes to FMS flight path. Look long enough to see (half-second minimum). Point if necessary.	
Setting MCP altitudes	Set intended altitude.	Deliberately check selected altitude. Look long enough to see. Point at and state selected altitude to aid focusing your eyes on it.
Lateral changes and speed changes	Momentarily defer non-monitoring tasks until path change is complete. Monitor flight path with high-sample-rate scan. Confirm aircraft actually does what you think you told it to do.	
	If flight guidance modes or aircraft actions don't agree with expected actions, intervene.	If flight guidance modes or aircraft actions don't agree with expected actions, call out to PF or intervene, as necessary.
During climb	Monitor flight path. Defer nonessential tasks until in lower area of vulnerability.	
	Avoid non-monitoring tasks. Delegate task to PM or transfer control (e.g., change to FMS routing). If flight guidance modes or aircraft actions don't agree with expected actions, intervene.	May perform essential non-monitoring tasks (e.g., FMS route change). If flight guidance modes or aircraft actions don't agree with expected actions, call out to PF or intervene, as necessary.
During descent	Monitor flight path. Defer nonessential tasks until in lower area of vulnerability. Mentally compute and confirm intermediate energy targets to validate progress toward the constraint.	
	Avoid non-monitoring tasks. Delegate task to PM or transfer control (e.g., runway change, change to FMS routing). If flight guidance modes or aircraft actions don't agree with expected actions, intervene.	May perform essential non-monitoring tasks (e.g., FMS route change). If flight guidance modes or aircraft actions don't agree with expected actions, call out to PF or intervene, as necessary.
1,000 ft prior to level-off	Treat last 1,000 ft as sterile cockpit.	
	Make altitude callout prior to hearing altitude alerter.	Make altitude callout if PF does not make altitude callout.
Approaching level-off/level-off	Momentarily defer non-monitoring tasks until fully established at new altitude. Concentrate on ensuring the aircraft levels at desired altitude, including proper FMA, and expected thrust response. Actively monitor aircraft *all the way* through the completion of the level-off.	
	If flight guidance modes or aircraft actions don't agree with expected actions, intervene.	If flight guidance modes or aircraft actions don't agree with expected actions, call out to PF or intervene, as necessary.
At low altitude or below surrounding terrain (climbing)	Monitor flight path with high-sample-rate scan. If possible, delay non-flight path–related tasks until at safe altitude (e.g., bleed trip checklist).	
At low altitude or below surrounding terrain (descending)	Monitor flight path with high-sample-rate scan. If possible, climb to safe altitude prior to addressing non-flight path–related issues. (e.g., flaps checklist) Plan profile to avoid excessive workload. Climb to a safe altitude if workload becomes excessive, or if experiencing confusion. Confirm glide path during final approach (especially while flying at night or in IMC) by checking altitude/distance targets.	
Cruise flight	To the extent possible, use this time to complete all anticipatable tasks (e.g., administrative tasks, stowing and pulling out charts, setting up and briefing approaches).	

FMA = flight mode annunciator; FMS = flight management system; IMC = instrument meteorological conditions; MCP = mode control panel; PF = pilot flying

Elevated Demand on Crew Attention

Phase	Pilot Flying	Pilot Monitoring
When interrupted by unanticipated tasks	Delegate task to PM (or transfer aircraft control). Continue monitoring flight path with high-sample-rate scan.	Perform task after visually ascertaining PF is monitoring the flight path. If PF inappropriately engages in non-monitoring task, then monitor flight path with high-sample-rate scan.
	Verbalize constraints as needed to reinforce awareness.	
When interrupted by non-normal situations	Monitor flight path with high-sample-rate scan Avoid initiating procedures until aircraft trajectory is safe.	Maintain awareness of flight path until it is established that the other crewmember is concentrating on monitoring the flight path.
When anticipating marginal, black-hole, white-out conditions, and/or terrain threats	Be aware of elevated potential for low-altitude-monitoring failure. Identify potential sources of workload spike or distraction, and plan an energy profile that minimizes time pressure. Establish the crew's intention to go around at the first indication of excessive workload, confusion or distraction.	
	Call for go-around at first sign of excessive workload, confusion or distraction.	
When confirming infrequently sampled items (e.g., MCP altitude, flaps, fuel, ground spoiler deployment or reverser deployment)	Slow down and check the item deliberately. Look long enough to see. Point or touch if necessary.	

MCP = mode control panel; PF = pilot flying; PM = pilot monitoring