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

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1 Executive Summary

In 1996, the *Federal Aviation Administration (FAA) Human Factors Team Report on the Interfaces between Flightcrews and Modern Flight Deck Systems* (FAA, 1996) was published. In this report, the Human Factors (HF) Team described how the aviation system is very safe. However, the review of data at that time identified issues that showed vulnerabilities in flightcrew management of automation and situation awareness. Since then, major improvements have been made in the design, training, and operational use of onboard systems for flight path management (autopilot, autothrottle/autothrust, flight director, flight management systems (FMS[1]), etc., and their associated flightcrew interfaces). These systems have contributed significantly to the impressive safety record of the air transportation system.

Currently, 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 (such as those mentioned above), pilot training, professional pilot skills, flightcrew and air traffic procedures, improved safety data collection and analysis, and other efforts by industry and government. However, incident and accident reports suggest that flightcrews sometimes have difficulties using flight path management systems. Appropriate use of these systems by the flightcrew is critical to safety and effective implementation of new operational concepts, such as Performance-based Navigation (PBN), which includes Area Navigation (RNAV) and Required Navigation Performance (RNP) operations.

To address these concerns, the Performance-Based Aviation Rulemaking Committee (PARC) and the Commercial Aviation Safety Team (CAST) established a joint working group of authorities, industry, and researchers to update the 1996 FAA report and to address, for current and projected operational use, the safety and efficiency of modern flight deck systems for flight path management (including energy-state management). This included a review of equipment design, flight operations in global airspace, operational policies, flightcrew procedures, and flightcrew qualification and training for jet transport aircraft operating with two-pilot "air-carrier-like" operations.

This joint working group, called the Flight Deck Automation Working Group (referred to as the WG), analyzed data from several different data sources. The group reviewed worldwide data from accidents, incidents, normal operations, structured interviews with manufacturers, operators, and training organizations, and reports from related activities. These data were analyzed and the results were used to identify changes since 1996, and to develop the WG findings[2] and recommendations.

[1] FMS is the generic term used throughout the report. Also sometimes call Flight Management Computer or Flight Management and Guidance System.

[2] The WG defined a finding as a conclusion based on the results of analyses of one or more data sources.

There have been a number of changes to the technical, operational, economic, and political environment since 1996 that affect current and future operational safety and effectiveness. These changes include increased aircraft onboard capabilities for flight path management, increased use of FMS functions, transition away from conventional procedures constructed upon ground-based navigation aids to increased use of RNAV-based navigation (RNAV and RNP), reliance on the quality and availability of digital data, increased focus on managing costs, and changes in new-hire pilot demographics.

The working group identified several factors that are projected to impact future operations to provide a context in which to consider the findings and recommendations:

- Growth in the number of aircraft operations,
- Continuing changes in the demographics of the aviation workforce,
- Evolution in the knowledge and skills needed by pilot and air traffic personnel,
- Historically low commercial aviation accident rates that make the cost/benefit case very challenging for additional safety and regulatory changes, and
- Future airspace operations that exploit new technology and operational concepts for navigation, communication, surveillance, and air traffic management.

Based on its analyses, the Working Group determined the following findings. It is important to note that these findings are not specific to a particular type of operation, manufacturer, operator, or other organization. Many of the findings and recommendations are interdependent and should not be considered in isolation. Each finding and recommendation is discussed in the body of the report.

<u>Finding 1 - Pilot Mitigation of Safety and Operational Risks.</u>
Pilots mitigate safety and operational risks on a frequent basis, and the aviation system is designed to rely on that mitigation.

<u>Finding 2 - Manual Flight Operations.</u>
Vulnerabilities[3] were identified in pilot knowledge and skills for manual flight operations, including:

- Prevention, recognition and recovery from upset conditions, stalls or unusual attitudes,
- Appropriate manual handling after transition from automated control,
- Inadequate energy management,
- Inappropriate control inputs for the situation,
- Crew coordination, especially relating to aircraft control, and
- Definition, development, and retention of such skills.

<u>Finding 3 - Managing Malfunctions.</u>
Pilots successfully manage equipment malfunctions[4] as threats[5] that occur in normal operations. However, insufficient system knowledge, flightcrew procedure, or understanding of aircraft state may decrease pilots' ability to respond to failure situations. This is a particular concern for

[3] Vulnerability refers to a characteristic or issues that renders the system or process more likely to breakdown or fail when faced with a particular set of circumstances or challenges.
[4] An equipment malfunction is when equipment fails to work or works improperly.
[5] A threat is something that can increase operational complexity and potentially decrease safety margins.

failure situations which do not have procedures or checklists, or where the procedures or checklists do not completely apply.

Finding 4 - Automated Systems.
Automated systems have been successfully used for many years, and have contributed significantly to improvements in safety, operational efficiency, and precise flight path management. However, pilot use of, and interaction with, automated systems[6] were found to be vulnerable in the following areas:

- Pilots sometimes rely too much on automated systems and may be reluctant to intervene,
- Autoflight mode confusion errors continue to occur,
- The use of information automation[7] is increasing, including implementations that may result in errors and confusion, and
- FMS programming and usage errors continue to occur.

Finding 5 - Pilot-to-Pilot Communication and Coordination.
Pilot-to-pilot communication and coordination have improved and been more formalized; however, communication and coordination vulnerabilities still contribute to accidents and incidents.

Finding 6 – Communication and Coordination between Pilots and Air Traffic Services.
Communication and coordination between pilots and air traffic services has vulnerabilities that can affect flight path management. Amended clearances from air traffic generally are issued with good intentions but can lead to misunderstandings, increased flightcrew workload, and potential pilot errors when using flight path management systems. Even properly issued clearances, if timed such that the flightcrew cannot reasonably execute the instruction in the time available, can result in similar difficulties and undesired aircraft states.

Finding 7 - Standard Operating Procedures.
Compliance with published standard operating procedures (SOPs) has been increasingly emphasized, with safety and operational benefits. However, the data analyses showed pilots do not always follow standard operating procedures, for a variety of reasons, including:

- Procedures may not match operational situations well,
- Workload may not permit completion of the procedures,
- Procedures may be too prescriptive or detailed, and
- No adverse flight consequences appear to occur by not following the SOP.

Finding 8 - Data Entry and Cross Verification Errors.
Data entry errors, together with cross verification errors, may cause significant flight path deviations leading to incidents or accidents.

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[6] This refers to automated systems within the scope of our tasking, related to flight path management.
[7] Information automation refers to automation of information-related tasks, such as calculation, management or integration and presentation of information.

Finding 9 – Operator Policies for Flight Path Management.
Increasingly, operators use a documented automation policy. Lessons learned in the application of these policies reveal that improvements could be made to better focus attention on the flight path management related tasks and more effectively use automated systems.

Finding 10 - Task/Workload Management.
Flight deck task/workload management continues to be an important factor affecting flight path management.

Finding 11 - Pilot Knowledge and Skills for Flight Path Management:
Pilots sometimes lack sufficient or in-depth knowledge and skills to most efficiently and effectively accomplish the desired flight path management related tasks.

Finding 12 - Current Training Time, Methods, and Content.
Current training methods, training devices, the time allotted for training, and content may not provide the flightcrews with the knowledge, skills and judgment to successfully manage flight path management systems.

Finding 13 – Flight Instructor Training and Qualification.
Flight instructor training, experience, and line-operation familiarity may not be sufficient to effectively train flightcrews for successful flight path management. This will be especially important for future operations.

Finding 14 – Flight Deck Equipment Design.
Current flight deck designs have incorporated many useful safety and operational improvements through new systems and technologies. However, the data suggest that the highly integrated nature of current flight decks, and additional "add-on" features and retrofits in older aircraft, have increased flightcrew knowledge requirements and introduced complexity that sometimes results in pilot confusion and errors in flight deck operations.

Finding 15 - Flight Deck Equipment Standardization.
There is significant variation in flight deck equipment design, in both flightcrew interfaces and in system functionality. Such variations can have important consequences for flightcrews (pilot error, increased training time, negative transfer of learning, etc.) and airspace operations (potential differences in the flight paths within the airspace), especially considering future airspace changes. Although standardization can reduce such variations, comprehensive changes to standardize existing equipment may not be realistic and complete standardization may inhibit advances in technology.

Finding 16 - Human Factors in the Flight Deck Design Process.
Human factors expertise has been increasingly incorporated into the design process at most manufacturers, but is still inconsistently applied at some manufacturers. Furthermore, HF specialists may not exist in some organizations or are called upon (either in-house or at another manufacturer) to resolve or mitigate crew-centered issues that are discovered late in the design schedule.

Finding 17 – Knowledge and Skills of Flight Deck Designers.
The WG found different definitions of "human factors specialist" being used within the aviation industry and by the regulators. In some cases, formal training or background in relevant areas was required (e.g., experimental psychology, industrial engineering, human/computer interaction), and in other cases, human factors expertise was related primarily to experience in piloting and flight test.

Finding 18 - Complex and Unfamiliar Instrument Flight Procedures.
Complex or unfamiliar airspace flight procedures can be confusing and lead to errors involving flight path management. In addition, airspace design and associated airspace procedures are not always compatible with aircraft capabilities.

Finding 19 - Knowledge and Skills of Air Traffic Personnel.
Air traffic service personnel often do not have sufficient knowledge of how airspace procedure design and clearances affect flight deck operations and often lack knowledge of aircraft capabilities. As a result, the airspace procedures and clearances are sometimes not compatible with the aircraft operating in the airspace system.

Finding 20 – Knowledge and Skills of Regulators.
Regulators have improved their knowledge and expertise in human performance evaluation methods, criteria, guidelines, and research results; identification of research requirements; and operational knowledge about how the airplane will be flown, but the demand for such capabilities within the regulator is greater than the capabilities available.

Finding 21 - Regulatory Process for New Technologies or Operations.
The WG found the following concerns about the regulatory process:

- Aircraft certification and operational approvals for new technologies take too long and are more burdensome than necessary.
- Standards and criteria to support new technologies sometimes are slow to be developed and approved.
- Regulators are sometimes reluctant to change existing policies and procedures to eliminate unnecessary, preexisting, requirements.
- Integration with existing systems and consequences from an operational/crew-centered perspective are not always sufficiently considered, possibly introducing unanticipated risks to the integrated type design or operation.

Finding 22 – Availability of Flight Operations Data.
The amount and types of data collected for analysis of flight operations have increased significantly since 1996, and utilization of these data has resulted in substantial benefits for safety.

Finding 23 - Data Source Strengths and Limitations.
Each data source has characteristics, limitations and strengths that affect its usefulness for addressing intended safety and operational questions.

Finding 24 - Organizing and Analyzing Operations Data.
The increased availability of operations data has resulted in a large quantity of those data. Effectively identifying and addressing the issues from these data require sophisticated means to organize and analyze the data and appropriate resources and expertise. The review and analysis of narrative-intensive safety data can be very labor intensive and require expertise in the analysis process and operations being addressed.

Finding 25 - Sources of Data about Positive Behaviors.
The majority of safety and operational data come from a negative perspective and describe negative events that have occurred, such as incidents or accidents. There are very few data sources that capture the positive aspects of the aviation system, such as those aspects that describe when pilots or controllers overcome adverse situations or successfully mitigate operational or safety risk.

Finding 26 - Variability in Safety Event Investigations.
There is significant variability in the topics covered or emphasized by different accident investigation agencies around the world.

Finding 27 – Interactions and Underlying Factors in Accidents and Incidents.
Current practices for accident and incident investigation are not designed to enable diagnoses of interactions between safety elements and underlying or "latent" factors that are increasingly recognized as important contributors to safety risks. One reason is because there is a lack of data available addressing such factors. When developing safety enhancements, such factors (e.g. organizational culture or policies) are just as important to understand as the human errors that occur.

Finding 28 - Precursors to Accidents.
The relationship between incidents and accidents is complex. The characteristics of this relationship should be understood when using incidents (or other data sources) as precursors or predictors of more serious safety events. Mitigations to one risk factor can create other, unanticipated risks.

Regardless of how low the accident rate gets, all stakeholders must remain vigilant to ensure that risks are continuously evaluated and mitigated. The ongoing evolution in airspace operations will require careful attention to change management to maintain or improve safety. Therefore, based on the above findings, the following recommendations are made:

Recommendation 1 – Manual Flight Operations.
Develop and implement standards and guidance for maintaining and improving knowledge and skills for manual flight operations that include the following:

- Pilots must be provided with opportunities to refine this knowledge and practice the skills;
- Training and checking should directly address this topic; and
- Operators' policies for flight path management must support and be consistent with the training and practice in the aircraft type.

This should be done in an integrated manner with related recommendations.

Recommendation 2 - Autoflight Mode Awareness.
For the near term, emphasize and encourage improved training and flightcrew procedures to improve autoflight mode awareness as part of an emphasis on flight path management. For the longer term, equipment design should emphasize reducing the number and complexity of autoflight modes from the pilot's perspective and improve the feedback to pilots (e.g., on mode transitions) while ensuring that the design of the mode logic assists with pilots' intuitive interpretation of failures and reversions.

Recommendation 3 – Information Automation.
Develop or enhance guidance for documentation, training, and procedures for information automation systems (e.g., Electronic Flight Bags (EFBs), moving map displays, performance management calculations, multi-function displays) or functions:

- Describe what is meant by Information Automation and what systems, equipment are included,
- Define terms associated with Information Automation,
- Develop guidelines concerning the content and structure of policy statements in Flight Operations Policy Manuals for Information Automation, and
- Develop operational procedures to avoid information-automation-related errors.

Recommendation 4 – FMS Documentation, Design, Training, and Procedures for Operational Use.
In the near term, develop or enhance guidance for flightcrew documentation, training and procedures for FMS use. For the longer term, research should be conducted on new interface designs and technologies that support pilot tasks, strategies and processes, as opposed to machine or technology-driven strategies.

Recommendation 5 – Verification and Validation for Equipment Design.
Research should be conducted and implemented on processes and methods of verification and validation (includes validation of requirements) during the design of highly integrated systems that specifically address failures and failure effects resulting from the integration.

Recommendation 6 - Flight Deck System Design.
Flightcrew training should be enhanced to include characteristics of the flight deck system design that are needed for operation of the aircraft (such as system relationships and interdependencies during normal and non-normal modes of operation for flight path management for existing aircraft fleets). For new systems, manufacturers should design flight deck systems such that the underlying system should be more understandable from the flightcrew's perspective by including human-centered design processes.

Recommendation 7 – Guidance for Flightcrew Procedures for Malfunctions.
Develop guidance for flightcrew strategies and procedures to address malfunctions for which there is no specific procedure.

Recommendation 8 – Design of Flightcrew Procedures.
For the near term, update guidance (e.g., Advisory Circular (AC) 120-71A) and develop recommended practices for design of SOPs based on manufacturer procedures, continuous feedback from operational experience, and lessons learned. This guidance should be updated to reflect operational experience and research findings on a recurring basis. For the longer term, conduct research to understand and address when and why SOPs are not followed. The activities should place particular emphasis on monitoring, cross verification, and appropriate allocation of tasks between pilot flying and pilot monitoring.

Recommendation 9 - Operational Policy for Flight Path Management.
Operators should have a clearly stated flight path management policy as follows:

- The policy should highlight and stress that the responsibility for flight path management remains with the pilots at all times. Focus the policy on flight path management, rather than automated systems.
- Identify appropriate opportunities for manual flight operations.
- Recognize the importance of automated systems as a tool (among other tools) to support the flight path management task, and provide operational policy for the use of automated systems.
- Distinguish between guidance and control.
- Encourage flightcrews to tell Air Traffic "unable" when appropriate.
- Adapt to the operator's needs and operations.
- Develop consistent terminology for automated systems, guidance, control, and other terms that form the foundation of the policy.
- Develop guidance for development of policies for managing information automation.

Recommendation 10 - Pilot-Air Traffic Communication and Coordination.
Discourage the use of regional or country-specific terminology in favor of international harmonization. Implement harmonized phraseology for amendments to clearances and for re-clearing onto procedures with vertical profiles and speed restrictions. Implement education and familiarization outreach for air traffic personnel to better understand flight deck systems and operational issues associated with amended clearances and other air traffic communications. In operations, minimize the threats associated with runway assignment changes through a combination of better planning and understanding of the risks involved.

Recommendation 11 - Airspace Procedure Design.
Continue the transition to PBN operations and drawdown of those conventional procedures with limited utility. As part of that transition, address procedure design complexity (from the perspective of operational use) and mixed equipage issues. Standardize PBN procedure design and implementation processes with inclusion of recommended practices and lessons learned. This includes arrivals, departures, and approaches.

Recommendation 12 – Flight Deck Design Process and Resources.
Ensure that appropriate human factors expertise is integrated into the flight deck design process in partnership with other disciplines with the goal of contributing to a human-centered design. To assist in this process, an accessible repository of references should be developed that identifies the core documents relevant to "recommended practices" for human-centered flight deck and equipment design. Early in the design process, designers should document their assumptions on how the equipment should be used in operation.

Recommendation 13 - Pilot Training and Qualification.
Revise initial and recurrent pilot training, qualification requirements (as necessary) and revise guidance for the development and maintenance of improved knowledge and skills for successful flight path management. As part of the implementation of this recommendation, improve the oversight of air carriers and Part 142 Training Centers.

Recommendation 14 - Instructor/Evaluator Training and Qualification.
Review and revise, as necessary, guidance and oversight for initial and recurrent training and qualification for instructors/evaluators. This review should focus on the development and maintenance of skills and knowledge to enable instructors and evaluators to successfully teach and evaluate airplane flight path management, including use of automated systems.

Recommendation 15 - Regulatory Process and Guidance for Aircraft Certification and Operational Approvals.
Improve the regulatory processes and guidance for aircraft certification and operational approvals, especially for new technologies and operations, to improve consideration of human performance and operational consequences in the following areas:

- Changes to existing flight deck design through Supplemental Type Certificates (STCs), Technical Standard Orders (TSOs), or field approvals, and
- Introduction of new operations or changes to operations, to include implications for training, flightcrew procedures, and operational risk management.

Recommendation 16 – Flight Deck Equipment Standardization.
Develop standards to encourage consistency for flightcrew interfaces for new technologies and operations as they are introduced into the airspace system. Standards should be developed which establish consistency of system functionality (from an airspace operations perspective) for those operations deemed necessary for current and future airspace operations.

Recommendation 17 - Monitor Implementation of New Operations and New Technologies.
Encourage the identification, gathering, and use of appropriate data to monitor implementation of new operations, technologies, procedures, etc. based on the specified objectives for safety and effectiveness. Particular attention should be paid to human performance aspects, both positive and negative.

<u>Recommendation 18 – Methods and Recommended Practices for Data Collection, Analysis and Event Investigation That Address Human Performance and Underlying Factors.</u>
Develop methods and recommended practices for improved data collection, operational data analysis and accident and incident investigations. The methods and recommended practices should address the following:

- When reviewing and analyzing operational, accident and incident data, or any other narrative-intensive dataset, ensure that the team has adequate expertise in the appropriate domains to understand the reports and apply appropriate judgment and ensure that the time allotted for the activity is adequate.
- Explicitly address underlying factors in the investigation, including factors such as organizational culture, regulatory policies, and others.
- Provide guidance on strengths and limitations of different data sources and different methodologies and taxonomies.
- Encourage the use of multiple, dissimilar data sources to provide better coverage of events.
- Encourage the wide sharing of safety related information and analysis results, especially lessons learned and risk mitigations.

In summary, the Working Group identified numerous areas that contribute to safety and operational effectiveness. However, vulnerabilities were identified in the accident, incident and operational data reviewed by the Working Group. Some underlying themes that the Working Group has identified include complexity (in systems and in operations); concerns about degradation of pilot knowledge and skills; and integration and interdependence of the components of the aviation system.

Since the Working Group completed its data collection and analysis, several accidents have occurred where the investigative reports identified vulnerabilities in the events that are similar to those vulnerabilities identified in this report. The Working Group believes that implementing these recommendations will be necessary to make improvements in safety and operational effectiveness, especially considering the expected changes in future operations.

2 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, flightcrew and air traffic procedures, improved safety data collection and analysis, professional pilot skills, and other efforts by industry and government. One of the characteristics of this aviation community that has contributed is a commitment to continuously improve safety and operations.

2.1 Background

Managing the flight path of the aircraft is a basic pilot responsibility, and the means of accomplishing it have evolved considerably. Previous generations of airplanes, such as B707, 727, DC10, etc. were controlled by manual flight controls or an autopilot and navigation was accomplished by displays driven by radios receiving signals from ground based navigation stations. Navigation was “relative” to a ground navigation station. The pilot would tune the radio to the appropriate frequency, aurally verify that the correct station was tuned, and then set the desired radial or bearing to or from the ground station into the flight deck course deviation indictor display. Once set, the pilot would engage the autopilot to “track” the displayed course. Errors sometime happened, usually benign, although sometimes serious, if the pilot inadvertently entered the wrong frequency or bearing and failed to adequately cross verify to detect the error. These navigation errors were regarded as navigation errors rather than “automation” errors even though the autopilot was controlling the airplane.

Automatic landing systems have been commonplace on commercial airliners since the seventies, developed to enhance safety while landing in conditions of very low visibility. These types of landings can be only accomplished on certain designated runways and airports that have substantially more infrastructure requirements than normal. The circumstances requiring or allowing an automatic landing are rare, and pilots normally prefer to manually land the airplane.

Modern flight deck systems for flight path control are similar in many respects to previous generations, although much more tightly integrated so that it functions as a system usually referred to in the singular, as the “automation system.” Instead of a course deviation indicator, navigation information is presented to the pilot in the form of a “moving map” which shows the position of the relevant navigation waypoints which are coordinate based, by latitude and longitude. The position of the airplane is determined by Global Positioning System (GPS) satellites or autonomous inertial reference units rather than a fixed ground radio station. The desired route of flight is pre-programmed by the pilot (or uploaded automatically) and the pilot can couple the autopilot with the displayed route. In addition, vertical navigation (VNAV) and lateral navigation (LNAV) can be programmed. Programming of the navigation system is accomplished by the pilot through the Flight Management System, which has a keyboard and multi-function display system, often called a Control Display Unit (CDU). Errors can be introduced into the system by incorrect data entry, or rarely, by an incorrect database. Error prevention, detection and mitigation are facilitated by detailed procedures and strict adherence to those procedures.

In 1996, the *Federal Aviation Administration Human Factors Team Report on the Interfaces between Flightcrews and Modern Flight Deck Systems* (FAA, 1996) was published[8]. In this report, the Human Factors Team described how the aviation system is very safe. However, the review of data at that time identified issues that showed vulnerabilities in flightcrew management of automation and situation awareness. These vulnerabilities identified in that study appeared to exist to varying degrees across the fleet of transport category airplanes reviewed, regardless of the manufacturer, the operator, or whether accidents have occurred in a particular airplane type. Although the HF Team found specific issues associated with particular design, operating, and training philosophies, they considered the generic issues and vulnerabilities to be the most important to address.

The HF Team that wrote the 1996 FAA report considered it important to examine why these vulnerabilities exist. The HF Team concluded that the vulnerabilities exist because of a number of interrelated deficiencies in the current aviation system:

- Insufficient communication and coordination.
- Processes used for design, training, and regulatory functions inadequately address human performance issues.
- Insufficient criteria, methods, and tools for design, training, and evaluation.
- Insufficient knowledge and skills of designers, pilots, operators, regulators, and researchers in certain areas related to human performance.
- Insufficient understanding and consideration of cultural differences in design, training, operations, and evaluation.

Recommendations were made in the 1996 FAA report to address these vulnerabilities. Many of these recommendations were fully or partially implemented by the FAA and the aviation industry, and improvements have been made since the report was published. These include:

- Regulatory criteria and policy for autoflight system design (14 CFR Part 25.1329 and Advisory Circular (AC) 25.1329) and design-related flightcrew error (§25.1302 and AC 25.1302; Certification Specification (CS) 25.1302 and Acceptable Means of Compliance (AMC) 25.1302) have been updated or developed to reflect current technology and practice;
- Generally, manufacturers' design processes reflect increased awareness and consideration of human performance issues;
- Many air carriers have increased the emphasis on autoflight mode awareness in flightcrew training;
- The FAA and industry conducted an extensive effort to update regulatory criteria for flightcrew qualification, to be published for public comment very soon;
- Increased implementation of voluntary safety reporting programs has increased the availability of safety data;
- Many airlines have explicitly documented an automation use policy; and

[88] Hereafter referred to as the 1996 FAA report.

- The risk of Controlled Flight Into Terrain (CFIT) has been significantly reduced by the mandate for terrain awareness and warning systems and by the implementation of approach procedures with vertical guidance.

Since 1996, improvements have been made in the design, training, and operational use of onboard systems for flight path management, including autopilots, flight directors, autothrottle/autothrust systems, FMS, etc., and their associated flightcrew interfaces. These systems have contributed significantly to the impressive safety record of the air transportation system.

However, more recent incident and accident reports suggested that flightcrews continue to have problems using these flight path management systems. Yet appropriate use of these systems by the flightcrew is critical to safety and effective implementation of new operational concepts, such as RNAV and RNP. New technologies and new operational concepts are a key part of the transition to future airspace changes. This Working Group was formed to address these concerns and to update the 1996 FAA report. The remainder of this report describes the tasking, processes, and results of the Working Group.

2.2 Tasking of This Working Group

The Performance-Based Aviation Rulemaking Committee (PARC) and the Commercial Aviation Safety Team (CAST) established a joint working group to address, for current and projected operational use, the safety and efficiency of modern flight deck systems for flight path management (including energy-state management). These systems include autopilot, flight director, autothrottle/autothrust, flight management computers/systems (the term FMS will be used generically throughout the remainder of the report) and associated flightcrew interfaces in the following:

- Part 121 transport aircraft operations (or equivalent international operations) and
- Jet transport aircraft operating with two-pilot "air-carrier-like"[9] operations, including air carrier operations under Part 135, Part 91 Subpart K, or Part 91 that use Part 142 training centers.

The WG scope includes equipment design, operational policies, flightcrew procedures, and flightcrew qualification and training for flight path management. The scope of flight path management, as used in this report, includes trajectory management and energy management. There are many systems that are automated in an aircraft, but the term "automated systems" in the rest of the report will include the systems listed above for flight path management, and will not include others not directly related to flight path management (such as autobrakes).

According to its terms of reference, the Working Group was tasked to:

- Conduct an analysis of current and projected operational use of flight deck systems for flight path and energy-state management, to identify potential safety vulnerabilities. This included a review of current experience and current practices embodied in training programs and operational procedures for the use of automation for flight path and energy-

[9]The phrase "air-carrier-like" refers to operations that require two pilots with authority-approved training programs.

state management. Compile and analyze relevant accident / incident reports involving the use of this equipment for flight path and energy state management.

- Review the outstanding recommendations issued in the 1996 FAA report, and update/revise these recommendations, as appropriate.
- Develop an automation management training aid for flight path and energy-state management, if appropriate.
- Develop operational guidelines for use of automation for flight path and energy-state management, including policies and procedures.
- As appropriate, recommend revisions to relevant FAA ACs, such as AC 120-51 on Crew Resource Management (CRM) Training, or the creation of, or revision to, other applicable ACs and other guidance, to incorporate information on automation training and procedures for automation management.
- Recommend relevant industry standards documents to communicate recommended practices for use of flight deck systems for flight path and energy-state management.
- Make recommendations for improved standardization for flightcrew interfaces with these systems in Part 25 aircraft, as appropriate.

In addition, the WG was asked to identify lessons learned from analyzing multiple data sources, as part of a prognostic (versus forensic) approach to safety data analysis. As the analysis progressed and findings were developed, the lessons learned were retained into a set of findings related to the data collection and analysis process.

See Appendix A for the Terms of Reference of the Flight Deck Automation Working Group (referred to as "the WG" in the remainder of this report). The WG membership consisted of representatives from the industry and the FAA.

2.3 Methods, Processes and Sources of Data

To guide the work, the details of the WG Terms of Reference were broken down into specific tasks that could be accomplished and together would address all aspects of the tasking and build the foundation necessary for making sound observations and recommendations. Figure 1 shows the seven tasks that were defined to address the analysis phase of the tasking.

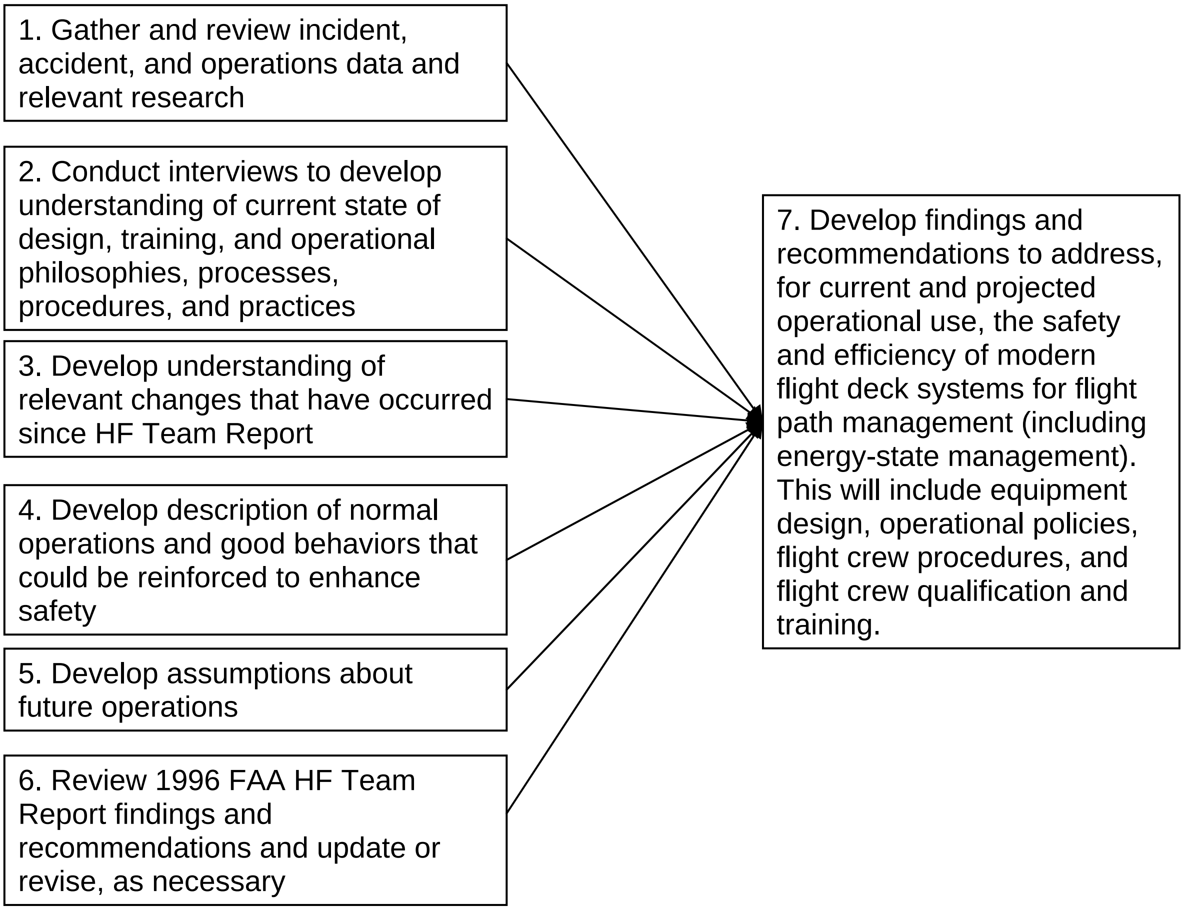

Figure 1. Overall Tasking of the Flight Deck Automation Working Group.

Task 1: Gathering and Review of Data
To accomplish Task 1, data from several sources were gathered and reviewed including ASRS incident reports, accident reports, major incident reports (reports developed by an investigating board for events that do not meet the definition of an accident), Line Operations Safety Audit (LOSA) aggregated reports, and research literature. Using multiple and diverse sources of data allows a more complete and thorough understanding of the issues of interest and provides a different perspective on current operations. Each source has strengths and weaknesses that bring different values to the analyses and must be taken into account when drawing conclusions. In general, the data sources differ in the perspective of those preparing the reports as well as the additional data that were available for understanding the events. Each of the data sources and their characteristics are described later in this section along with the methodology used to review the data.

Task 2: Organization Interviews and Observations
The WG conducted interviews with manufacturers and operators (including training organizations) by asking questions from a predefined list of topics. The lists of interview topics for manufacturers and operators can be found in Appendix B. The information gathered in these

interviews and observations is subjective but represents judgments by subject matter experts and describes operational experiences from a first-person perspective.

Task 3: Changes since the 1996 Human Factors Team Report
Relevant changes in design, operations, training, and regulatory oversight were identified and defined based on the experience of WG members, formal publications, and information gathered in the interviews of manufacturers and operators.

Task 4: Normal Operations and Positive Behaviors
When developing an understanding of safety and operations for the purpose of making recommendations, it is important to include a description of the normal operations and positive behaviors that should not be changed. This is a difficult task to accomplish, but access to LOSA data allows insight into normal operations at the observed airlines and includes when things go right as well as when things go wrong. In addition, some of the major incidents represent cases where the pilots' positive behaviors mitigated risk and prevented accidents.

Task 5: Assumptions about Future Operations
There are many changes being implemented in the next decade or so that will have significant effects on the airspace system as a whole and all operations within the airspace system. A thorough definition of how these operations will transpire is not yet available, but it is important to make assumptions about these future operations to allow a better understanding of the impact of observations made and data gathered during the project. This is also important for the effective development of findings and recommendations.

Task 6: Status of 1996 HF Team Report Recommendations
It is also important to understand the status of implementation and evaluation of efforts put in place as a result of the recommendations from the 1996 HF Team report. The terms of reference for the WG explicitly state that an assessment of the status of these recommendations is to be made along with a judgment about the continued relevance of the recommendations that have not yet been addressed. This task was accomplished using the results of the data analysis, the expertise and industry awareness of the working group members and the information gathered through the interviews.

Task 7: Develop Findings and Recommendations
The resulting data and information from all of the other tasks were used to develop findings and recommendations in all areas related to the scope of work. The results of the data analysis determined the areas in which findings and recommendations are described. These areas are reflected in the descriptions of findings and recommendations in the next section of this report.

Final Data Sets
The WG gathered and reviewed several types of data. Each of the data sets is described below.

Aviation Safety Reporting System (ASRS) and other incident reports (data from US only)

ASRS reports are useful for identifying topics of interest in current operations, as reported by pilots and air traffic service personnel who are involved in those operations. The strength of incident reports is that they describe an event that was personally experienced by the reporter. There are many insights that can be provided and information described and understood only by someone who experienced the event including the intentions, actions taken, and decisions made, which are often not available from any other source. When reviewing each report, it is important to understand that the report is a self-report, and therefore is subjective and written from memory after the time of the event. The reporters usually are not trained observers. Without training, it is difficult to clearly observe one's own situation and performance. Therefore, the reports need to be reviewed with this in mind. ASRS reports are self-reported and the frequency of reporting cannot be assumed to represent the frequency of occurrence in actual line operations.

The ASRS database was searched for incident reports that fall within the scope of work using the keywords described in Appendix C. After a high level review of all the search results, the WG did a detailed review of 734 reports submitted from 2001 to 2007 that were relevant to the WG scope.

Another type of incident report comes from operators' Aviation Safety Action Programs (ASAP). These are voluntary reports provided by pilots to the operator for whom they fly. Some ASAP reports are also submitted as ASRS reports and included in the ASRS database. ASAP reports are typically reviewed by an Event Review Committee (ERC) that may interview the pilot(s) or otherwise gather additional information to understand the event and develop action plans to prevent similar events in the future. ASAP data are often more thoroughly reviewed and may provide more insight into an event than reports filed only as an ASRS report. Some aggregated ASAP data were provided to the WG, but due to the timing of the WG study, the WG did not have access to a broad set of individual ASAP reports for review. ASAP reports are self-reported and the frequency of reporting cannot be assumed to represent the frequency of occurrence in actual line operations.

Accident Reports (Worldwide)

Accident reports are developed as the result of an in-depth investigation by formal boards. These reports usually include both objective and subjective data and analyses. Multiple data sources are used to reconstruct events and develop findings, conclusions, and recommendations. Accident reports are much more thorough than incident reports because the board is able to investigate different lines of inquiry as suggested by the data. However, unlike incident reports, the people involved in the event often are not available to provide their first-person insights. Many aspects of an event are not knowable through re-creation of the event with the data available after the fact. Such things as intentions, decision making, and use of automated systems usually cannot be reconstructed with a high level of confidence.

The WG identified 26 accidents that fell within the scope of the work, occurred since the Human Factors Team report, and for which the final reports were available by July 2009. See Appendix E for a list of the reports reviewed.

Major incident reports (Worldwide)

Events that are investigated by a formal investigative board and do not meet the criteria to be classified as an accident were reviewed and classified in the data set as "major incidents."

The WG identified 20 major incidents that fell within the scope of the work, each of which occurred since the FAA Human Factors Team report was published, and for which the final reports were available by July 2009. See Appendix E for a list of the reports reviewed.

Line Operations Safety Audit (LOSA) (Worldwide)

LOSA (see Klinect 2005 and FAA 2006) is a process by which trained observers audit a sampling of normal line operations for an operator during a specified period of time. Information resulting from a LOSA includes:

- **Event reports -** Individual operations observed and documented by trained observers. Documentation is made using an observation taxonomy developed for these audits, which includes a tallying of defined event types and rating of crew performance during the full flight and in handling specific events.
- **Narratives –** The trained observers will document additional information under some circumstances, to provide a rationale for the ratings of crew performance.
- **LOSA reports:** A report provided to an operator after a LOSA that describes their operational strengths, challenges, and safety vulnerabilities.
- **Aggregated reports -** These reports include LOSA results organized by event types and attributes aggregated across multiple operators.
- **Pilot interviews –** If time is available during appropriate parts of the flight, the LOSA observer asks the pilots predetermined questions. Of particular interest for this WG are the questions about areas of confusion the pilots have for the particular airplane type. The responses are subjective comments by the pilots across the airline and can represent perceptions of areas of concern or attitudes toward operations.

Data from LOSA observations on 9155 flights worldwide were shared with the WG by the LOSA Collaborative through aggregate reports that could be compared with other WG data. Also, input was provided from LOSA data that described positive pilot behaviors. Such information cannot easily be understood from the other data sets.

The LOSA Collaborative also supplied a representative sample of over 2200 de-identified narratives where the observer had indicated either a poor/marginal or outstanding assessment for the "use of automation" marker. These narratives provided further insight into threats flightcrew face that operationally impact automated systems. The narratives were analyzed to better understand how flightcrew may either err or adapt their use of automated systems.

Interviews (Worldwide)

The WG interviewed eleven operators, six manufacturers, and one training organization about their experiences and challenges. A structured interview method was used that was guided by a set of topics developed for the manufacturers and a set developed for the airlines and training organizations. The interview topics are included in Appendix C.

Reports from related activities, etc. (Worldwide**)**

This type of information ranged from previous research to descriptions of operational experience from many sources. This information was provided by aviation individuals and organizations, often confidentially, and included individual event reports, aggregated ASAP data, internal operator studies, and others. These were considered and incorporated in the WG analysis and results.

Data Review Methodology

The WG reviewed each of the ASRS incident reports, accident reports, and major incident reports and coded them using an online form that included categories organized in the following sections:

1. Report descriptive information;
2. Systems involved;
3. Automated system design, operation, and training issues;
4. Threats and errors;
5. Undesired aircraft states.

This form represented a categorization scheme for identifying characteristics of each event. The categorization scheme was developed based on previous work that developed issues related to the autoflight/flight path management systems, and based on the Threat and Error Management (TEM) categories used in LOSA reviews and by several airlines. In addition, the WG included categories based on other activities (such as, the CAST SE-30 analysis) and a cross verification against some current operational data. Appendix F contains a full description of the categorization scheme developed and used for this analysis.

It is important to note that, as with all safety reviews based on accident and incident reports, the data can only represent the information written in the reports that were reviewed. The WG did not reanalyze the data associated with the accidents or incidents, but used the findings and conclusions of the reporters or investigating boards as written in the reports to enter them in review categories.

The frequency of occurrence of all components of the categorization scheme was calculated and compared. While it cannot be assumed that these represent the frequency of occurrence in actual operations, some interesting results were found. In addition, factor analyses were conducted on the ASRS incident review results and the accident/major incident review results. The factor analyses were conducted to identify which groups of reports tended to account for the variability of the data and what insights or lessons could be learned from reviewing the factors.

Finally, a co-occurrence analysis was conducted and Pathfinder[10] networks were created to try to understand the relationships between categories that consistently co-occurred with other categories to take findings beyond what can be developed with frequency analyses alone. The detailed results of all analyses are described in Appendix G, and the findings and recommendations based on those results are discussed below in Sections 3 and 4.

All of the data analyses, the information gathered from interviews and other sources, and the expertise and experiences of the WG members were used to develop findings and recommendations that address the objectives and scope of the WG terms of reference. The data and analysis results were divided into subsets addressing design, operations, training, and regulatory issues. Each of these subsets was broken down and organized into appropriate categories to best understand and describe the conclusions that can be derived from the information. The WG identified conclusions from the data about operational experience on the "front line" from the multiple data sources and analysis results. The WG members then reviewed the data and analysis results to identify underlying factors to explain why the "front line" findings were there.

The subgroups drafted the findings that came from their set of information and then developed associated recommendations that could be traced back to the findings and the information from which the findings were developed. These findings and recommendations were then reviewed by the remainder of the WG. The process had many of the characteristics of other review and recommendation processes such as that used by CAST, but was driven by the specific tasking that addressed both operational effectiveness and safety, the breadth of data sources reviewed, and the diverse areas of expertise included in the WG. Appendix G contains more information about the process used.

It is important to note that the analysis results discussed within this report for accidents, major incidents, and ASRS incidents are based on the subsets of events that fell within the scope of this WG and were reviewed by the WG. These statistics do not represent frequency of occurrence for all accidents, major incidents, ASRS incidents that occurred during the time frame of this study.

[10] Schvaneveldt, Durso, Dearholt, "Network Structures in Proximity Data," The Psychology of Learning and motivation, Vol 24, 1989.

3 Findings and Observations

This section summarizes the results of the analysis done by the WG and describes the findings and observations based on those results. The WG defined a finding as a conclusion based on the results of one or more data sources.

First, the section sets the stage for the findings by describing factors from the technical and operational environment that affect flightcrew interaction with Flight Path Management Systems. Then the material is divided into topics, starting with a discussion of what the WG found in operational experience on "the front line." This is followed by topics related to the underlying reasons *why* the findings from operational experience are there.

Within each of those topic areas, the report identifies positive aspects (contributions to safety, effectiveness, or efficiency); vulnerabilities; changes since the 1996 FAA report was released (if appropriate); and implications for future operations. Positive aspects refer to contributions to safety, efficiency or effectiveness. The term "vulnerability" refers to a characteristic or issues that renders the system or process more likely to breakdown or fail when faced with a particular set of circumstances or challenges.[11]

It is important to note that these findings are not specific to a particular type of operation, manufacturer, operator, or other organization. Many of the findings and recommendations are interdependent and should not be considered in isolation.

3.1 Technical and Operational Environment – Changes

There have been a number of changes to the technical, operational, economic, and political environment:

- The retirement of older, less capable and less efficient aircraft has resulted in a fleet with more onboard capability for flight path management.
- Increased use of FMS functions, especially providing lateral and vertical guidance to autopilot functions.
- A transition away from conventional procedures constructed upon ground-based navigation aids to increased use of RNAV-based navigation. This has been a lengthy transition and is still underway;
- Reliance on the quality and availability of digital data (e.g., navigation databases, terrain databases) is growing for various purposes, although problems persist with the origination, development, and distribution of these data.
- The worldwide economic environment since 9/11/2001 has led to increased focus on managing costs resulting in increased utilization of aircraft and flightcrew members, reduction in technical engineering departments, and minimizing pilot training costs.

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[11] The LOSA data identified numerous vulnerabilities, threats or errors that did not result in any consequential issues. However, many of these vulnerabilities captured through the LOSA data also reflect causal categories assigned during accident or incident investigations.

- Since the mid-1990s, there is a broader range of capabilities in aircraft for flight path management.
- Changes in new-hire pilot flight experience and training background from military and civil aviation to collegiate level programs that overall has reduced the average flight time but has increased the number of new entry pilots that have completed comprehensive, highly structured programs that often includes experience in the advanced flight deck technology.
- Global aviation expansion and growth have resulted in a high demand worldwide for pilots, producing a perception that overall aeronautical flight experience[12] levels for entry-level pilots may be decreasing in some high growth regions.
- Modern aircraft system capability and reliability have contributed to a significant reduction in commercial aircraft accidents. Commercial aviation is the safest it has ever been.

To predict potential flight path and energy management issues for future operations, the WG reviewed various forecasts and plans then considered the operational implications of the findings via varying degrees of extrapolation against notable drivers/factors. By doing so, the WG was able to identify a number of general areas of concern/threats against which broad recommendations were developed. It is recognized that ongoing work by various groups may address some of these recommendations either directly or indirectly, and the WG findings support continuing these efforts.

Driver/Factor 1 – Aviation Growth

As a result of the general downturn in economic activity over the last decade, there was a reduction in previously forecasted growth in number of aircraft and associated operations in the US. See Figure 2, Figure 3, and Figure 4 from the 2013 FAA Aerospace Forecast for the updated forecast with respect to growth between now and 2033. During the same period, the variety in aircraft types and operations will increase but continued retirement of older aircraft fleets will offset this expansion to some degree. Demands for improvements in operational efficiency and reductions in environmental effects are anticipated to persist well into the future.

[12] The effect on pilot experience of US Public Law 111-216 and its requirement for increase in the minimum hours for airline pilots has yet to be determined.

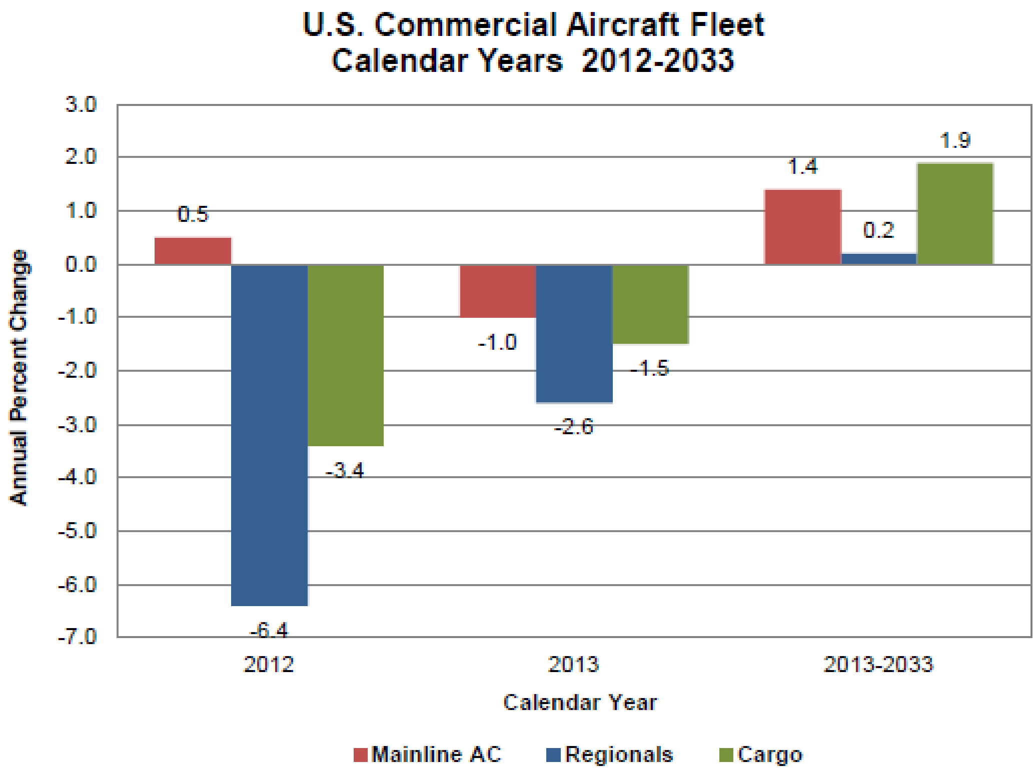

Figure 2. US Aircraft Fleet Growth.

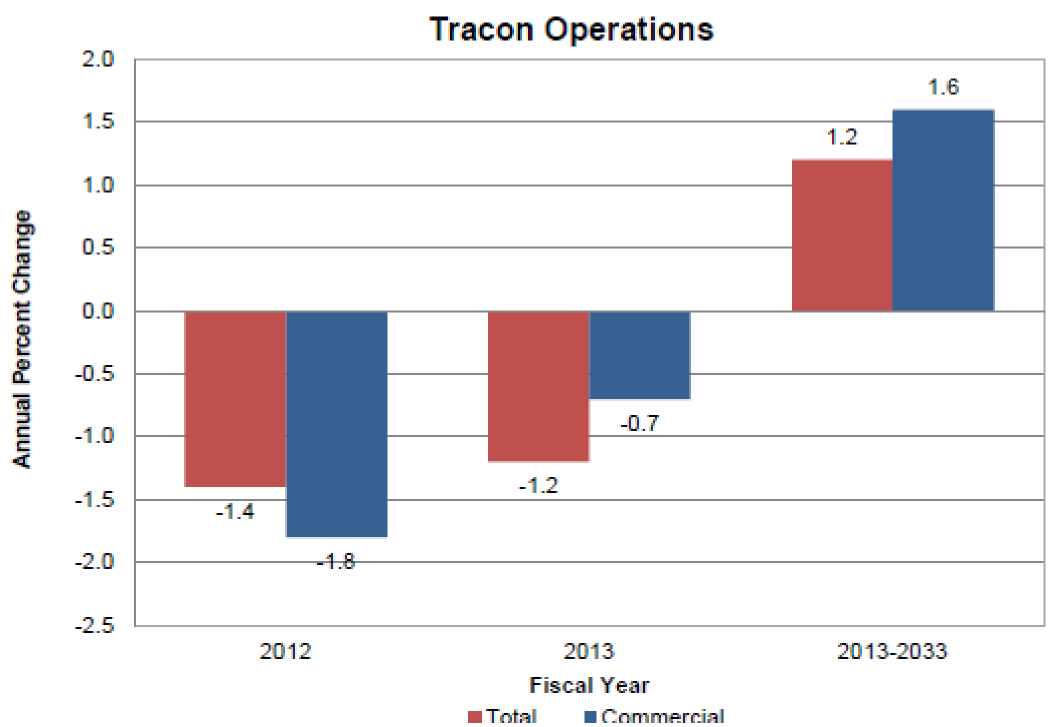

Figure 3. Growth in US TRACON Operations.

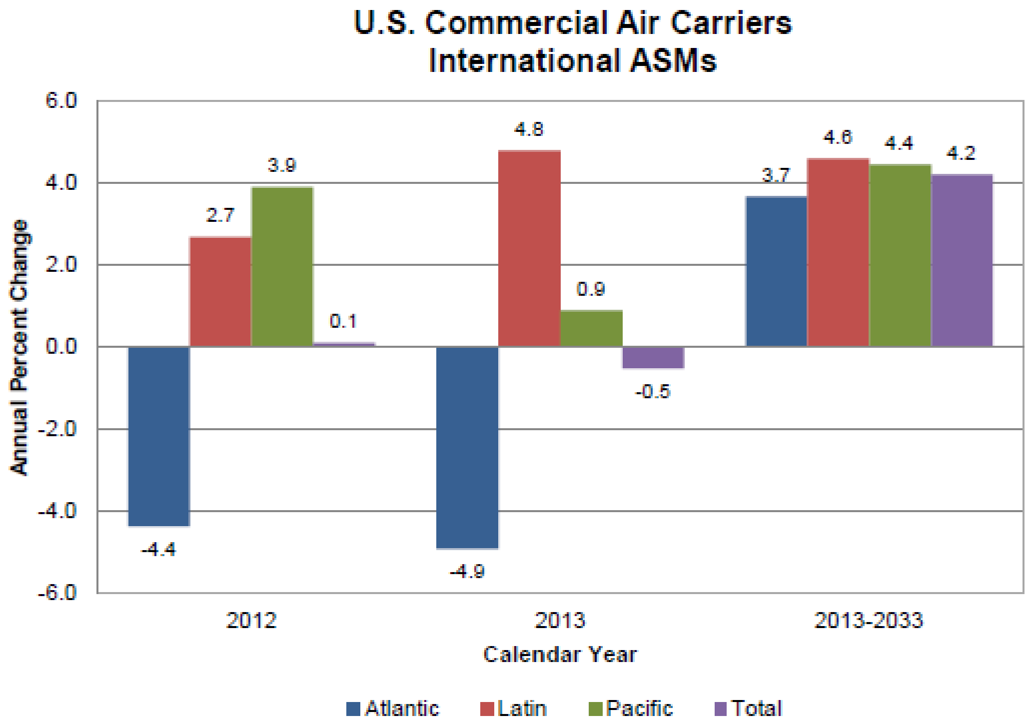

Figure 4. Growth in US Air Carriers International Available Seat Miles (ASM) by Region.

Driver/Factor 2 – Aviation Workforce

The demographics and experience of the aviation workforce will also change considerably. Retirements and attrition in some regions and growth in others will strain the available talent pool and challenge normal recruiting practices. In addition, concern was expressed that aviation as a career field is not as appealing as in years past. These factors are leading to a concern that a significant pilot shortage is imminent.[13]

When entering their aviation career, the new generation of personnel is expected to bring high levels of computer skills but some may not have the robust aviation background and aeronautical experience[14] that current pilots have from actual flight experience. However, great improvements have been made in collegiate and academy training programs which include comprehensive, high quality, and structured training that help develop aeronautical experience. Future pilots will require improved computer aptitude suited for many advanced operations and automation tools, as well as a broad aviation experience and fundamental knowledge and skills, including manual flying, spatial awareness, decision making, and understanding of aircraft performance.

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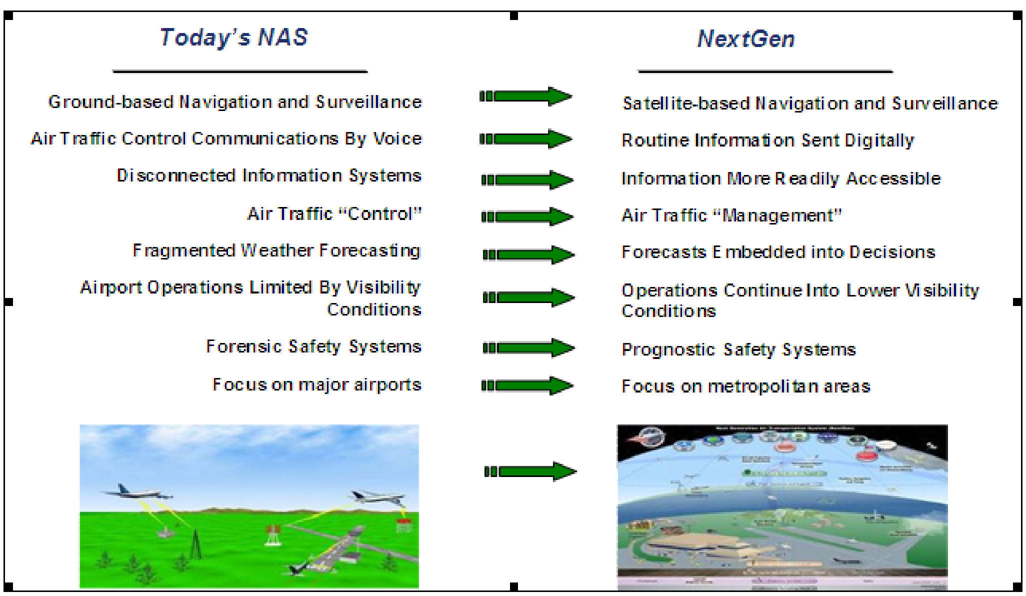
[13] http://www.boeing.com/boeing/commercial/cmo/pilot_technician_outlook.page

[14] Pilot aeronautical experience refers to more than the number of flight hours, but also includes quality flight hours by which flight experience is acquired (breadth of experience), such as flight hours performed as a flight instructor or corporate pilot. It also includes quality of training and exposure to operational circumstances, including experience in difficult operational conditions (such as poor weather, difficult airports, icing) and operational complexity (i.e., multiengine, night instrument metrological conditions).

Driver/Factor 3 – Evolving Airspace Operations

In an effort to improve safety, capacity and efficiency, a number of States and organizations around the world are working to provide strategies for the future. In the US, the FAA is working with other federal agencies and the private sector to develop the Next Generation Air Transportation System or "NextGen" in order to lay out a system-wide evolution. Pieces of this broad strategy are brought into finer detail through various plans, such as the FAA's annual *NextGen Implementation Plan* (FAA 2013), which describes the transition of various "portfolios" (see Figure 5) and programs from concept to implementation. In Europe, EUROCONTROL and other organizations are employing Single European Sky ATM (Air Traffic Management) Research (SESAR) program,[15] primarily to improve airspace and air traffic management procedures within the region. Equivalent activities are ongoing elsewhere in the world. A common theme between NextGen and SESAR plans is the reliance upon highly integrated and interdependent designs at both the individual aircraft and system-wide levels.

It is likely that the variety of aviation operations will continue to increase well into the next decade for a number of reasons. First, a number of "legacy" operations will remain because of interest from specific user groups operating older aircraft wishing to retain access, as well as the need to maintain some amount of conventional procedures and routes as a back-up to operations reliant upon the Global Positioning System (GPS). Second, new implementations will proliferate based upon novel ways to leverage existing technologies, widespread applications of current and evolving technologies, and frequent demonstrations and trials of emerging technologies. The amount and rate of these changes coupled with the breadth of operations will introduce new complexities to pilots and other end-users. The continued implementation of performance based operations, which allow for flexibility in equipage by operators and implementation strategies by air navigation service providers, may also add to system complexity.



[15] http://www.eurocontrol.int/content/sesar-and-research

Figure 5. NextGen Summary.

Driver/Factor 4 – Evolving Flight Deck Equipment and Operations with Corresponding Evolution in Pilot Knowledge and Skills

The transition from classic flight instruments and ground based navigation to modern flight decks began in the early nineteen eighties with the introduction of the Boeing 757, 767 and Airbus 320. These airplane types incorporated features such as integrated “glass” displays, flight guidance systems and flight management systems, all integrated with the autoflight and autothrottle/autothrust systems. Adapting to the modern flight deck design required entirely new paradigms in spatial orientation and system management for pilots, as well as new operational procedures and policies that had to be developed and evolved.

The operations are evolving, as described under Factor 3. For example, flying visual or non-precision approaches was very common in the past. However, data analysis identified the challenges of non-precision approaches and unstabilized approaches, and their contribution to CFIT accidents. In addition, technologies such as GPS and RNP have enabled approaches with vertical guidance. Because of these circumstances, older approaches are now only used when absolutely necessary, and are considered as reversionary when other, better approaches are not available for some reason. This is just one example of operations that were normal or typical in the past but now are considered reversionary because improved operational capabilities are available. Over time, the scope of operations, together with the complexity of airspace, procedures, and automated tools on the flight decks has evolved, which has resulted in a corresponding increase in the set of required skills and knowledge that pilots need for flight path and energy management for today’s complex aircraft and airspace.

Because of the changes in aircraft equipment and in flight operations as described above, there has been a corresponding change in needed pilot knowledge and skills. It also became apparent in the work of the WG that the definition of “normal” pilot skills has changed over time, and pilot skills that were once thought of as “typical” are now thought of as “basic or reversionary” skills. Figure 6 shows this in a notional manner.

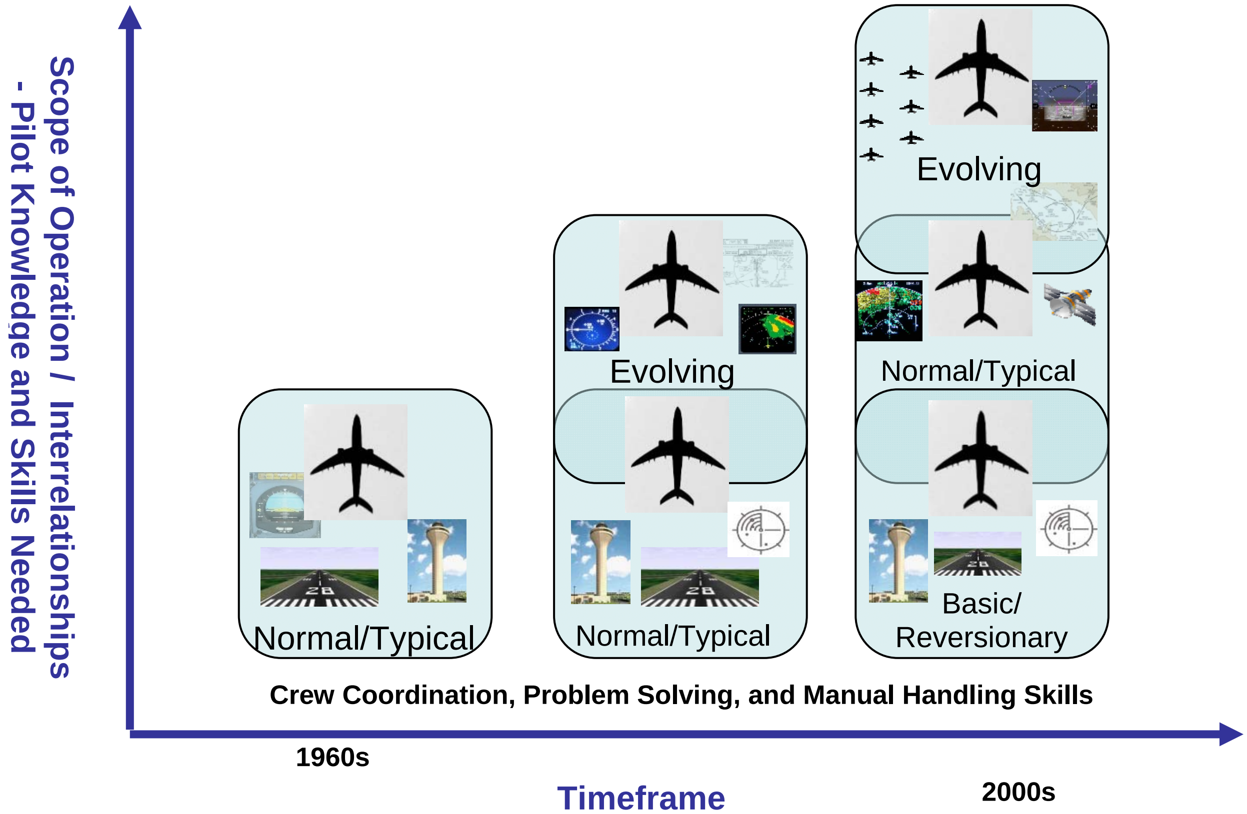


Figure 6. Evolving Pilot Knowledge and Skills.

In addition, the WG concluded that the role and requirements for pilot knowledge and skills has not diminished as a result of automated systems or modern flight deck design, but has actually increased to include being a manager of systems as well as maintaining all their basic knowledge and skills as shown in Figure 6. Furthermore, pilots will need to continue to perform as a system-of-systems manager, with additional roles and responsibilities, while retaining basic cognitive and manual handling skills necessary for evolving and reversionary operations.

Driver/Factor 5 – Aviation Safety Expectations

Commercial aviation is currently at its safest levels ever. This can be attributed to many factors. These include:

- Improved reliability of systems (e.g., jet engines).
- Improved procedures:
  - Standard Operating Procedures and
  - Improved Airspace Procedures, including approaches with vertical guidance.
- Improved pilot training:
  - Crew Resource Management and
  - Improved capabilities of flight simulators.

- Improved aircraft technologies,[16] such as:
  - Collision Avoidance Systems,
  - Terrain Awareness and Warning Systems, and
  - Envelope Protection Systems.
- Adaptation by professional pilots to new technologies and develop new skills.
- Safety data collection, analysis, and sharing.

The CAST[17] was founded in 1998 with a goal to reduce the commercial aviation fatality rate in the United States by 80 percent by 2007. To achieve this ambitious goal, the CAST developed and started implementing a comprehensive Safety Enhancement Plan. By 2007, CAST was able to report that, by implementing the most promising safety enhancements, the fatality rate of commercial air travel in the United States was reduced by 83 percent.

Today's accident rates make the cost/benefit case very challenging for investments in safety and in regulatory changes. Also, US safety standards must be harmonized internationally.

Regardless of how low the accident rate gets, all stakeholders must remain vigilant to ensure that risks are continuously identified, evaluated, and mitigated so that accident rates and other indicative statistics continue to improve. The ongoing evolution in airspace operations and on-board capabilities will require careful attention to change management for all stakeholders to maintain or improve safety.

[16] Nevertheless, these advances, while significantly contributing to lowering accident rates do introduce their own set of failure modes and vulnerabilities that require vigilance on the part of operators and regulators to ensure that they are fully understood and mitigated.
[17] http://www.cast-safety.org/

3.2 Operational Experience: Results from the Front Line

This section describes results, findings and recommendations based on data from operational experience, including accidents, incidents, interviews and normal operations. Each subsection begins with the overall finding, and then discusses each finding in more detail, with references to the supporting data. Appendix G describes the detailed results of the WG analyses of the different data sources. The discussion below will highlight the specific data and analysis results that support the findings.

The WG found that pilots mitigate operational risk in all areas in which they are involved – and the aviation system is designed to rely on that mitigation. Thousands of flights are completed safely, efficiently and effectively every day because of the contribution of professional pilots (and others in the system).

However, the WG found vulnerabilities (and therefore, potential for improvement), in the following areas as a result of reviewing data from operational experience. These areas include:

- Manual flight operations;
- Managing malfunctions;
- Pilot use of, and interaction with, automated systems;
- Communications between pilots in a flightcrew; and
- Communication between flightcrews and Air Traffic Services (ATS).

Each area is discussed in more detail below.

3.2.1 Pilots Mitigate Risk

Finding 1 - Pilot Mitigation of Safety and Operational Risks.
Pilots mitigate safety and operational risks on a frequent basis, and the aviation system is designed to rely on that mitigation.

This finding is based on accident, incident, and interview data.

A great deal of attention is paid to pilot error in the investigation of accidents and incidents. While such errors are important to understand, it is equally important to understand that pilots fly thousands of flights every day that are conducted safely and effectively. The safety and effectiveness of the civil aviation system rely on the risk mitigation done by well trained and qualified pilots (and other humans) on a regular basis.

Pilots mitigate a variety of risks, including:

- Adapting to changes in operational circumstances (such as, changes in air traffic clearances, weather, malfunctions, airport congestion, and diversions). The LOSA data show that only one in ten flights is completed as originally planned and entered into the FMS.

- Managing operational threats (such as, adverse weather. The LOSA data show that adverse weather is a threat that is present in almost 60% of normal flights.[18]);
- Mitigating or managing errors made by themselves or by other humans in the system (other pilots, dispatchers, maintenance technicians, air traffic personnel, equipment designers; e.g., altitude awareness procedures).
- Mitigating equipment limitations. In implementing new operations, the operational approval process accounts for the equipment design-assurance level, and a lower level of precision, design assurance, or lesser equipage may be acceptable in some cases, if pilot mitigation is assumed (such as, use of an appropriate navigation map to confirm aircraft position within 1000 feet at the start of takeoff roll, instead of automatic runway updating). Another example is that not all holding patterns stored in the FMS databases are correct and pilots are expected to cross verify the selected holding pattern. This cross verification may be made more difficult as the correct holding fix information may not be readily available, and may be depicted on a different map or chart than the one being used by the pilot.
- Manage equipment malfunctions. As discussed in Section 3.2.3, malfunctions that require operational mitigation on the part of the pilot occur in normal operations, and pilots manage those malfunctions regularly through procedures and checklists that are written for that purpose. However, the data show some malfunction cases where no checklist exists, or there are multiple failures that involve multiple checklists and complex situations. In such rare cases, the pilots mitigate the associated risk based on their knowledge, skills, and experience (such as, Malaysia 777[19], British Airways 777,[20] QF32,[21] DHL Baghdad).
- Managing other situations involving unexpected operational risk (such as, the decision making required in the USAirways 1549[22]).

The WG is concerned that an exclusive focus on pilot errors will not take into account the positive actions and decisions that pilots do on a frequent basis, including the pilot skills required to prevent and mitigate system and operational threats. These positive actions that prevent problems from occurring, or mitigate problems that arise, are rarely noted explicitly and data

[18] LOSA includes thunderstorms, turbulence, poor visibility, wind-shear, icing conditions, and low visibility conditions. The level of threat is not distinguished among these items.

[19] Australian Transportation Safety Board (ATSB) (2007), In-flight upset event 240 km north-west of Perth, WA Boeing Company 777-200, 9M-MRG 1 August 2005, Aviation Occurrence Report – 200503722. "CONTRIBUTING SAFETY FACTORS: "An anomaly existed in the component software hierarchy that allowed inputs from a known faulty accelerometer to be processed by the air data inertial reference unit (ADIRU) and used by the primary flight computer, autopilot and other aircraft systems. .. The aircraft documentation did not provide the flight crew with specific information and action items to assess and respond to the aircraft upset event."”

[20] Air Accidents Investigation Branch (AAIB) (2010) *Report on the accident to Boeing 777-236ER, G-YMMM, at London Heathrow Airport on 17 January 2008*. Aircraft Accident Report 1/2010., "On the final approach to land the flight crew were presented with an operational situation, a double-engine rollback at a low height, which was unprecedented. Most importantly at this point, when the stick shaker was alerting them to an impending stall, they kept the aircraft flying and under control so that, at impact, it was wings level and at a moderate pitch attitude."

[21] ATSB (2013) *Final Investigation In-flight uncontained engine failure Airbus A380-842, VH-OQA*, ATSB Transport Safety Report Final Aviation Occurrence Investigation AO-2010-089 – 27 June 2013.

[22] National Transportation Safety Board (NTSB) (2010). *Loss of Thrust in Both Engines After Encountering a Flock of Birds and Subsequent Ditching on the Hudson River US Airways Flight 1549 Airbus A320-214, N106US Weehawken, New Jersey January 15, 2009*. NTSB/AAR-10/03, May 4, 2010, "the NTSB concludes that the captain's decision to ditch on the Hudson River rather than attempting to land at an airport provided the highest probability that the accident would be survivable."

from operational experience about positive behaviors are rarely collected. If positive pilot actions are not taken into account, then changes to the aviation system may not recognize and support positive behaviors that are a critical foundation for aviation safety and operational effectiveness.

3.2.2 Manual Flight Operations

Finding 2 - Manual Flight Operations.
Vulnerabilities were identified in pilot knowledge and skills for manual flight operations, including:

- **Prevention, recognition and recovery from upset conditions, stalls or unusual attitudes;**
- **Appropriate manual handling after transition from automated control;**
- **Inadequate energy management;**
- **Inappropriate control inputs for the situation;**
- **Crew coordination, especially about aircraft control;**
- **Definition, development, and retention of such skills.**

This finding is based on accident, major incident, LOSA, and interview data.

Manual handling skills, stick and rudder skill, basic airmanship, basic piloting skills – all of these are phrases used to describe pilot knowledge and skill sets that are a basic foundation of safe and successful flight. Therefore, pilots developing and maintaining the knowledge and skills for excellent manual flight operations is very important to the safety and effectiveness of aviation operations. The WG analyses of the LOSA, accident and incident data show that this is an area of system vulnerability. Therefore, measures that promote the development and maintenance of pilot skills for manual flight operations remain important for the safety and effectiveness of aviation operations.

LOSA defines a manual handling/flight control error as an error related to “Hand flying vertical, lateral, or speed deviations; approach deviations (e.g., flying below the glide slope (GS)); Missed runway/taxiway, failure to hold short, incorrect flaps, speed brake, autobrake, thrust reverser or power settings.” Figure 7 shows the data for these manual handling/flight control errors and their presence in the accident, incident and LOSA data that the WG reviewed and classified.

Over 60% of the accident reports reviewed by the WG identified a manual handling error as a factor in the accident. In examining the accidents and major incidents, the WG found the following as a summary of the types of manual handling errors identified in the investigative reports:

- Incorrect upset recovery,
- Inappropriate control inputs,
- Lack of correct manual handling (taking control of the aircraft manually) after autopilot or autothrottle/autothrust disconnect, in some cases because of lack of recognition of disconnect,
- Lack of monitoring/maintaining energy/speed, and
- Mismanagement of autothrottle/autothrust.

Note that this is simply a list of the error types and not intended to convey frequency, importance, or any other hierarchical relationship.

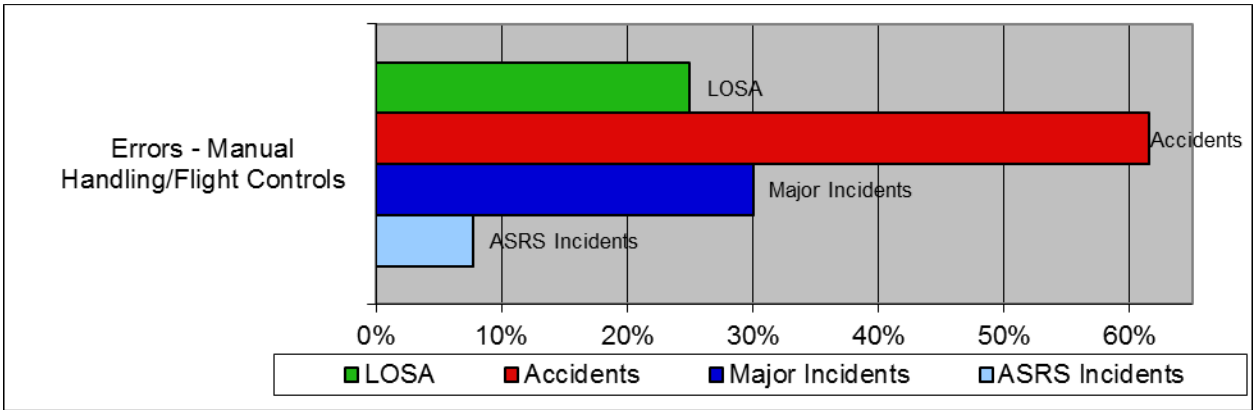


Figure 7. Manual Handling/Flight Control Errors.

The co-occurrence analysis showed that several factors significantly co-occurred with manual handling/flight control errors in the accidents. As described in Appendix G, Table 23, these included:

- Issue: Manual operation is difficult after transition from automated control
- Issue: Crew coordination problems occur
- Issue: Training is inadequate
- Issue: Behavior of automation, based on pilot input or other factors, may not be apparent to pilots
- Issue: Understanding of automation is inadequate
- Threat: Inadequate knowledge
- Error: Cross-verification

In the interviews and other communications, the WG heard significant concerns about the development and retention of manual handling skills. This was described as a concern for several operational situations, such as visual approaches and crosswind landings. Associated issues also mentioned included the definition of specific knowledge and skills that comprise "manual flying skills;" e.g., instrument pattern scan, knowledge and "stick and rudder." While almost every interview group mentioned a possible decrease in manual handling skills, few were able to provide direct evidence because specific data on manual handling skills usually are not collected.

An additional concern was the level of basic knowledge and skills necessary for identifying and handling different situations; that is, knowing what to do, especially those situations that occur very infrequently. One example is the ability to "reconfigure" – knowing how to get back to normal operations after a change (such as, pilots knowing how to respond to wind shear alerts but not how to recover to nominal flight path following the wind shear encounter, which may be the more demanding maneuver).

Another example is an all-engine go-around, especially (but not only) when commenced at higher than decision altitude. This is a topic that was raised by multiple pilots and training instructors. Pilots expressed the concern that high power, low weight, low altitude level off , and autoflight logic combined to result in a very challenging maneuver, all while cleaning up the configuration of the aircraft. In the LOSA data, 87% of unstabilized approaches result in safe landings within all parameters. An additional 10% of those approaches resulted in safe landings, but with some parameter exceeded (e.g., landing slightly long). The other 3% conducted a go-around, but 98% of those go-arounds exceeded some parameter (e.g., flap speed). The NTSB raised the issue as a concern for aircraft separation when one aircraft must go around.[23]

Concern has been expressed that pilot skill degradation occurs because of the use of automated systems results in lack of practice or over confidence in those systems. Veillette et al (1995) found statistically significant differences in manual control inputs between pilots of more and less automated aircraft, particularly during abnormal operations. A related issue mentioned was the possibility that pilots who have not yet developed extensive manual flying skills may not get opportunities to practice and develop those skills, due to an increased emphasis on the use of automated systems. See Section 3.2.4 for additional discussion of the use of automated systems.

Although operators and trainers expressed numerous concerns about the perceived deterioration of manual handling skills, they expressed uncertainty as to how these skills may decay, what could be done to retain them, how operational policies may assist in promoting the use of the skills, regular practice on the line, and how this may help skill retention. These discussions illustrate that there is a lack of consensus over what skills underpin manual handling. Opinions varied greatly on what was an adequate level of skill and tended to follow the operator's philosophy of operations.

Many trainers also expressed the opinion that their recurrent training and checking schemes were insufficient to promote or test the retention of such skills. Exercises that are required to be hand flown are well known and repetitive and may not measure the true underlying skill level outside of those specific exercises.

Some trainers also noted that pilots sometimes learn to use the automated systems by "watching things happen" in fixed-base trainers. When the pilots have to actually hand fly, they are accustomed to watching things happen, and reacting, instead of being proactive. One operator described the measures they were undertaking to refresh their pilots' skills for manual flight including investing in an extra simulator session for all pilots and revising their automation policy to encourage more hand flying.

This topic was noted as a concern in the 1996 FAA report and the situation may be escalating as accidents continue to occur that involve vulnerabilities in these skills. Future operations are expected to require more operations using the autopilot and autothrottle/autothrust, because of operations using precise navigation paths. In addition, future operations are expected to involve increased number and types of automated systems, but the need for reversion to manual flight operations will still exist. For all these reasons, the WG believes that specifically addressing the development and maintenance of pilots' manual flight operations knowledge and skills is critically important.

[23] NTSB Recommendation A-13-024, July 1, 2013.

3.2.3 Managing Malfunctions

Finding 3 - Managing Malfunctions.
Pilots successfully manage equipment malfunctions as threats that occur in normal operations. However, insufficient system knowledge, flightcrew procedure, or understanding of aircraft state may decrease pilots' ability to respond to failure situations. This is a particular concern for failure situations which do not have procedures or checklists, or where the procedures or checklists do not completely apply.

This finding is based on accident, major incident, LOSA, and interview data.

Complex modern transport category airplanes have thousands of components. All mechanical and electric parts are subject to failure. Most failure modes are well understood and mitigated by redundancies or procedures.

However, flight deck systems are often dependent on input from various sensors including pitot/static, angle of attack, and others. Failure of these sensors or incorrect outputs can cause unexpected and unpredictable cascading indications in the flight deck which may lead to incorrect response by the pilot. Most equipment malfunctions do not result in accidents/incidents, but can pose a threat to the operations and must be dealt with by the crew.

Pilots are expected to manage malfunctions as an important part of their tasks. Figure 8 shows that aircraft malfunctions were noted to be a threat in 20% of normal flights (based on LOSA data). Malfunctions were identified as a threat in over 50% of the major incidents reviewed by the WG. These major incidents represent cases where pilots successfully mitigated the risk of the malfunction. In 15% of the accident cases reviewed, the investigative board identified malfunctions as a factor.

Below, Figure 9 shows three different issues related to failures, and it shows the normalized data for each issue from accidents, major incidents and ASRS incidents. Failure assessment and failure recovery may be difficult for a variety of reasons. "Failures unanticipated by designers" represents those cases where there was no checklist or defined procedure for the pilots to use. In many cases, these major incidents under this issue represent cases where the pilots relied on their knowledge, skills and other aspects of airmanship to mitigate the risk in serious situations, when they had no procedures to use. The other two issues related to failures shown on the chart are that the assessment of the failure is difficult or the recovery from the failure is difficult.

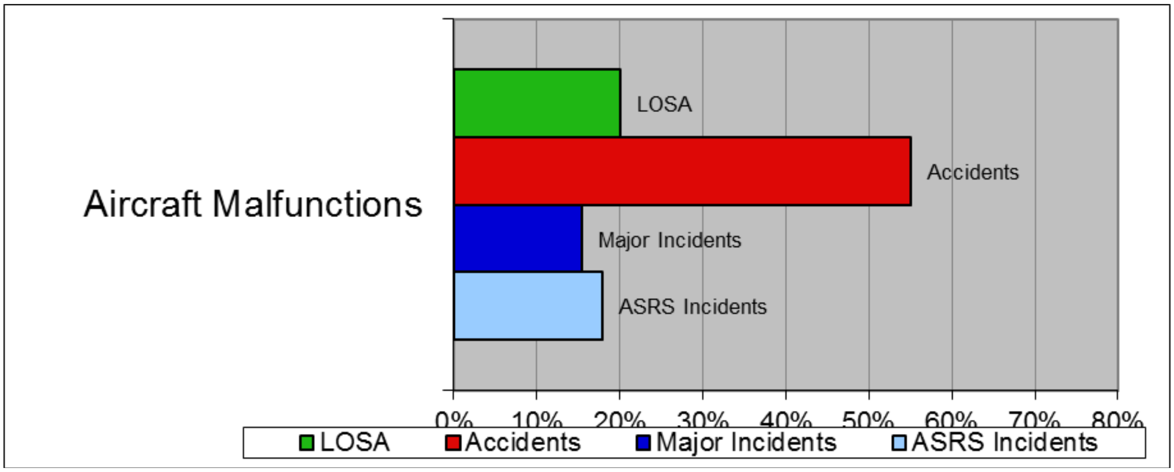


Figure 8. Aircraft Malfunctions.

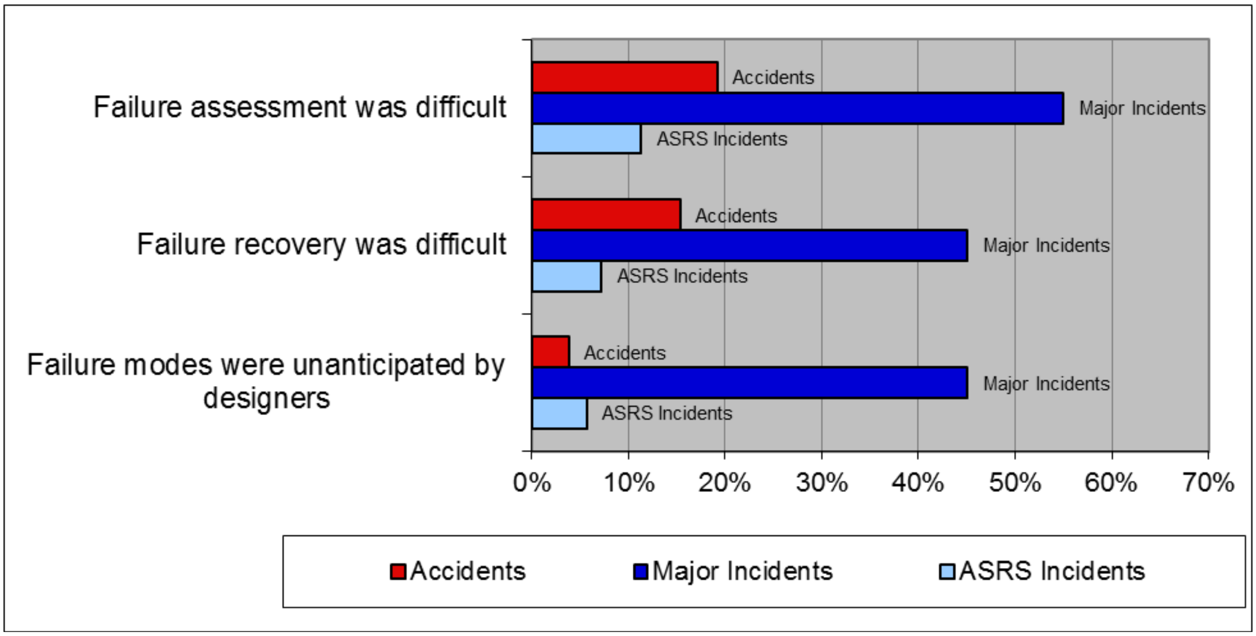


Figure 9. Failure Issues.

In the interviews, one concern that was expressed was that failures for which there are no crew procedures or checklists may be becoming more prevalent. This may be partly because avionics systems are now increasingly integrated and complex as opposed to the federated systems used in the past. Despite robust failure modes testing, the highly integrated nature of these systems makes it more difficult for manufacturers to test for all potential failures or combinations of failures and subsequently identify all of the detailed procedures needed by the pilots.

Operators expressed concerns to the WG regarding management of malfunctions. These concerns addressed especially the decision-making, judgment, knowledge and skills surrounding the management of equipment failures, whether failures of the automated systems or failures of other systems. The WG was told that some training programs and non-normal procedures did not adequately address partial failures and uncertain situations. These points were often linked to a concern that insufficient depth of system knowledge and/or over-reliance of automated checklist systems could lead to problems when managing unspecified failures or combination of failures or flight circumstances.

It is not possible to train pilots in all possible malfunctions or failure scenarios, nor is it possible (or desirable) for line pilots to perform functions as test pilots. However, pilots must be prepared to recognize the results of both complete and partial system failures (including sensor failures) and intervene appropriately. For example, training on attitude and power management for sensor failures can be very effective and can be implemented by operators.

3.2.4 Pilot Use of, and Interaction with, Automated Systems

Finding 4 - Automated Systems.
Automated systems have been successfully used for many years, and have contributed significantly to improvements in safety, operational efficiency, and precise flight path management. However, the following aspects of pilot use of, and interaction with, automated systems were found to have some vulnerability areas:

- **Pilots sometimes rely too much on automated systems and may be reluctant to intervene;**
- **Autoflight mode confusion errors continue to occur;**
- **The use of information automation is increasing, including implementations that may result in errors and confusion; and**
- **FMS programming and usage errors continue to occur.**

This finding is based on accident, major incident, ASRS incident, LOSA, and interview data.

Automated systems are an important subset of the broader flight path management topic. The WG found that automated systems have made important positive contributions to safety, through reduction in workload and other factors. Examples from accident/incident cases include USAirways 1549.[24] In addition, automated systems have contributed to improvements in several aspects of flight operations, such as accuracy and fuel efficiency. However, the WG found vulnerabilities related to the pilot use of, and interaction with automated systems. While some of these were identified in the 1996 FAA report, others have emerged since then. Each one is discussed below.

3.2.4.1 Pilot reliance on automated systems

The WG found in its investigations that pilots sometimes over-rely on automated systems – in effect, delegating authority to those systems, which sometimes resulted in deviating from the desired flight path under automated system control. Figure 10 shows that in roughly one quarter of the accidents, pilots were overconfident in the automated systems and in some cases, were reluctant to intervene. Figure 11 shows that pilot situation awareness was a factor in over 50% of the accidents reviewed, as identified in the investigative report. More specifically, the extended description of this category is "Reliance on automation reduces pilots' awareness of the present and projected state of the aircraft and its environment, resulting in incorrect decisions and

[24] NTSB AAR1003, page 189, "The high AOA protection played a positive role in this event. "

actions." In addition, Figure 12 shows that the accident investigation boards identified that pilots were out of the control loop in over 50% of the accidents reviewed by the WG. The extended description of this category is "Pilots are out of the control loop and peripheral to the actual operation of the aircraft and therefore not prepared to assume control when necessary."

The previous discussion in Section 3.2.2 illustrates some of the issues with manual handling. It provided insights into pilot explanations that they sometimes did not have confidence in their own skills, and did not always get the opportunity to practice those skills to enhance their confidence. In those cases, they were more comfortable with the automated system handling the situation.

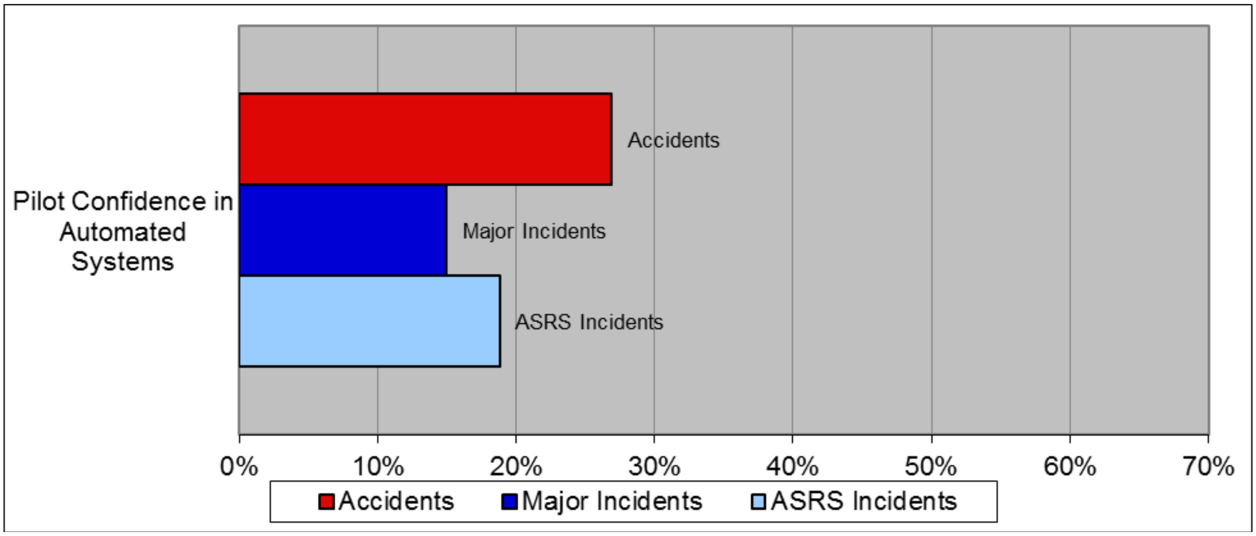


Figure 10. Pilot Confidence in Automated Systems.

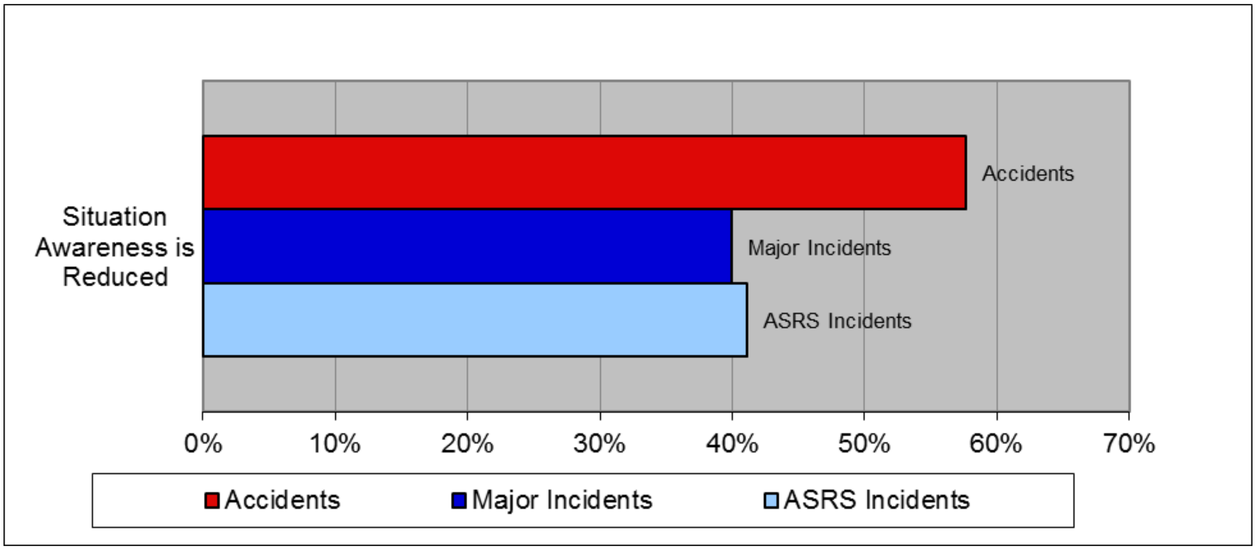


Figure 11. Situation Awareness is Reduced.

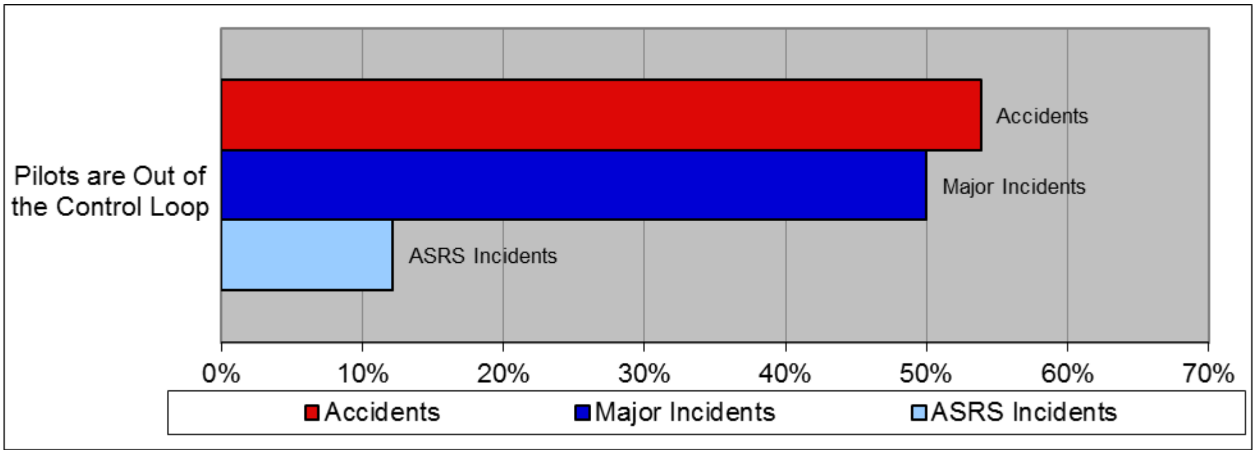


Figure 12. Pilots are out of the Control Loop.

In addition, pilots sometimes do not have sufficient knowledge to understand the potential consequences of selection of certain modes in certain circumstances (e.g., climbing in vertical speed mode under autopilot control at higher altitudes); "The Safety Board concludes that the flightcrew's inappropriate use of the vertical speed mode during the climb was a misuse of automation that allowed the airplane to reach 41,000 feet in a critically low energy state."[25]

Other factors that affect the pilots' decisions include the high reliability of the systems (fostering insufficient cross verification, not recognizing autopilot or autothrottle disengagement, or not maintaining target speed, heading, or altitude). Another factor is the operational policies that direct the pilots to use automated systems over manual flying. Such policies are said to be preferred by some operators because the automated systems can perform more precisely while reducing pilot workload. However, this may lead to an erosion of manual flying skills and a subsequent over-reliance on automation. This may be exacerbated in the future by some new airspace procedures that are so complex and require such precision that flying manually is impractical or not allowed, because of the likelihood of deviation (see Section 3.7.1 Airspace/Air Traffic Procedures).

When these complex procedures are combined with policies that encourage use of automated systems over manual operations and monitoring of pilots to ensure that they comply with those policies, it may encourage pilots to over-rely on those systems. When there is insufficient training, experience, or judgment, this reliance on the automated systems can aggravate and adversely affect the situation.

One important potential consequence is that pilots may not be prepared to handle non-routine situations, such as malfunctions or off-nominal conditions.

[25] National Transportation Safety Board (2007, January 9). *Crash of Pinnacle Airlines Flight 3701, Bombardier CL-600-2B19, N8396A, Jefferson City, Missouri, October 14, 2004.* Accident Report NTSB/AAR-07/01. PB2007-910402. Washington, DC: National Transportation Safety Board.

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3.2.4.2 Autoflight Mode Confusion

The 1996 FAA report identified insufficient autoflight mode awareness as an important vulnerability area. Factors that contributed to insufficient awareness included: insufficient salience of mode annunciations; insufficient methods for monitoring mode changes; indirect mode changes (mode changes not due to a direct flight action); differences in mode nomenclature and display among different airplane types; differences in the design implementation of modes intended to meet the same objective; proliferation in the number of modes; complexity in the flightcrew interface (as perceived by the flightcrew); and conflicting information provided by the control panel used for selecting autoflight modes.

Since that report was published, some changes to flight deck equipment design have been made in new aircraft to address this vulnerability area (e.g., only showing selected target values or modes on the PFD, to foster the pilots reviewing the information on the mode annunciator display rather than on the mode selection panel).

In addition, the issue has been addressed in training through increased emphasis on mode awareness and in some operators' flightcrew procedures by having the pilots call out all mode changes. However, other operators find this use of callouts to be too burdensome and a potential distraction.

These mitigations are only partially successful. The data analysis reveals that autoflight mode selection, awareness and understanding continue to be common vulnerabilities. Data from the "Accident/Incident Comparison" indicate that "mode selection errors" were cited in 27 % of the accidents reviewed, as shown in Figure 13. Mode changes that occur without direct pilot commands to do so (indirect mode changes, e.g., changing from VNAV Path to VNAV Speed because the aircraft could not maintain the path with the selected cost index) were cited as a common occurrence in the interviews with operators. In addition, mode confusion was a consistent category seen in aggregated ASAP data.

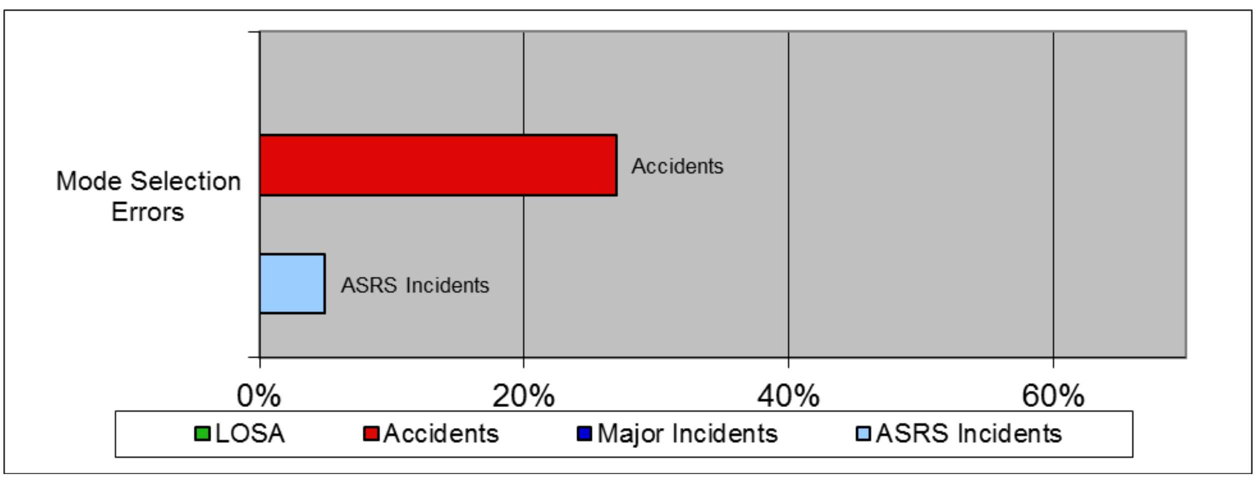


Figure 13. Mode Selection Errors.

The LOSA narrative analysis found that the pilots' mode usage contributed to more than 40 % of poor/marginal ratings in their use of automation in the take-off/climb and descent/approach/landing phases. The LOSA narrative analysis also showed that SOP compliance alone, in terms of correct annunciation of modes, cross-check and verification, did not completely protect crews from mode confusion and adverse flight path consequences.

Instead, pilots avoided mode confusion through anticipation; that is, application of a higher than expected degree of knowledge and briefing above and beyond what was required by SOPs. This data highlighted the importance of being able to anticipate the results of mode selections rather than just being aware of those mode selections and correctly cross-checking and confirming them.

In the interviews, operators and training organizations expressed concerns that flight path management tasks risked being overlooked by a focus on mode awareness and callouts at the expense of understanding the relationship of those modes to the flight path itself. Several operators reflected that they had over-emphasized the mode awareness task at the expense of the broader task of flight path management.

3.2.4.3 Information Automation

Billings (1991) described three categories of aircraft automation. The first was "control automation" or automation whose functions are the control and direction of an airplane (a system such as the autopilot is an example of control automation). Prior material in this section addresses findings about control automation. The second category was "information automation" or automation devoted to the calculation, management and presentation of relevant information to flightcrew members. The third category was "management automation," or automation of the management tasks. This subsection addresses the category of information automation.

Unquestionably, the information automation systems enabled by digital technology have increased safety and improved pilot awareness by calculation and integration of data into a form more usable by the pilots. These include alerting systems (such as integrated caution and warning systems and Terrain Awareness and Warning Systems (TAWS)), and integrated flight deck displays (such as moving map displays and Heads-up Displays (HUD)), all of which affect the pilot's management of the airplane flight path. Other potential types of information automation include advanced alerting systems (to alert the pilots to various non-normal system or operational conditions) and systems that change display characteristics in real time based on assessment of the situation (e.g., automatically changing the range on the moving map or declutter a display).

There is significant growth in the use of EFBs as a mechanism to introduce applications of information automation (e.g., electronic navigation charts) into the flight deck. The number of EFBs is growing. The number and types of applications implemented on these devices are also increasing, many of which affect flight path management.

EFBs have the potential to be beneficial in many ways, and enable applications in the flight deck that would be difficult to provide in other ways. However, EFBs may have negative side effects if not implemented appropriately. They could increase pilot work load, increase head-down time, distract the flightcrew from higher priority tasks, and contribute to crew communication and coordination issues. These potential impacts of EFBs need to be addressed during both design and evaluation.[26]

In addition, vulnerabilities can occur, especially if the pilots are not aware of assumptions made in the system design or if information is not fully understood by the pilot. An example where such vulnerability had safety consequences for flight path management is an accident where the pilots were not fully aware of the assumptions and limitations used by the onboard laptop computer for calculating landing distance.[27] As a result of investigation of that accident, the NTSB issued recommendation A-07-58 “Require that all 14 Code of Federal Regulations (CFR) Part 121 and 135 operators ensure that all onboard electronic computing devices they use automatically and clearly display critical performance calculation assumptions.”

Another potential issue is information overload. The WG was told by several manufacturers that today’s technology allows for too much information to be presented to the pilot, which could overload the pilot during routine or critical phases of flight. What is presented, how it is presented, and resulting pilot understanding, especially in regards to flight path management, must be addressed for safe operations.

Another example of information automation is Synthetic Vision. There are considered to be many potential safety benefits, especially to improve pilot awareness. However, several concerns were expressed about such systems. One manufacturer was concerned that such systems would be especially susceptible to confirmation bias. This is a phenomenon wherein humans have been shown to actively seek out and assign more weight to evidence that confirms a previously made conclusion, and ignore or under-weigh evidence that could disconfirm their decision or conclusion. Such displays can be very compelling. The accuracy and integrity of the underlying terrain data is critical, and illustrates the point made earlier about reliance on electronic data.

Future applications of information automation have potential for additional safety and operational benefits, but also may introduce additional vulnerabilities, and should be studied for future operations.

[26] See http://www.volpe.dot.gov/coi/hfrsa/work/aviation/efb/vreppub.html for references that discuss EFB considerations.

[27] NTSB AAR 0706, Runway Overrun and Collision Southwest Airlines Flight 1248 Boeing 737-7H4, N471WN, Chicago Midway International Airport, Chicago, Illinois, December 8, 2005.

3.2.4.4 Flight Management System Programming and Use

The data show that FMS programming by the pilots continues to be an area of concern just as it was described in the 1996 FAA report. The WG data reveal FMS programming as a source of error, as shown in Figure 14. In addition to pilot interface and data entry vulnerabilities, the FMS uses algorithms and protocols to compute descent/deceleration profiles that by their very nature are complex (power on / idle / geometric segments, headwinds/tailwinds, crossing restrictions etc.); therefore flightcrews need to make accurate FMS entries and initiate FMS descent profiles when prompted. The use of pilot's rules of thumb to cross verify the FMS descent profiles may not be effective if these rules do not account for the possible variables mentioned above, and this may result in a diminished ability to cross-check and verify against pilot expectations.

However, even if a pilot enters the data correctly, certain FMSs may not be able to accomplish the desired flight path required by the procedure or expected by the pilot, requiring the pilot to recognize the impending deviation in a timely manner and to take appropriate action.

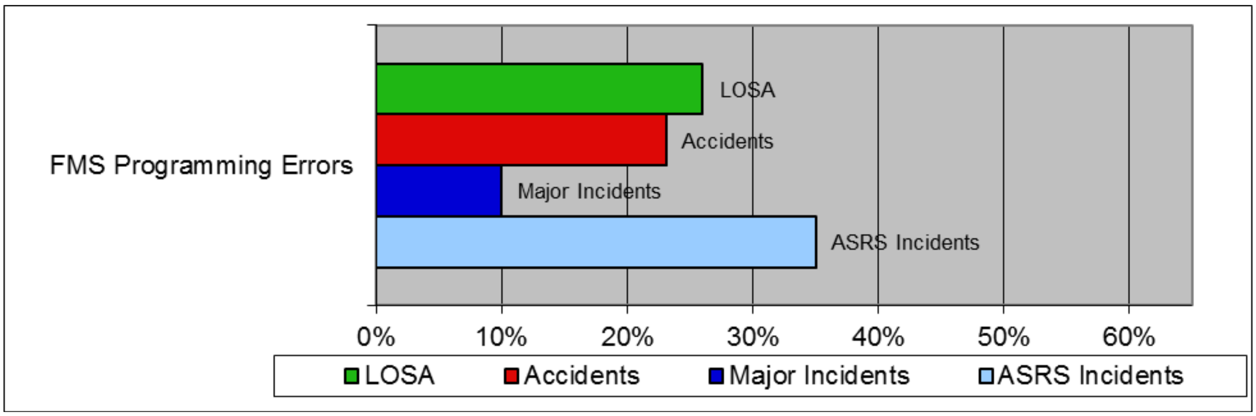


Figure 14. Flight Management System Programming errors.

The LOSA narrative analysis also showed that pilots regularly had to revert to the use of more basic modes (such as, vertical speed, often supplemented by aggressive speed intervention or use of drag devices such as speed brakes) in order to comply with clearances and requests that could not be easily accommodated through use of designed system functions. Instead of reducing pilot workload, meeting such restrictions required reversion to "old school" techniques and ongoing monitoring and recalculation.

One operator explained how a seemingly simple en-route descent requirement – to be at a specific level by a waypoint – could not be correctly programmed into a specific type of FMS. Of even more concern is that the requirement could be entered in the same way crews entered altitude restrictions in the climb or descent phases and, at a cursory inspection, may appear to be correct when the projections and guidance supplied would be erroneous.

FMS programming errors and issues with understanding FMS operations were still the major "pilot input/control" issue cited in the ASRS reports reviewed. This result, which also reflects issues with cross-checking FMS entries, is supported through analysis of the incident data. The analysis also showed that lateral deviations appear to be more prevalent than expected, and the lateral deviation significantly co-occurred with FMS use errors (see Appendix G). This result did not reflect the pilot's ability to track a lateral path, but rather that an incorrect path was programmed into the FMS.

Training for use of the FMS has improved at some operators, but FMS-related programming errors continue to be prevalent. A recent 2011 study by Boeing (Holder 2013) on worldwide airline pilot perspectives on training effectiveness revealed that FMS training can be improved to address operational situations and tasks encountered in operations. In the first 6-months of flying their current type airplane, 61% of the surveyed pilots reported multiple encounters of difficulty completing tasks using the FMS during line operations while only 25% said they were adequately prepared. Just over 42% of the pilots surveyed believed that their FMS training for the type airplane they are currently flying was minimal and stated there was room for improvement or it did not adequately cover operational use. The survey also showed that the operational FMS learning and "comfort" acquisition occur on the line, with 42% of the pilots reporting they learned the operational use of FMS during line experience and 62% reported it took 3-12 months of line experience to obtain comfort with using the FMS. Areas of specific FMS training improvements recommended by the pilots include:

- Automation surprises,
- Hands on use in operational situations,
- Transition between modes,
- Basic knowledge of the system, and
- Programming.

The occurrence of FMS programming errors and lack of understanding about FMS operation appear across age groups and cultures. The errors are noteworthy and it has not been possible to mitigate them completely through training (although training could be improved). This reflects that these are complex systems and that other mitigations are necessary.

Future operations are expected to make more use of the FMS. Consequently, the WG believes that improvements to future FMS design (both crew interface and functionality), should be studied and implemented.

3.2.4.5 General Considerations for Automated Systems for Flight Path Management

Although this report discussed several vulnerabilities related to the interaction with, and use of automated systems in modern flight decks, it is important to recognize and acknowledge that automated systems have contributed significantly to improvements in safety, efficiency, and operations. Additionally, some of the vulnerabilities can be attributed (at least partially) to the fact that these systems and their operations are inherently complex from the pilots' perspective, rather than simply because the systems are "automated." Areas of complexity include pilot tasks related to use of the systems, the crew interface and interaction with the system, and integration with the airspace.

Future airspace operations are expected to use more automated systems in order to support PBN operations. If the pilots become more accustomed to using automated modes of operations, and do not practice manual flight operations, they may become less familiar and able to revert to more basic modes to manage deviations and off-path operations.

3.2.5 Communication between Pilots in a Flightcrew

Finding 5 - Pilot-to-Pilot Communication and Coordination.
Pilot-to-pilot communication and coordination have improved and been more formalized; however, communication and coordination vulnerabilities still contribute to accidents and incidents.

This finding is based on accident, major incident, ASRS incident, and LOSA data.

Operators have increased emphasis on crew communication and cross verification in many airlines. They recognize the value of formalized confirmation and cross-verification of selected modes, such as verbalize, verify, monitor; or confirm, analyze, monitor, and intervene). This has been valuable, but has not yet achieved the level of performance desired.

As shown below in Figure 15, incident/accident analysis revealed that a lack of or erroneous communication between pilots was an important factor. This is supported by the analysis of LOSA narratives where breakdowns in communication characterized poorly performing crews.

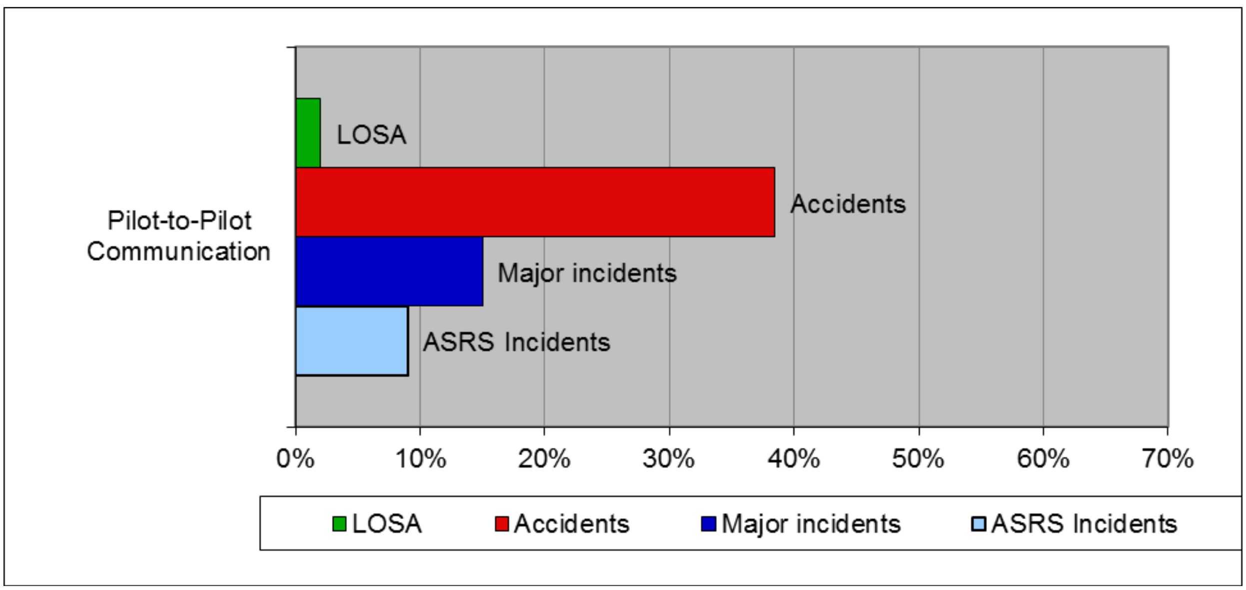


Figure 15. Pilot-to-Pilot Communications Errors.

The LOSA narratives described situations where briefings or communication of intent between pilots regarding the planned use of systems appears more important than mere confirmation of selections or inputs. The LOSA narrative analysis also found that briefings figured significantly in proactive threat and error management behaviors and were a highly consequential factor in avoiding an adverse consequence.

Also, the data show that crew cross-verification is sometimes insufficient (see Figure 16, below). Furthermore, as discussed later, the LOSA narrative analysis suggests such insufficient cross-verification may be a wide-spread, normative behavior. The WG found that crew coordination and cross-verification issues were present in many reports, even though CRM training is generally viewed as effective. However, the safety data show that crew coordination problems are still a factor, and were identified by the investigative board in over 60% of the accidents reviewed by the WG (see Figure 17).

Many operators include and recognize the value of formalized confirmation and cross-verification of selected autoflight modes. However, such procedures vary markedly between operators and may also differ depending upon the phase of flight. Operational/time pressures leading to work-a-rounds or abbreviating the cross-verification procedures continue to be a significant factor in incidents and accidents. For example, breakdowns in FMS entry and verification procedures occur more often during periods of busy flight deck workload such as during taxi.

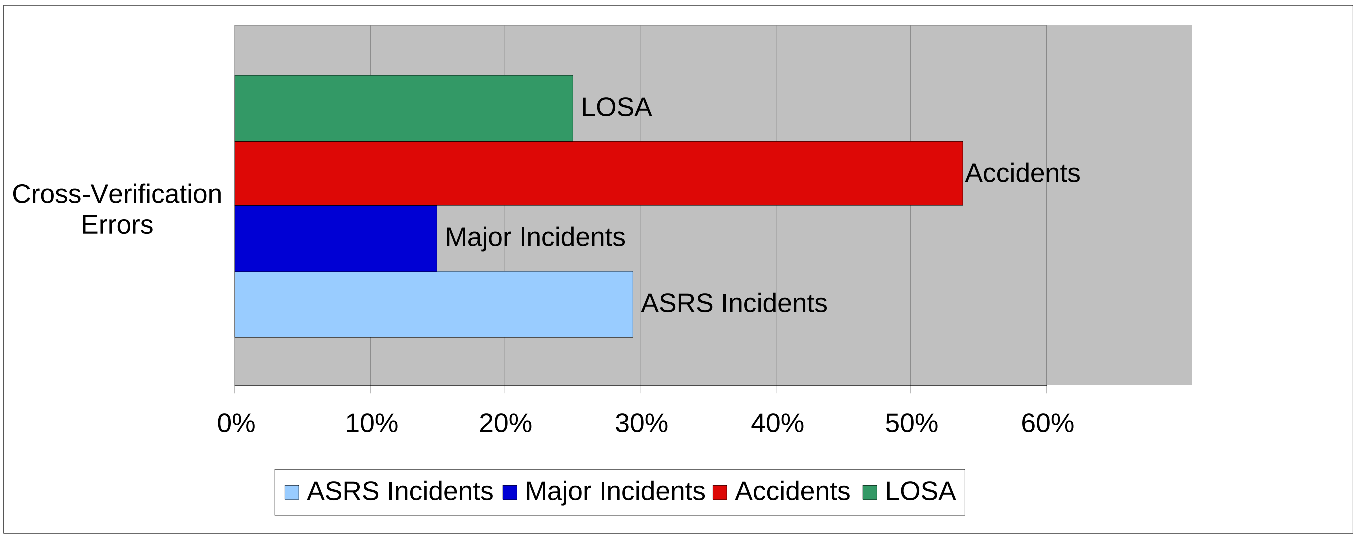


Figure 16. Cross-Verification Errors.

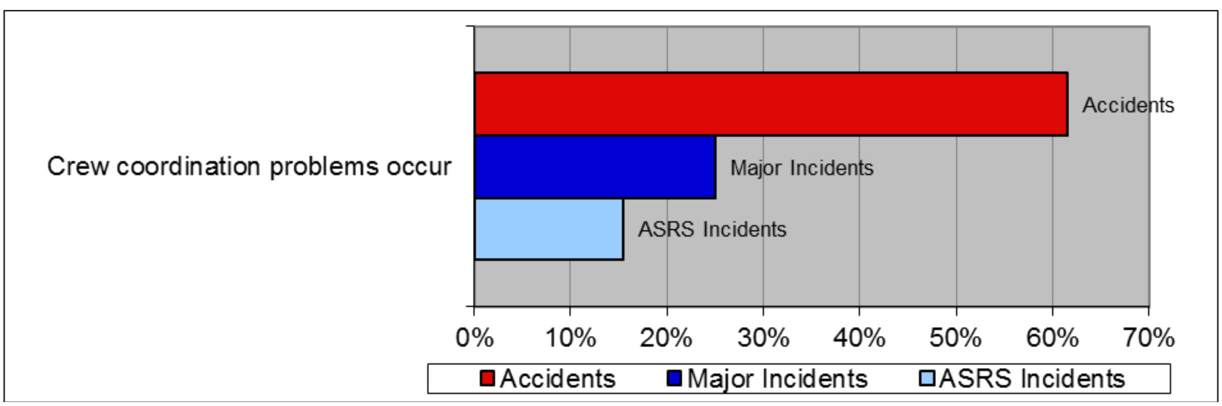


Figure 17. Crew Coordination Problems Occur.

The high degree of reliability and integrity of systems, including FMS data, may also encourage more crew complacency towards the cross-verification process. Quite simply, when faced with conflicting goals or other resource demands, the pilot may choose to short cut the cross-verification procedures because performing it properly provides less payoff or utility than performing other duties. The LOSA analysis supports this concern. It shows that the systems have become so reliable that there is perceived to be little payoff in normal line operations of onerous cross-verification procedures. Reflecting this inherent reliability, the LOSA narrative analysis found that failure to cross verify correctly was rarely related to any adverse flight path outcomes. One operator termed this syndrome as a “lack of suspicion” and is now trying to adapt training programs to encourage suspicion.

LOSA data also reveal that it is not sufficient to merely urge crews to perform such procedures while subjecting them to time and other operational pressures. Reflecting this, breakdowns in FMS entry and verification procedures tend to occur with:

- ATS cleared SID or runways changes after entry of flight planned or expected departure into the FMS,
- Periods of busy flight deck workload (e.g., pre-departure or taxi) and
- Revision of performance related figures.

See Section 3.2.4.4 for previous discussion of FMS Programming errors.

Apart from noting problems in these areas, operators also indicated that they needed further guidance on how to best conduct a cross verification. Cross verification spans several interrelated areas, including the timing and delivery method of ATC instructions or clearances; the use of uplinked data such as flight plans; the integration of other electronic equipment such as displays and EFBs; and the actual process or procedure to be carried out on the flight deck.

Discussion with operators revealed wide variation, even between those with similar equipage, in how they approached the integration of displays or EFBs into the cross-verification and briefing processes. Some ignored the displays entirely; others conceded their use as a “technique” while others embraced the display technology and had rewritten both training and operational procedures to integrate their use. However, the correctness of the data displayed still needs to be verified. One operator described a problem concerning the confusion between the coding of a departure based on traditional navigation aids versus a similar looking overlay RNAV departure. Pilots were tempted to program the incorrect, but similar departure and, during their check were prepared to overlook waypoint names as the tracks and distances looked correct.

The method of verification, whether it concerns performance and loading data or departure and arrival details, also varies between operators. While a variety of supporting processes surround this task, variation occurs in what is essentially two ways. Some operators check by reading what has been entered or programmed and verify from looking at the paperwork or chart. Others read from the paperwork or chart and then confirm by looking at appropriate fields in the FMS. Operators differ upon which way they believe is superior and their procedures may also reflect their own history and culture.

3.2.5.1 Procedures and Training for Cross Verification and Monitoring

As discussed above, insufficient cross-verification and monitoring procedures are commonly cited causal factors in flight-path-management-related incidents and accidents. The LOSA data show that lax procedures in some areas may have become normalized because of the underlying reliability of the data that is being cross verified. This means that toughening existing procedures or simply adding further cross-verification requirements will not address the complex way that critical data calculation, entry and verification errors occur.

Although there is general industry consensus that monitoring, cross verification, and error management are important, these topics are not always explicitly trained. A recent survey by Boeing on worldwide airline pilot perspectives on training effectiveness (Holder 2013) showed evidence of training gaps for monitoring and cross verification. While 99% of the pilots believe that monitoring and cross verification are important skills, when asked if the topics of detecting and managing errors were included in their recurrent training, only 47% responded that it was explicitly discussed as a specific topic. In addition, 34% stated that monitoring and cross verification were covered somehow, but not explicitly, while 19% said it was marginally covered or not covered at all.

3.2.5.2 Future Considerations

Uplinking of centrally prepared flight planning (or other performance) information directly into the FMS has the potential to greatly reduce flightcrew workload and errors. In many ways this might be a similar reduction to that associated with the use of standard flight plans called from within the FMS database, versus the manual entry of specific waypoints and route designators to connect an airport pair. However, the potential for error remains whenever data entry and processing takes place. The LOSA narrative review shows how the reliability of such data gradually erodes the cross-checking imperative. Operators expressed some concerns over the reduction in the flightcrew's ability to pick-up an error in centrally provided information. Particularly, when considering centrally provided and uplinked performance data, these concerns appear to express a general belief that the pilots' "feel" for correct numbers was reduced when the crew no longer calculates them. In these cases, operators indicated that they were searching for information concerning robust and efficient gross-error checks that could be employed by flightcrew members.

3.2.6 Communication between Flightcrews and Air Traffic Services

<u>Finding 6 – Communication and Coordination between Pilots and Air Traffic Services.</u> Communication and coordination between pilots and air traffic services has vulnerabilities that can affect flight path management. Amended clearances from air traffic generally are issued with good intentions but can lead to misunderstandings, increased flightcrew workload, and potential pilot errors when using flight path management systems. Even properly issued clearances, if timed such that the flightcrew cannot reasonably execute the instruction in the time available, can result in similar difficulties and undesired aircraft states.

This finding is based on accident, incident, and LOSA data, as well as other references.

Communication between pilots and air traffic services can be a threat in flight operations that can have safety and operational consequences. Figure 18 presents the data, showing that communication errors between pilots and external parties are a factor in more than a quarter of the accidents reviewed by the WG. Of those errors, most are related to communication with air traffic services.

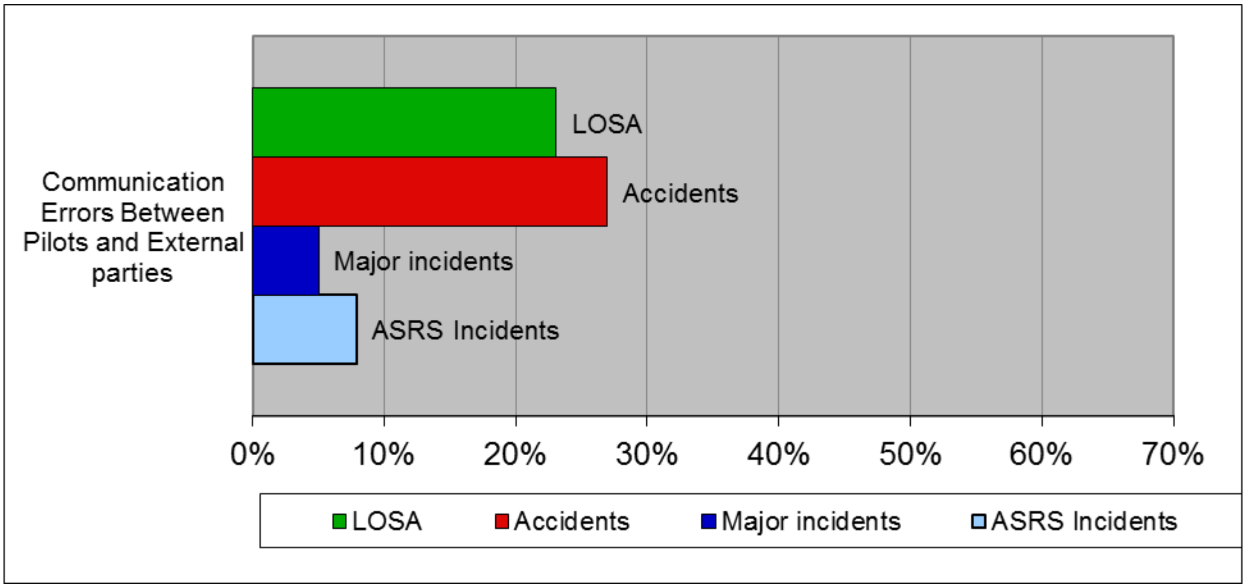


Figure 18. Communication Errors between Pilots and External Parties.

Clearances continue to place among the top communications issues between pilots and air traffic controllers.[28] Figure 19 shows that 10% of accidents reviewed were subject to a threat related to an ATS clearance. The LOSA data supports that ATS clearances are a common threat in normal line operations.

Several contributing factors to these threats were identified in the data analysis in Appendix G; such as nonstandard phraseology, complex procedures and clearances, and mismatch between ATS and aircraft capabilities. Complex procedures are discussed in Section 3.7.1, Airspace/Air Traffic Procedures.

[28] Air Traffic Safety Action Program (ATSAP) report.

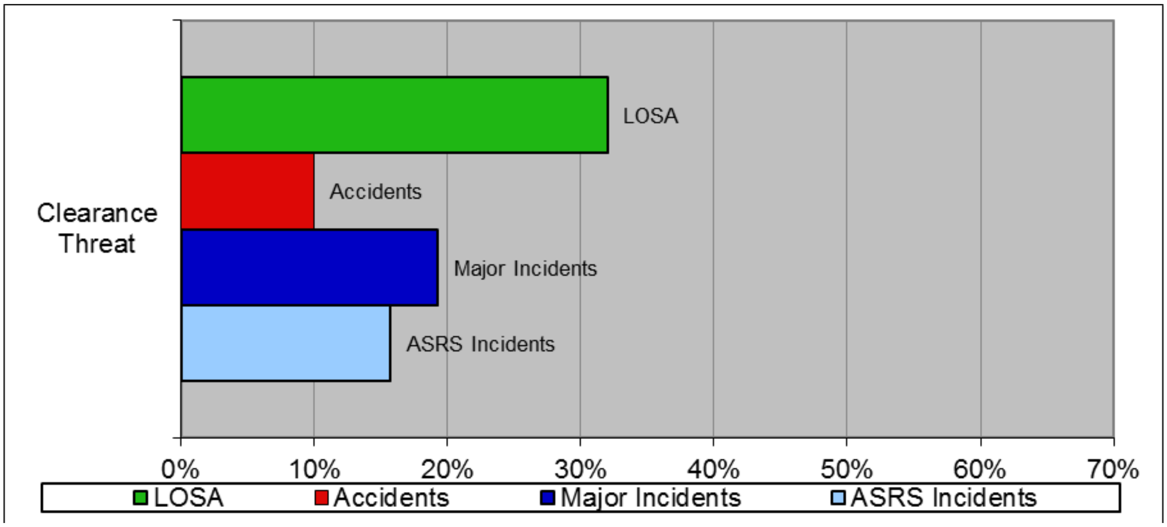


Figure 19. Air Traffic Threats - Clearances.

Air Traffic Services must have operational flexibility to make tactical clearance changes to ensure separation and system efficiency. Most instrument flight procedures (IFPs) are intentionally designed for the worst normal case operations, sometimes including air traffic restrictions and route segments that may be rarely necessary. The purpose is to design safety into the airspace system by procedural separation (lateral/vertical spacing between different instrument flight procedures or airspace and speed restrictions for longitudinal spacing on same track) during peak traffic periods. However, this practice can also set the stage for ATS to tactically amend clearances on a routine basis for greater system efficiency.

One operator told the WG that only one in ten flights took place as originally flight planned and entered into the FMS. For the other nine, some change was made by ATS – often with the best of intentions. This type of air traffic intervention, where the pilot is told to fly a procedure differently than published, planned, programmed or expected provides flexibility for the controller and may occur for several reasons, including:

- To try to “help” the pilot or provide a more efficient operational solution;
- Result from a procedure design or clearance issue, which may be incompatible with onboard systems or flightcrew procedures;
- Result from a training issue for controllers;
- Result from the failure to fully coordinate the introduction of new technology and operations into the airspace; and
- Reflect a discord between controller expectations and flightcrew actions.

Although PBN procedures can produce stable and predictable flight paths, ATS intervention is still often desired for a variety of reasons, including the lack of effective merging and spacing tools. In some cases, ATS attempts to provide operational benefit to aircrew by offering shorter flight paths, shorter taxi routes, and deleting unnecessary published restrictions. In addition, ATS intervention is common with newly implemented PBN procedures until controllers build confidence in the procedure as a traffic management tool. Effective changes to the lateral and vertical flight paths may be challenging to execute in modern flight decks, unless the pilots have an in-depth understanding of how to use the flight deck systems for that purpose. Although the intent is to provide operational benefit, ATS may not realize the additional workload and system risk introduced.

The timing and methods used by ATS to pass instructions and clearances to pilots have a significant effect on workload and how the pilots manage the flight deck. Operators described a wide range of delivery methods and timing of air traffic departure clearances received in line operations. These differences occur on top of changes to previously received clearances, which pose differing issues for flightcrew. Depending on the operator equipment and airport location, clearances may be received by voice at any time, from immediately before to more than 40 minutes before pushback and start. Pre-departure clearances received via ACARS sometimes are confusing and have contributed to numerous pilot errors.

Flight deck workload, preparation, cross-verification and briefing procedures and processes need to incorporate all of these variations. For example, many operators do not allow pre-programming of expected take-off and departure clearances until received, while others allow expected clearances to be inserted and briefed. Both approaches have benefits and disadvantages. Early programming and briefing will probably allow more time for an effective cross-check, however, what was expected may differ to what was eventually received and risks failure to recognize, change, cross-check and brief later. Delaying the programming until actual receipt may lead to increased workload and shortcuts in the cross-verification and briefing process.

The LOSA narrative analysis reveals the difficulties faced by some crews in complying with ATS changes to the expected departure, routing or other clearance. A poor or marginal rating of automation usage was associated with such a change in about 30 percent of cases before take-off. Many of these ratings also reflect a failure to cross-check and verify properly when faced with a reprogramming requirement. Once airborne and climbing away, flights described in the LOSA narratives tend to highlight outstanding rather than poor crew performance when faced with an ATS-based challenge.

Many of the narratives identified crews who employed a great degree of anticipation or optimized use of modes to meet ATC requirements rather than the actual avoidance of an adverse consequence such as an altitude or crossing restriction bust. During descent, approach and landing, the LOSA narrative analysis again identifies that an ATS intervention, such as speed control, direct routing, track shortening or other clearance deviation, caused poorly rated[29] crews numerous problems. While this factor was only identified in 16 percent of narratives, it was highly consequential with more than nine out of ten resulting in an adverse outcome.

A failure to react with appropriate mode selections when the programmed path was varied by ATS is typical of these situations. The narratives suggest that the poor rating is because of insufficient knowledge of modes and poor energy management, rather than poor compliance with SOPs. While ATS interventions caused problems for numerous crews, they also allowed others to shine with nearly 60 percent of outstanding ratings associated with an ATS factor. Again ATS factors were extremely consequential and were linked to crew action in nearly three quarters of all adverse outcomes avoided in this phase. Typically, high performing crews applied appropriate modes and demonstrated a higher degree of knowledge and anticipation than other

[29] This refers to pilot rated poorly for specific tasks by the LOSA observers.

crews. The inclusion of a briefing that went above and beyond what could be considered as standard SOPs was strongly linked to these crews' positive threat management.

Changes to the anticipated and programmed runway are frequently cited as an issue in the analyzed data. These changes occur for both arrivals and departures. Runway changes compound flightcrew workload, create distractions, and often require reprogramming of the FMS, especially when additional constraints and amendments are issued by ATS. The nature and timing of a runway or procedure change is often perceptual and situational. For instance, a flightcrew may program an assumed SID and departure runway while at the gate, based on the ATIS or operational experience. If the ATS clearance contains a different runway, this becomes a runway change to the crew, but not to ATS. Regardless, any change from the preplanned departure/arrival runway presents a threat, even if initiated by the flightcrew.

Many airspace procedures in use today affect pilot workload, depending on aircraft performance considerations (e.g., "expect direct in 5 miles," restrictions on combining control instructions with number sets or altitude assignments with speed adjustments, etc.). For runway changes on arrivals, the current ATS rule is to issue an amendment no closer than 10 miles from the runway transition waypoint. From the number of "late" runway changes reported in the data, it is unclear if this is a sufficient distance or whether it is consistently complied with. Time pressure and reluctance to refuse or question air traffic clearances sometimes results in FMS input errors and omissions.

This issue was especially highlighted by flightcrew reactions to changes to the expected path. The WG heard concerns from both operators and trainers that suggested crews sometimes exhibited poor knowledge of flight path management system functionality when issued a change that affected the path. Numerous examples were provided of how crews struggled to recover an optimum path after a clearance amendment. Crews tended not to intervene but to simply rely on the autoflight system's own algorithms without understanding how the built-in assumptions concerning flight path may be lacking.

One operator described how this factor led to inefficient flight paths, particularly when ATS initially forced the aircraft low relative to the planned, optimum descent path due to airspace boundary or other issues. Following this restriction the aircraft was normally free to regain its optimum path, however, crews failed to intervene and over-ride the computed flight path which assumed a continued descent from the altitude restriction. Such inefficiencies incurred a significant business cost and triggered awareness training and emphasis on the intervention techniques during annual line checks. This operator's LOSA captured high-performing crews as those that intervened following ATS disruptions to flight path and used a variety of modes to regain an optimum path.

However, the LOSA data also indicate that this is NOT a normative behavior. The LOSA data showed that observers only characterized flightcrews as poorly performing when their interventions were inappropriate. Leaving the autoflight system to "do its own thing" rather than taking action seemed to be the accepted response. The broader LOSA narrative supports this operator's individual experience and also suggests that flightcrews exhibit lack of flight path management system functionality (especially FMS and mode functionality) knowledge, which contributed to vulnerabilities when reacting to ATS interventions.

Alternatively, ATS clearances may not be easily selectable or complied with using existing system interfaces. For example, a requirement to make an Optimum Profile Descent or, as previously discussed, to make an en-route descent requirement by a fix or point is not easily selectable and must be performed by the crew using basic modes. This situation happens when airspace/ATS demands step outside the envisioned design criteria of the flight path management system functionality. Flightcrews have no choice except to select more basic modes of operation, such as the use of heading, speed, and vertical speed, to either meet more complex ATS requirements or alternative instructions. Several operators gave numerous examples of these types of clearances which merely overlay a fully managed path which would have been available from the flight path management system functionality. Flightcrew procedures, exposure and training vary so much in the way they are taught to manage these situations that flightcrews use differing ways to comply. This, in turn, may exacerbate any deviations from ATS expectations.

Another study[30] found the following operational factors would increase the likelihood of communication errors between flightcrews and Air Traffic Services:

- Non-standard phraseology,
- Rate of speech delivery,
- Use of general English in lieu of standard phraseology,
- Use of slang,
- Ambiguity in general aviation language, and
- Lack of harmonization.

As airspace changes are implemented for future operations, it is increasingly important to have effective ATS intervention and clearance amendments. Lack of standardized phraseology to accurately convey pilot/controller intent is part of the problem, but universal solutions are difficult to implement as air traffic systems worldwide are becoming more risk averse and less fault tolerant. As promulgated by ICAO, the process for making changes in airspace and air traffic systems has become oriented towards the Safety Management System (SMS), a mostly data-driven process. At least in the US, the workload overhead involved with implementing the SMS process has resulted in substantially slower implementation of previously planned air traffic procedure changes and sometimes frustrated international harmonization efforts. For instance, the delay in SMS approval and implementation of “climb via” phraseology for departures on RNAV and conventional SIDs with vertical profiles has contributed to delay in implementations and resulted in a conflict with newer ICAO phraseology developed for similar purposes.

Future airspace operations are expected to use datalinked information more extensively than currently available. To avoid potential pilot confusion and errors, it will be important for the message sets used for datacomm and for other datalinked information (such as Pre-Departure Clearances) to be consistent with voice phraseology.

[30] International Air Transport Association, Pilots and Air Traffic Controllers Phraseology Study, 2011.

3.3 Flight Operational Philosophies, Procedures and Policies

Operational procedures and the philosophies and policies that underlie them are a primary foundation for safety and operational effectiveness. This section describes the findings related to SOPs and to policies for operational use of flight path management systems.

3.3.1 Flightcrew Procedures – Standard Operating Procedures

Finding 7 - Standard Operating Procedures.
Compliance with published standard operating procedures has been increasingly emphasized, with safety and operational benefits. However, the data analyses showed pilots do not always follow standard operating procedures, for a variety of reasons, including:

- **Procedures may not match operational situations well,**
- **Workload may not permit completion of the procedures,**
- **Procedures may be too prescriptive or detailed, and**
- **No adverse flight consequences appear to occur by not following the SOP.**

This finding is based on accident, incident, LOSA, and interview data.

Flightcrew procedures and their underlying policies have been and continue to be a key risk mitigation strategy and defense against pilot errors. There has been increased emphasis on SOPs in the last ten to fifteen years, as recommended in the 1996 FAA report, by CAST, and others. Among other reasons, SOPs are increasingly used to mitigate potential risks such as cultural differences among flightcrew members, differing levels of pilot experience, and other factors.

There are open questions about the appropriate level of proceduralization, including how prescriptive and detailed the procedures are, and how comprehensive they should be. Sometimes procedures are used as mitigation for insufficient pilot experience, knowledge and skills. As a result, vulnerabilities may occur because procedures cannot cover all possible operational situations and circumstances. If the operation is excessively reliant on procedures, the pilots may not be prepared for unexpected or non-routine situations. In addition, the LOSA data and interview feedback suggest that overly prescriptive SOPs may be less likely to be followed.

The LOSA analysis suggests that failing to completely comply with SOP requirements to cross-verify FMS entries is commonplace in line operations. Indeed the LOSA analysis found that crews may be reported as high performing if they merely demonstrated a high degree of compliance with required SOP cross-verification procedures. This result suggests that it is common to not follow these procedures.

There has also been increased use of manufacturers recommended procedures. This has significant benefits, because the manufacturers can leverage their knowledge of the airplanes and how they were designed. However, manufacturers have to develop one set of procedures for use by all operators, and therefore may not create the best match in any particular operator's environment. In addition, the operators may not have the expertise to effectively modify manufacturer recommended procedures to their particular operations.

While the accident and incident data clearly indicate that failure to cross-check and verify is a problem, the LOSA data show that it occurs regularly without consequence. This indicates to the pilots that the existing FMS databases usually are very reliable. Crews can line select a departure or arrival confident in the knowledge that it has already been cross verified. It may be the same one they checked on a previous flight or; if not, certainly other crews would have selected the same entry and found it to be satisfactory.

Simply put, it is easy to omit an onerous cross verification, or merely perform a perfunctory one when workload is high, time is short, or confidence is high and the likelihood of finding a mistake is low. However, this confidence is invalidated if an incorrect selection is made by the crew in the first place. A similar sounding or looking departure from the wrong runway can be easily mis-selected, pass a cursory check and yet have disastrous consequences.

In many ways, cross-checks and verifications can be thought of as risk mitigations in much the same way as seat belts. Seat belts only perform their role when something has gone wrong; they are not missed until after the accident has happened. Failure to wear a seat belt would figure prominently as a factor in any post-accident review. The consequences can only be linked to the lack of a seat belt when the accident happens rather than reflect how many incident free journeys are undertaken without one. This analogy does not excuse the failure to conduct a thorough cross verification; rather, it helps explain why compliance with even more onerous procedures is not a viable, universally acceptable solution.

Finding 8 - Data Entry and Cross Verification Errors
Data entry errors, together with cross verification errors, may cause significant flight path deviations leading to incidents or accidents.

This finding is based on accident and major incident data, together with interview data and pilot reports.

Several examples of incidents that involved mis-entry of data into the FMS (such as aircraft weight) have resulted in incidents that could have resulted in loss of life (Emirates 407, A340-500, Melbourne Airport, 20 March 2009 (tailstrike)[31]). The International Air Transport Association (IATA) recently documented a study of such data entry errors.[32] The NTSB has made several safety recommendations on this topic.[33] Since this is a type of FMS programming error identified in the WG data, as well as other studies, it is one that needs to be addressed. The cross-verification of such entries is intended to be a defense against such error, but the data show that cross-verification errors may occur often enough to question whether it is a sufficient defense.

[31] *Tail Strike - Melbourne Airport, Vic. - 20 March 2009 - A6-ERG - Airbus A340-500*. ATSB Transport Safety Report. 30 April 2009. ISBN 9781921602436. AO-2009-012. http://www.atsb.gov.au/publications/investigation_reports/2009/AAIR/pdf/AO2009012_Prelim.pdf. Retrieved 27 January 2011
[32] IATA (2011). Flight Crew Computer Errors (FMS, EFB) Case Studies, Montreal, Quebec, October 2011.
[33] NTSB recommendations A-05-006, A-05-007.

3.3.2 Policies for use of Flight Path Management Systems

<u>Finding 9 – Operator Policies for Flight Path Management.</u>
Increasingly, operators use a documented automation policy. Lessons learned in the application of these policies reveal that improvements could be made to better focus attention on the flight path management related tasks and more effectively use automated systems.

This finding is based on interview data and additional references.

The WG found significant variation in the philosophies, policies and procedures for the use of automated systems by operators. Of the operators with an explicit automation use policy, we found policies ranging from allowing the pilots to use whatever they consider appropriate to policies that require use of the highest level of automation possible for the circumstances. Even operators of the same airplane type, which are supported by common, manufacturer based philosophy and procedures, differed markedly from each other.

Operators differ in their approach to "Automation" philosophies, policies and procedures for a variety of valid reasons that include the operators own unique history, culture and operational environment. The WG found that several operators started with a policy that used explicit definitions of levels of automation described as a simple hierarchy in a rigid and prescribed fashion. After gaining operational experience with training and operational use of these rigid definitions, several airlines concluded that such a description assumed a linear hierarchy that does not exist. The various features of the autoflight system (autopilot, flight director, autothrottle/autothrust, FMS, etc.), can be, and are, selected independently and in different combinations that do not lend themselves to simple hierarchical description. As a result of this experience, those operators revised their policies to allow the pilot to use the appropriate combination of automation features for the situation, without rigidly defining them in terms of levels.

One important part of many automation policies is the recommendation for what to do if a problem occurs, especially if the pilots are confused about the current mode or about what the systems are doing. In some cases, a recommendation is made to have the pilots turn all autoflight off and revert to a completely manual set of modes until the situation is sorted out. However, this may be too simplistic and may be inconsistent with the automation policy recommended by some manufacturers. It may be that leaving some of the automated systems on may be best, depending on the aircraft system design and the current situation. For example, it might be appropriate in some situations, with certain system designs, to disengage the autopilot but leave the autothrust system on. There may not be a single, simple answer for all cases.

The WG observed that the focus on management of automated systems was not always well integrated with the focus on managing the flight path of the aircraft, and may distract from the tasks associated with flight path management.

The following points provide additional findings on philosophies and policies adopted by some operators:

- Wide variation. There is significant variation between operators in philosophy/ policy/ procedures/ practice and terminology concerning flight path management systems operational use. This variation may reflect differences in the type of operations and organizational culture of the operator.
- No one "best" policy. There is no one "best" operational policy for the use of flight path management systems that should be adopted by all operators. It depends on many factors, including differences in equipment type, organizational culture and operating environment.
- No common terminology. There is no common terminology that can be used to describe the elements and functions of the flight path management systems. For example, the use of the term "automation" is not clear and may be applied differently within and across organizations.

The intent of the last bullet is not to highlight variations in the way that components are named or described (i.e., Mode Control Panel (MCP) versus Flight Control Unit (FCU)), although that is an issue. Rather, this refers to the broader conceptual issues that an operator draws upon when formulating a general philosophy and supporting policies that describe their unique stance on the use of flight path management systems.

Airlines operate different fleets and there is a strong desire to standardize across fleets. In some cases, airlines avoided the use of certain aircraft features because they don't have those features on all fleets. Most operators extend or modify the manufacturers' guidance when developing guidelines concerning operational use of flight path management systems in Flight Operations Policy Manuals.

It should be noted that there are important differences between policy for *design* of flight path management systems (by manufacturers) and policy for *operational use* of flight path management systems. Design philosophy/policy is established by the manufacturer (either explicitly or implicitly), and provide designers with a basis to develop new flight decks and modifications. Operational policy is established by the airline/operator, and describes how and when the pilot should use the systems. Regulatory policy may be established with respect to any of the above.

3.4 Task/Workload Management

Deficiencies in task management, such as distraction[34] or loss of vigilance, have been cited as either causal or contributory factors in accident cases. When viewed in isolation, such findings may suggest a contributory lack of proficiency or skill and the question often has been raised "how could the pilot have missed that?" (e.g., low airspeed,[35] setting flaps for takeoff,[36] etc.*)*. However, the WG found that task management, the maintenance of vigilance and avoidance of distraction are not trivial tasks. Managing the tasks on the flight deck as described here includes:

- Task prioritization;
- Management of workload;
- Management of attention, including managing distractions;
- Information management,
- Managing time available for tasks, and
- Allocation of tasks between Pilot Flying (PF) and Pilot Monitoring (PM).

This section presents the results of the WG analysis for task/workload management in general, and then discusses each individual aspect of task/workload management. The section concludes with a discussion of considerations for future operations.

<u>Finding 10 - Task/workload Management.</u>
Flight deck task/workload management continues to be an important factor affecting flight path management.

This finding is based on accident, incident, and interview data.

Figure 20 shows that the issue "task management is more difficult" was a factor in almost 20% of the accidents reviewed, and in approximately one third of the major incidents. Other data that relate to this topic are shown in Figure 21, which shows the presence of the issue "new tasks and errors" as a factor in accidents and major incidents. This issue specifically addresses new tasks and errors related to use of automated systems. These new tasks and errors are related to operation and monitoring of such systems. Whenever additional flight deck systems are incorporated into an aircraft, the pilots are expected to operate and monitor those systems.

Managing tasks within the flight deck is complex and requires managing flight deck workload, distractions, and tasks generated by others outside the flight deck. Most airlines do not explicitly teach task management or strategies for managing the myriad of tasks encountered in the current operational environment. Some airlines teach TEM (or similar risk management methods) and discuss workload and distractions in their CRM courses, but many operators and trainers expressed concerns that crews were not adequately prepared for how to manage the flight deck tasks when faced with high demand situations.

[34] http://www.ntsb.gov/news/2010/100318.html
[35] Dutch Safety Board (2010). Crashed during approach, Boeing 737-800, near Amsterdam Schiphol Airport, 25 February 2009. The Hague, May 2010., NTSB (2010b)
[36] CIAIAC (2008). Accident involving a McDonnell Douglas DC-9-82 (MD-82) aircraft, registration EC-HFP, operated by Spanair, at Madrid-Barajas Airport, on 20 August 2008. Report A-032/2008.

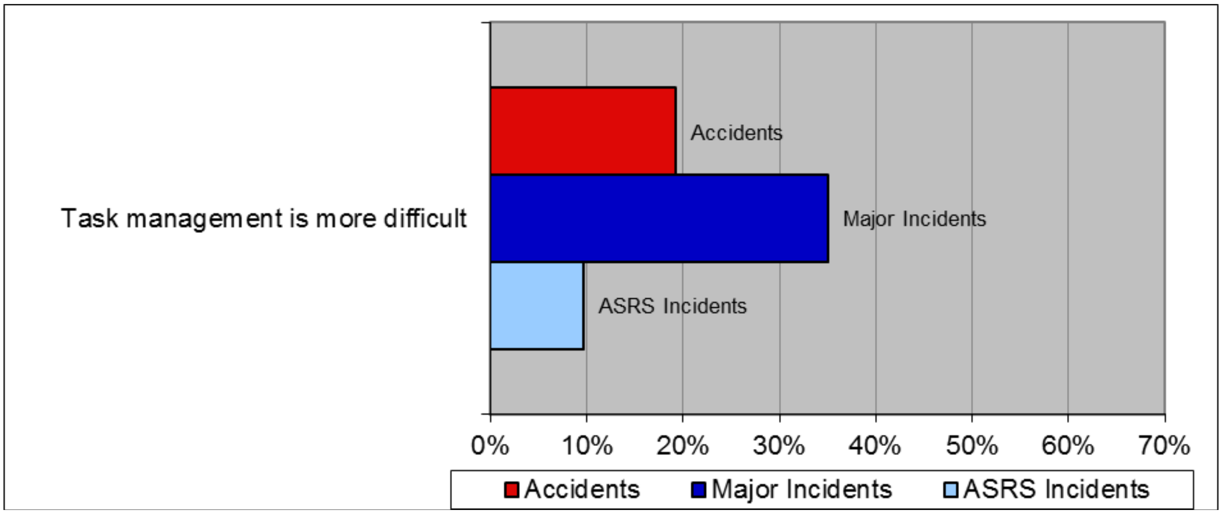


Figure 20. Task Management is More Difficult.

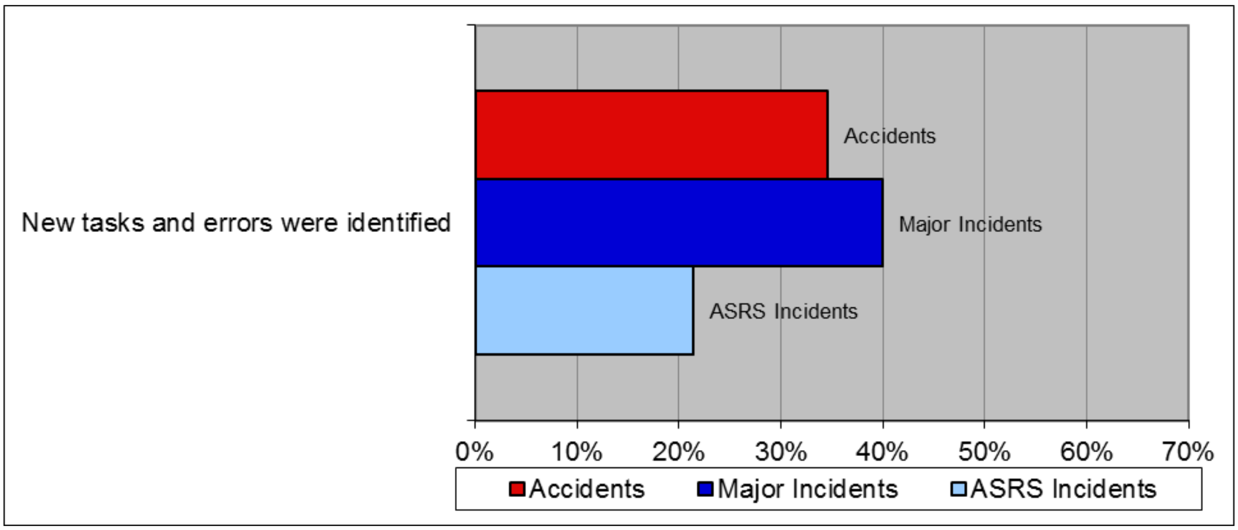


Figure 21. New Tasks and Errors were Identified.

3.4.1 Prioritization of Tasks

For prioritization of tasks, pilots are taught to Aviate, Navigate, and Communicate. This was much easier when they only had to monitor four or five primary flight instruments and clear for other aircraft. It is also easy to discuss these three concepts at a high level for flying today's complex airplanes in complex airspace. The WG analysis shows that it becomes harder to operationalize these concepts when there are many tasks within each area, and tasks often overlap or are left awaiting a further trigger for completion or continuation. This may explain why the data show that during times of high workload (i.e., during a complex arrival or emergency), the myriad of tasks required of the pilots may result in no one monitoring the flight path of the airplane, or breakdown in communication between the pilots, or breakdown of cross-verification procedures of FMS inputs. When overloaded, the pilots shed tasks based on their own experience, skill, and risk management of the situation. Without any formal training in task management, pilots develop their own techniques.

3.4.2 Workload Management

Pilots often described long periods of time in modern, highly automated aircraft where workload was very low. It appears that use of automated systems may reduce workload during much of normal operations, but during demanding situations (e.g., certain phases of flight when the pre-planned flight path is changed, such as being vectored off a complex procedure, then vectored back on to resume the procedures, or programming and verifying an RNAV approach, change of runway assignment during taxi, or during non-normal or emergency procedures), use of the automated systems may add complexity and workload to the pilots tasks. [37] [38] [39] In normal operations a highly automated airliner may be easier to fly than previous generations of aircraft but, in a non-normal situation, it sometimes is comparatively harder. In the WG analysis, high workload and time pressure were common vulnerabilities identified in the factor analysis of incident data (see Appendix G).

Many operators recognize this and provide procedural guidance to reduce/manage workload (normally the workload of the PF) at critical phases of flight. Methods seen included;

- Focusing on the task – procedures that described the task to be accomplished and define who, when or how it is to be completed;
- Focusing on workload – procedures that shed tasks to other crewmembers when workload is high;
- Focusing on threats – procedures that guide the use of flight path management systems, depending on the threats being managed by the crew; or
- A combination of the above.

Many operators are attempting to deal with these issues through procedural change. One operator described a major distraction management program inspired by a recent LOSA that attempted to limit the number of intrusions into the flight deck during the critical pre-departure phase.

The above paragraphs discuss high workload situations; however, the WG also heard concerns about low workload and attempts to maintain flightcrew engagement with the tasks at hand. Pilot may be further out of the control loop in some operational situations (see Figure 12) – how do we re-engage them given the best possible use of automated flight path management systems? One solution that was cited by an operator was to have the pilots use the Heads-Up Display to hand-fly precision approaches instead of using autoland for approach and landing operations. Their experience was that the pilot was more engaged in the approach and was ready to hand-fly the complicated go-around if necessary, which was not the case when the pilot had to make the transition from watching the automated systems fly the approach to taking control of the aircraft from the autopilot.

[37] E. L. Wiener, “Cockpit automation,” in *Human Factors in Aviation*, E. L. Wiener and D. C. Nagel, Eds. New York: Academic, 1988, pp. 433-461.

[38] R. Parasuraman and V. A. Riley, “Humans and automation: Use, misuse, disuse, abuse,” *Human Factors*, vol. 39, pp. 230–253.

[39] Parasuran, Sheridan, and Wickens, “A Model for Types and Levels of Human Interaction with Automation,” IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems And Humans, VOL. 30, NO. 3, May 2000.

3.4.3 Information Management

One of the important aspects of managing the flight deck is managing information. This includes many aspects of dealing with information – accessing it, using it, and others. As discussed in Section 3.1, the quantity and type of information available to the flightcrew has changed substantially. There is more information available to the pilots, and they must use it appropriately. They must access it, which means they must have knowledge of where and when to get it, and the act of accessing it is an additional task. In addition, they need to understand what the information means, its reliability, and how to use it. Sometimes they have to reconcile differences in sources of information (for example, between charts and the FMS database).

Another aspect of managing the information available to the flightcrews was the use of systems that were designed to be “safety nets” or defenses as primary for the task. For example, the takeoff configuration warning system is intended to provide information as a backup to pilot procedures, in case an important step related to configuring the aircraft for takeoff is missed. Another example is an altitude alerter is intended to alert the pilot to assure awareness of approaching a target altitude; but procedural callouts are intended to be the primary mechanism for pilot awareness. These systems represent safety defenses. However, the WG observed that in some cases, these “safety nets” are being used as a primary defense against threats, rather than the backup they were intended to be.

The following example, drawn from instructor interviews, illustrates this subtle change in the role of a back-up system and possible safety consequences. Some pilots are trained to rely on the automated TCAS system warning and not to react or take normal collision prevention strategies until they get the Resolution Alert (RA) warning. During training an engine is failed during a simulator scenario and the procedure requires the TCAS system be switched from Traffic Advisory (TA)/ RA mode to TA mode only. At the completion of that exercise, the TCAS is left in TA mode. When the crew is given a traffic conflict exercise in a later scenario, instructors reported it was common for crews to fail to take any avoidance action, even though the aircraft may be clearly visible and a collision hazard. They reported that they believed that this was because pilots have been conditioned during training to rely on the automated RA warning and directions in order to react. If the TCAS system fails or for some other reason doesn’t warn the pilots, the inaction of the pilots could have significant safety consequences during line operations.

3.4.4 Time Management

Effective time and energy management skills are important for every pilot to learn and use in both normal and non-normal operations. An example is using time wisely to manage the speed, energy, and momentum of the airplane when configuring and flying an approach. During student pilot training, pilots are taught to think ahead and “stay in front of the airplane.” This requires good planning skills and anticipation of what will happen, including those possible threats and errors that might develop.

The faster things are happening, the less time pilots have to anticipate threats and errors. If time is getting away from the pilot, the pilot needs to be able to recognize this, slow things down, re-evaluate the situation, and handle it safely. As discussed in section 3.4.1 with communication errors, operational/time pressures that lead to work-arounds or shortcutting of procedures continue to be a significant factor in incidents and accidents. For example, breakdowns in FMS entry and verification procedures occur more often during busy periods, such as during taxi out for takeoff or time-constrained approaches.

Sometimes pilots cannot slow things down or are given too many tasks to perform in the time they have available. Pilots are required to analyze the situation and use their knowledge and skills to assess the situation and prioritize the tasks that need to be done in the time available.

Sometimes the tasks required cannot be performed within the time available. For example, as discussed in section 3.4.1, when faced with conflicting goals or other resource demands, the pilot may choose to short cut the cross-verification procedures as performing it properly provides less payoff or utility than performing other duties. The same is true of completing checklists during an emergency when time is not available to do so. The pilots may not have enough time to complete all the required checklists (NTSB 2010, ATSB 2013). Instead, they have to prioritize and perform the tasks in the time they have available based on their systems and non-normal checklist knowledge. Based on interview data, current training programs and variations in instructor experience may not provide the flightcrews with the knowledge, skills and judgment to successfully manage the flight path in the time allotted.

3.4.5 Allocation of Tasks between Pilot Flying and Pilot Monitoring

The definition of PF/PM duties, responsibilities and functions differ markedly across operators. Examples include the assignment of FMS entries, how changes are made to the FMS, and use of the MCP. Procedures also vary on which pilot handles the radios, company communications, flight attendant calls, and normal and non-normal checklists.

Operators varied markedly in the division of performance calculation, data entry and cross-checking duties. In terms of performance calculations completed by crew, it is common for one crew member to carry-out the initial calculations, record them and then be checked by the other crew members. Alternatively, some operators insist on totally independent calculation process followed by a comparison of results. Even in these cases, operators varied in how the original parameters to be entered were derived and agreed upon by crew before independent entry.

The process is also affected by how the data is subsequently entered and verified. In a crew environment, one pilot is normally assigned the data entry responsibility, the other may or may not complete an independent check, while there is normally a formalized read back and check process involving both crew members. Operators described a variety of processes that all sought reliability and robustness. Some cited a perceived higher reliability by insisting that the crew member that performed data entry should never be the one who verified the entry against the original data source; instead, that crew member should read back what was entered for the other to verify.

For example, one pilot may enter load sheet data into the FMS such as final weight and center of gravity data. A variety of procedures may be undertaken to cross-check and verify this information. First, the other pilot may independently verify correct entry from the original data source. Secondly, there may be a formalized read-back by one pilot of either the entered or original data while the other pilot checks it.[40] This can be accomplished in a variety of ways. One operator suggested that it was more robust for the pilot who entered the data to read it back from the FMS for the other to cross verify from the original load sheet to avoid the possibility of the same pilot repeating the same error made during data entry when subsequently verifying that data entry error.

The variability of task allocation between PF and PM may be a result a lack of industry standards or may be a legacy of changing from three crewmembers to two crewmembers in the flight deck. Not all of the tasks previously assigned to the engineer were completely automated, such as performing takeoff and landing data computations, handling outside communications with the flight attendants and company, and performing non-normal checklists to name a few. Instead, these and similar tasks were added to the workload of the Captain and First Officer to accomplish while they were flying the airplane as PF and PM. As new systems and functions are added to modern flight decks, they may exacerbate the difficulty of maintaining structured task management. Regardless of the reason for current circumstances, there is a lack of guidance on the allocation of tasks between pilots.

3.4.6 Future Considerations

Flightcrew members will continue to be required to manage increased complexity when they transition to new operations, as additional tasks may be added to the pilots' task loading. Often, when examined in isolation, each new task may appear to reduce overall workload, but in reality may not. Therefore, the overall pilot task loading of the combination and integration of the systems needs to be examined for both normal and non-normal operations. One example cited was a system which had aural callouts that over-rode air traffic instructions at critical times and how, even though there are few requirements to "respond" to the automatic calls, pilots invent their own responses because they are uncomfortable doing nothing.

[40] Note that not all operators have formal cross verification procedures.

3.5 Pilot Knowledge and Skills

Commercial pilots are professionals who regularly mitigate operational and safety risk, as discussed in Section 3.2.1. Pilot knowledge is critical to this risk mitigation and must be acquired and maintained to be accessed and used at appropriate times, just as skills must be introduced, practiced to a level of proficiency, and maintained. These knowledge and skills are acquired and maintained through several mechanisms, including selection, operational experience, informal information exchange, pilot training, pilot qualification, and others.

This section addresses the findings and observations related to the acquisition, development, retention and maintenance of pilot knowledge and skills. It describes results related to operational experience and to pilot training. The first part of this section discusses the results of the data analysis regarding vulnerabilities in pilot knowledge and skills, as seen in operational experience. The second part addresses pilot training. The third part addresses the instructors who are a critical part of any successful training and qualification program.

3.5.1 Vulnerabilities in Pilot Knowledge and Skills

Finding 11 - Pilot Knowledge and Skills for Flight Path Management:
Pilots sometimes lack sufficient or in-depth knowledge and skills to most efficiently and effectively accomplish the desired flight path management related tasks.

This finding is based on data from accidents, incidents, other operational data and interview data.

The results of the data analysis are described below in three parts. The first part describes data directly related to pilot knowledge and skills. The second part discusses insufficient knowledge and skills as indicated by errors made in flight operations. The third part summarizes the results from the structured interviews related to these topics.

3.5.1.1 Data Directly Related to Pilot Knowledge and Skills

Flightcrew knowledge was a category in the review and analysis of the accident and incident reports. The analysis showed that over 40% of the accidents reviewed had some type of knowledge deficit identified by the investigating board as being associated with the accident (shown in Figure 22). Similarly, 30% of the major incidents reviewed by the WG noted some type of knowledge deficit associated with the event. LOSA narrative analysis found that an adverse flight path outcome was much more likely when some lack of knowledge was associated with a poor or marginal rating of automation use.

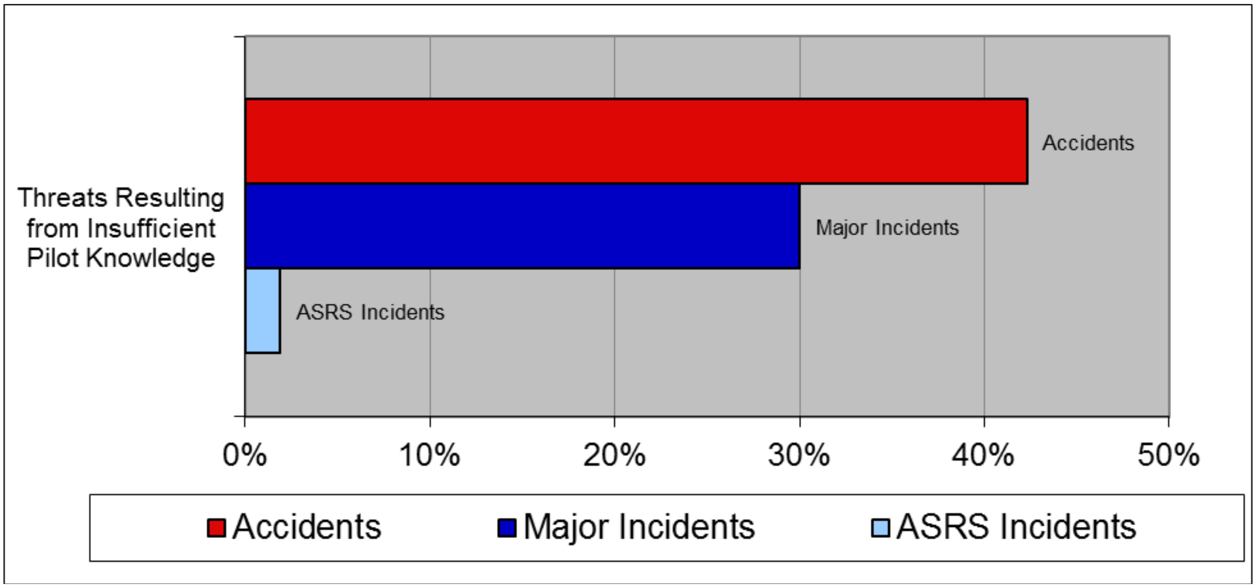


Figure 22. Threats Resulting from Insufficient Knowledge by Pilots or Flightcrew.

The following list summarizes areas of knowledge identified as insufficient by the investigative boards:

- Incomplete understanding of the complex relationships and modes of flight director, autopilot, autothrottle/autothrust, and flight management system/computer, including:
  - Systems and limitations
  - Operating procedures (approach, descent, TCAS, FMS)
  - Need for confirmation and cross verification
  - Mode transitions and behavior
- Crew Resource Management,
- Unusual attitude prevention, recognition and recovery, and
- Operating limits, aerodynamic capability, and energy management.

3.5.1.2 Insufficient Knowledge and Skills as Indicated by Errors in Flight Operations

Examining pilot errors made during flight operations provides another way to understand potential challenges with pilot knowledge and skills. In previous sections of this report, various errors were discussed, including:

- Manual handling/flight control errors (Section 3.2.2 Manual Flight Operations)
- Mode selection errors (Section 3.2.4.2 Autoflight Mode Confusion)
- Programming and FMS errors (Section 3.2.4.4 Flight Management System Programming and Use)
- Cross-verification errors (Section 3.2.5 Communication between Pilots in a Flightcrew)
- Callouts (See Figure 33. Procedural Errors.)
- Briefings (See Figure 33. Procedural Errors.)
- Checklist errors (See Figure 33. Procedural Errors.)
- Pilot-pilot communication errors (See Section 3.2.5 Communication between Pilots in a Flightcrew)

A detailed look at the accident and incident reports associated with each of the error types provided more specific information for understanding the specific errors committed. Table 1 provides a listing of pilot knowledge and skill deficiencies based on those detailed reviews. More of the results of these reviews can also be found in Appendix G.

3.5.1.3 Data related to Pilot Knowledge and Skills from Structured Interviews

The areas of vulnerability identified in the accident and incident analysis are consistent with the interviews with operators and training organizations. The WG was told about concerns over instances of flightcrew's lack of full understanding of flight path energy and trajectory management. These concerns appeared to be twofold. First, they referred to a perceived erosion in basic knowledge required to manage the flight path itself (i.e., knowledge of the power plus attitude equals performance relationship across a wide range of flight scenarios and configurations; situation awareness in terms of knowing where the aircraft should be versus where it actually was in terms of the desired or intended flight path). Second, the WG heard from several operators that they were concerned that crews may accept unrealistic clearances because they lack the knowledge to assess what is reasonable for the current aircraft situation or the confidence to reject such a clearance.

Additionally, deficiencies were identified in the understanding of the computation of desired flight path by the automated systems. These deficiencies were described as leading to a lack of pilot anticipation of performance changes associated with autoflight selections and mode changes. This lack of anticipation could be leaning toward the norm in operations as shown in the LOSA narrative analysis. Crews that were able to demonstrate such anticipation were rated highly by their peers. Conversely, lack of such anticipation was considered normative and was rarely categorized as poor or marginal during peer observation.

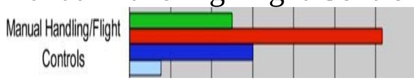
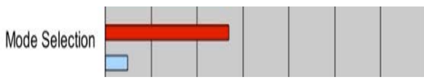
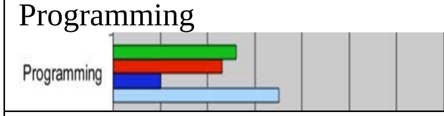
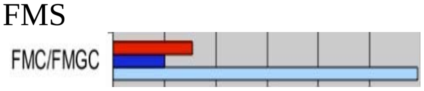
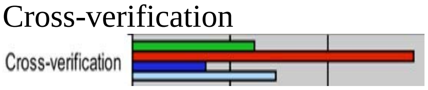
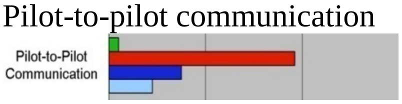
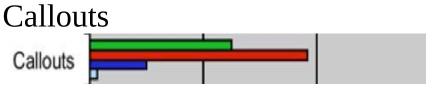
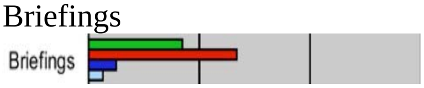
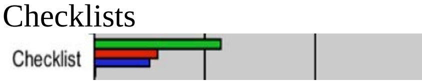
Error Categories	**Knowledge or Skill Deficiencies in Events (based on analysis of accident/incident reports)**
Manual Handling Flight Controls 	o Stall recovery o Upset recovery o Flight path management o Throttles/thrust management o Manual handling after autopilot or autothrottle disconnect o Appropriate rotation o Appropriate automation configuration
Mode Selection 	o Appropriate use of vertical speed mode o Programming for a VNAV descent o Appropriately selecting the correct mode
Programming 	o Programming a lateral route o Programming a departure o Programming for vertical restrictions
FMS 	o Using FMS for runway change o Managing use of FMC o Verification of FMS programming o Programming FMS for departure o Programming FMS for arrival
Cross-verification 	o Cross-verification of FMS/CDU input o Cross-verification of changes to MCP o Cross-verification of takeoff programming o Cross-verification of thrust settings
Pilot-to-pilot communication 	o Communication about task sharing o Communication during cross-verification o Timing of communications o Coordination of heads-down time
Callouts 	o Altitude callouts o Speed callouts o Aircraft configuration callouts o Go-around callouts
Briefings 	o Timing of briefings o Approach briefings o Takeoff/departure briefings o Appropriate briefing content
Checklists 	o Appropriate checklist use o Timing of checklist use o Emergency checklist use
■LOSA ■Accidents ■Major Incidents ■ASRS Incidents	

Table 1. Potential Knowledge or Skill Deficiencies Associated with Error Categories.

Areas of pilot knowledge and skills that could be improved in training programs, based on structured interviews,[41] include:

- Sufficient system knowledge to take appropriate actions during emergency or abnormal situations including when and how to intervene as necessary;
- Knowledge about appropriate times to use various combinations of automation;
- Knowledge of air traffic procedures;
- Situations that lead to distractions;
- Strategies to prevent and mitigate distractions;
- Briefing requirements;
- Knowledge related to mode logic and maintaining awareness of the state of system modes;
- Basic flying skills;
- Normal (all-engine) go-arounds;
- Task/workload management;
- Automation management (including judgment for level of use and intervention when appropriate);
- Automated system mode management for specific situations;
- Decision making;
- Handling of radios;
- Effective briefings, including automation configurations and crew roles and responsibilities;
- FMC programming and use of CDU/MCDU;
- Trajectory and energy management;
- Developing a mental picture of the flight path from FMS and other information;
- Monitoring automation behavior and backing it up with mental calculations;
- Manually flying approaches;
- Hand flying proficiency; and
- Flying in alternate control laws.

It is clear from the WG data and interviews that use of automated systems has not replaced the need for basic knowledge and skills, including hand flying, instrument cross-check, system knowledge and maintaining situation awareness and aircraft state awareness.

3.5.1.4 Consequences for Flight Path Management

To summarize this section on pilot knowledge and skills, the WG identified several themes related to pilot knowledge and skill vulnerabilities. As a result of these knowledge and skill vulnerabilities, the flight path management task may be compromised in the following ways:

- Knowledge Issues: Pilot knowledge of the basic airplane systems is not as detailed as in the past. The WG recognizes that in the past, information was trained that was not needed or beneficial. The concern is that depth of systems knowledge may now be insufficient, and this may be operator dependent.
- Practice and Exposure: Long term use of FMS-derived flight path trajectory without the need to critically assess or intervene may atrophy the skills needed to anticipate, monitor and react.

[41] See Appendix C for questions asked during structured interviews.

- Understanding of underlying systems: Procedures and training practices may emphasize the use of autoflight modes, procedural execution and selections rather than facilitate an understanding of the architecture, logic and algorithms of how those modes and selections relate to the flight path management task, from the pilot's perspective.
- Deviation and off-path management: Flightcrews manage or react to deviations and off-path situations in extremely variable ways, and training is often limited in this area. While this inconsistency is found within operations that are subject to the same procedural guidance and training program, the variation in practices observed are common across the industry.

As mentioned earlier, pilot knowledge and skills are acquired and maintained through several mechanisms, including selection, operational experience, informal information exchange, pilot training, pilot qualification, and others. Although each of these mechanisms is important, the WG scope specifically focused on pilot training and qualification.

3.5.2 Pilot Training and Qualification

Finding 12 - Current Training Time, Methods, and Content.
Current training methods, training devices, the time allotted for training, and content may not provide the flightcrews with the knowledge, skills and judgment to successfully manage flight path management systems.

This finding is based on data from accidents, major incidents, ASRS incidents, and interview data.

Figure 23 shows the accident and incident results from the issues related to training. The issues were originally developed to relate to the design, training, and use of automated systems. However, when reviewing the safety event reports, the WG identified all reports that noted training issues for flight path management and then separated them into deficiencies with training related to the use of automated systems (e.g., training for mode awareness) and other training deficiencies (e.g., manual handling). Results for both categories are presented in the figure.

Interviews with training organizations and instructors also suggest that there are improvements that can be made in flightcrew training and qualification. The following sections organize the interview results into: design of training and qualification programs; content of programs; and training for manual and automated flight operations.

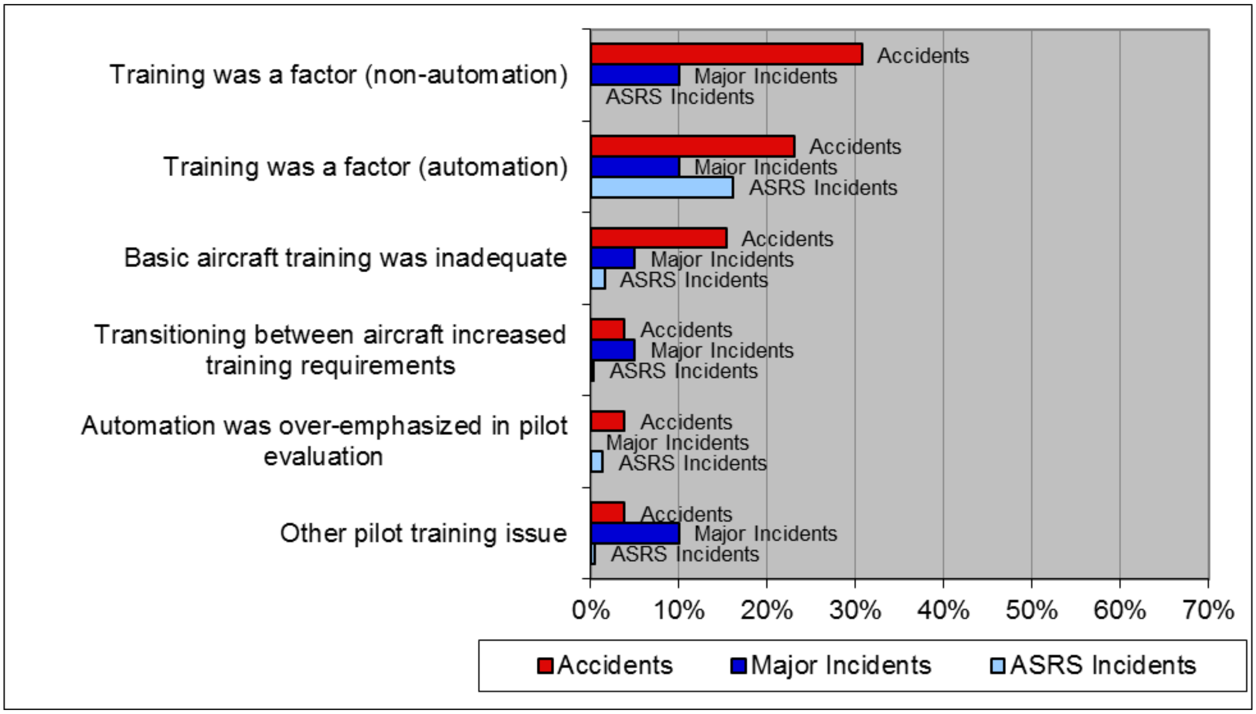


Figure 23. Training Related Issues.

3.5.2.1 Design of Training and Qualification Programs

Operators design their training programs based on defined objectives. The structure and organization of training programs for different operators vary depending on a number of factors, including the quality of instructional methodology, previous experience of trainees, type of operations, type of training devices used, and training philosophy. The programs also differ based on whether they are being developed for a 14 CFR Part 121 operator (under the AQP regulation or under the traditional approach to training (14 CFR Part 121 Appendix E, F and H)) or operating under other Parts.[42]

Notwithstanding regulatory requirements and FAA approval, operators determine the extent of training based on operational needs, specific airline history and fleet requirements. Some operators contract with training centers which can reduce the initial course development costs. When training centers are utilized, operators must be diligent to ensure training delivery content is consistent with their approved training program.

Currently, some manufacturers have arrangements with non-affiliated training organizations that develop and market aircraft-specific training courses. This has a great appeal as it reduces the cost of the course development for the manufacturer but it means that the control of the material is often in the hands of the training providers and not the manufacturers.

[42] Note that the scope of the working group includes some operators under the authority of Part 135 and Part 91 Subpart K.

Many pilot skills are developed over time and, as with any skills, they need to be practiced to be maintained at the appropriate level of expertise. Intervals of practice to maintain skills are dependent on initial skill level and type of skill (e.g. visual flying skills are more durable than instrument flying skills), along with decisions to provide the resources in time and money that allow the program to build in time for practice as necessary to supplement the practice pilots get when they are flying the line. Although there is more emphasis on training for use of flight path management systems, especially mode awareness, most training courses don't have time to teach all aspects of normal line operations. Many training programs and trainees are focused on passing tests/checkrides. This may be effective if the tests/checkrides are comprehensive and well designed, but often there is a risk that the training programs do not adequately assure that pilots fully experience the operational and systems interface.

Several challenging areas were raised during interviews related to training program structure and organization. The most prevalent challenge described was that of balancing the program focus on developing and maintaining skills using the automated systems and those related to flying and making decisions without those automated systems. Other challenging areas mentioned are including enough time:

- For pilots to make mistakes and find their own way out.
- Teaching decision making and command judgment.
- To train departures and arrivals, including realistic line-oriented scenarios.
- For additional training to hone specialized skills or specific events beyond the minimum standards. This training would be accomplished separately from recurrent and qualification training, where the pilot is not under pressure to pass a checkride.

Operators make trade-offs to keep the amount of training required within a reasonable budget while ensuring that the required levels of knowledge and skills are provided to the pilots. The WG heard many comments during interviews about increases in required knowledge and skills and the challenges in incorporating those new knowledge and skills in training while continuing to meet basic requirements and address any operator-specific topics that arise through safety data review. This becomes even more difficult when introducing new systems and procedures resulting from new technology and Next Gen operations.

In addition to the concerns about additional knowledge and skill requirements from NextGen operations, some believe not enough training time is spent training known problem areas identified by LOSA, ASAP, or other operational data. This is because training courses are already filled with required maneuvers or other topics that may not be as highly related to the safety data. Introducing new material would eliminate current course content or reduces the time spent on a particular topic. It is difficult to make such trade-offs and every organization has their own strategies for defining their requirements and developing programs that balance them to the extent possible.

Concern was expressed that there was not enough time allocated in training programs to develop skills and to convey the desired depth of knowledge of topics such as the underlying logic and features of FMS and other flight path management systems. Time constraints are exacerbated by the need to maintain proficiency on classic procedures, such as multiple types of non-precision approaches (recognizing that pilots will only be checked on approaches they are authorized to perform).

The WG recognizes that the amount of training time is not the only consideration – the training methodology and training devices[43] used are very important as well. One operator described frustration that they have training time that goes far beyond the minimum, yet pilots still have issues understanding some of the systems and operations.

The WG was told that some training providers wrote their own training manuals because some manufacturers do not provide them. In such situations, the training manuals were not updated as modifications were made to the new airplane. After several years, the training center used manuals and procedures that were outdated. The result was there were some significant differences between the airplane systems and procedures taught to the students during training and the actual airplane and procedures they flew in line operations. While improvements have been made, some training providers still write their own manuals and they must be kept updated. The air carrier is responsible for the training program, and the regulator is responsible for oversight to assure that such situations do not occur.

Another challenge is how to reach at least the required level of proficiency during the training program, and realizing that much knowledge and skill development will continue after pilots begin flying the line. Other decisions must be made about how to conduct the initial experience of pilots as they start line operations. Approaches vary related to the qualification of who flies with the pilots just out of training and how long they continue with them. A concern raised about including too much on-the-job training in lieu of simulator training was that pilots do not have many opportunities to learn what NOT to do during actual line operations. The line check airman does not have the same control over the learning environment during actual line operations as a simulator instructor has in a simulator.

A recent study by Boeing (Holder 2013) on worldwide airline pilot perspectives on training effectiveness revealed that FMS training can be improved to address operational situations and tasks encountered in operations. In the first 6-months of flying their current type airplane, 61% of the surveyed pilots reported multiple encounters of difficulty completing tasks using the FMS during line operations while only 25% said they were adequately prepared. Just over 42% of the pilots surveyed believed that their FMS training for the type airplane they are currently flying was minimal and stated there was room for improvement or it did not adequately cover operational use. The survey also showed that the operational FMS learning and "comfort" acquisition occur on the line, with 42% of the pilots reporting they learned the operational use of FMS during line experience and 62% reported it took 3-12 months of line experience to obtain comfort with using the FMS. Areas of specific FMS training improvements recommended by the pilots surveyed include:

- Automation surprises,
- Hands-on use in operational situations,
- Transition between modes,
- Basic knowledge of the system, and
- FMS programming.

[43] For the purpose of this paper, the generic term "training device" will be used to cover all training devices, to include table-top training devices, fixed-based simulators, and Full Flight Simulators with motion.

3.5.2.2 Content of Training and Checking

The knowledge that pilots need to know to effectively operate the airplane and perform all related operations makes up the content of a training program. This content is focused on building proficiency through providing the necessary knowledge and developing and maintaining the necessary skills, including skills for identifying, accessing, and using appropriate information. This is the information about the airplane, systems, policies, procedures, and operations that it takes to develop and maintain proficiency. This knowledge is the basis for the training and checking process whether that knowledge is explicitly or implicitly defined. The training programs are developed based on these criteria, together with information from instructors and the appropriate regulations.

Trainers consistently reported that training often addressed how to select and manage a “pristine” operation with limited efforts to address real world issues such as managing deviations and regaining on path operations when off-path. This means that training may focus on the procedural or “button pressing” issues concerning how to configure the autoflight systems (rather than understanding how the autoflight system works and how it relates to flight path management).

The emphasis is usually on training the separate tasks associated with how to interface with automated systems, instead of training the big picture, which is Flight Path management. The pilots are trained how to interface with the different pieces of the system (e.g., how to push buttons, program FMCS, use different modes), but spend little time during training practicing flight path management in real world operations where they are required to put it all together. Flight Path Management training needs to be developed and delivered as an overarching philosophy and pilot competency that includes training in:

- Overall flight path management philosophy,
- How each individual component works and how it relates to flight path management,
- How to interface with the individual components, and
- How to use the automated systems together to help manage the airplane’s flight path.

Trainers also expressed that training programs tended to concentrate on the ability to perform discrete maneuvers until out of the training center and into actual line operations. This means that crews are conditioned to manage a “by-the-book” pristine flight path task. While this has obvious benefits regarding training efficiency and does reflect a large proportion of the actual flight tasks, it does not fully prepare crews to address deviation management, off-path operations, or dealing with unexpected or non-routine events during line operations. Unfortunately, these otherwise benign off-path or unexpected situations occur frequently and can rapidly degenerate into high risk situations when mismanaged.

Several other points were raised during interviews that are related to training program content. The following list includes some of those points.

- Pilots are being trained on the steps to take to operate the systems, and not provided the training on how the systems work. This may contribute to errors.
- Information on how the systems work is not always explained or provided by the manufacturer.

- Training programs tend to focus on expected situations and may not provide emphasis on appropriate pilot actions outside of these norms. Therefore, pilots may not be prepared for unexpected or non-routine events. Therefore, they may not be prepared for unexpected or non-routine events.
- Recency of experience should be used to determine some aspects of training content. For example, if pilots have not recently conducted a certain type of operation in line operations, they may need to address it in recurrent training.
- Scenarios need to be realistic and reflect operational reality (e.g., air traffic intervention in arrivals and approaches)
- Subtle or partial failures are not often included in training scenarios.
- FMS and FGS systems are complex. Documentation and training materials may not sufficiently explain the underlying logic, intent and integration of the systems. Training tends to focus on using the FMS to perform certain required tasks and checking events rather than a full understanding of the system. Similarly, FGS modes can be complex and more attention needs to be devoted to the underlying logic.

3.5.2.3 Training For Manual and Automated Flight Operations

There has been an increased emphasis and improvement in training for use of automated systems, especially in mode awareness and understanding. However, there are still vulnerabilities in pilot knowledge and skills related to the use of these systems.

Some trainers expressed concern that the use and reliability of automated systems have caused some erosion of traditional manual flying skills. They described manual flying as including the ability to perform normal flight maneuvers without the use of autopilot; the ability to recognize unexpected autoflight deviation and intervene accordingly; the ability to recognize in-flight energy or flight path deviations that might lead to an upset condition and intervene timely and appropriately; and the ability to recover from an upset condition. (See discussion on manual flight operations in Section 3.2.2.)

They said that training and checking programs should counter this erosion in skills by including realistic events with varying combinations of automated systems and modes, including emergency situations with degraded control laws. Many trainers expressed concerns that their programs taught crews how to “fly” the autoflight systems rather than how to use the automated systems to “fly” the airplane. Pilots learn automation by “watching things happen” in fixed base trainers. When they have to actually hand fly, they are accustomed to watching things happen, and reacting, instead of being proactive.

Review of the safety reports and interviews show that manual flying skills are required when aircraft flight guidance systems or portions thereof, are deferred or fail. Several instances of such failures in modern transport category aircraft have required pilots to revert to basic flying and raw data instrument skills to fly an instrument approach in low visibility conditions to safely recover the airplane, yet it was often mentioned that these skills are not included in many of the training programs discussed in interviews.

An area that impacts the skills, knowledge, and training of pilots for manual flight operations is the type of operator policy for the use of automated systems. As discussed in 3.3.2, the WG was told about a broad range of approaches to such policies. Some operators described that their policy is for pilots to use the automated systems as much as possible. Such a policy affects the amount of manual flying skills practice (including the related decision making skills) that pilots will get during operations due to use of automated systems at most times. This means that to develop and maintain those basic piloting skills, there needs to be a different strategy implemented in the initial and recurrent training programs.

Some operators have policies about when to use automated systems that leave the decision open to the pilots. Such an operator has different challenges, since such a policy allows for a broad variety of performance. Therefore, decisions need to be made about what skills will be explicitly developed and maintained during training versus operations. The impact is also related to the scope of operations conducted by the operator, and may be related to recency of experience for long-haul pilots.

The WG was presented with one overseas case study that taught the use of the flight path management systems in an innovative way. This training concentrated on developing the flight path management skills using manual flight from the outset and then introduced the autoflight systems in basic and then more managed modes in order to achieve the same flight path tasks. The study compared the way that participants dealt with off-path and automation “surprises” with a control group that had completed a more traditional training program. The study showed that the intervention group was able to anticipate, recognize and take much more timely and appropriate interventions than the control group. While this study cannot be generalized to the industry as a whole, and did suffer from some limitations, it does demonstrate the potential of this type of approach and need for further research and investigation in the area.[44]

3.5.2.4 Summary of Pilot Training and Qualification

In summary, training programs (content and structure) may not completely prepare pilots for the flight path management task due to the following reasons:

- Syllabus requirements. Traditional FAA regulatory requirements (those other than AQP) tend to focus on performing discrete maneuvers correctly rather than real-world issues affecting the flight path management task. Advanced Qualification Programs are commonly implemented among the airlines. These programs are objective based and data driven rather than a regulatory defined, hours based, training program. Ideally, AQP programs allow airlines to tailor training programs to match their pilot populations and unique needs and objectives. However, even with the ability to tailor these programs, the WG data showed that some training programs, including some Advanced Qualification Programs, may not cover all the knowledge and skill sets considered essential for pilots.
- Variation in practices. There is wide variation in the training practices applied to establish the skills associated with the flight path management task, and may result in inconsistent performance.
- Limited training. Many training programs provide limited training in flight path and energy management during simulator and ground training. Training is also limited on how to handle known “automation surprises” and unknown situations.

[44] This approach is proposed for the A350 – see Flight Global article about A350 training: http://www.flightglobal.com/blogs/learmount/2012/09/airbus-takes-pilots-back-to-ba.html

- Unstructured training. Many training programs train pilots how to interface with the CDU but may not address the full use of onboard systems for flight-path and energy management until conducting line operations. This includes the understanding of flight path management system behavior and partial failures. As line operations cannot be controlled, the training received is necessarily less structured and more variable than that which would be presented in a training center. In many cases the pilots train themselves during unsupervised line operations.
- Deviation and off-path management. The WG 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 flight path management training and address current operational threats and errors.
- Content of training. Training may not cover all the needed topics at the depth necessary.

3.5.3 Instructor Training and Qualification

Finding 13 – Flight Instructor Training and Qualification.
Flight instructor training, experience, and line-operation familiarity may not provide the required flight instructor experience and skills to effectively train flightcrews for successful flight path management. This will be especially important for future operations.

This finding is based on interviews with training organizations and instructors.

Many interviewed instructors stated they would benefit from better instructor training on how to teach the use of automated systems as well as instruction on the underlying principles and intricacies of how the automation works. While 14 CFR Part 121.414 is the foundation for instructor training requirements, it addresses the topic only in general terms. There is no supporting guidance for trainers on how to teach pilots how to use automated systems for flight path management.

Further research showed major differences across the industry in implementing recurrent instructor training, which may exist because of lack of industry standards, FAA guidance, and vulnerabilities of FAA oversight of existing instructor training regulations and instructor recurrent training. Improved regulatory guidance and better guidance for inspectors would provide better tools to develop and assess what constitutes a satisfactory training program to meet required instructor recurrent requirements.

A wide variation was found in the degree of instructor familiarity with line operations between, or even within, training programs. Ground and simulator instructors may not be current line crewmembers and their degree of familiarity with the operator's line operations can be extremely variable. Consequently, ground and simulator training may not adequately address "line" issues.

Some specific points from the interviews related to instructor qualification and training are included in the following list:

- Many airlines do not provide specific training for the instructors on how to teach automated systems. The instructors are prepared to teach students to interact with the automated systems, but not to teach the underlying system logic and effect on flight path management.
- Many instructors stated they would benefit from better instructor training on how to teach the use of automation as well as instruction on the underlying principles and intricacies of how the automation works.
- Instructors stated improvement is needed for training and developing instructor skills. The focus should be on developing the skills needed to be a good teacher or instructor.
- Instructors strongly recommended that airlines emphasize their policy for managing automated systems at check airmen and instructor meetings.
- During recurrent training, some training programs provide instructor evaluation recurrent training as well as line pilot regular recurrent training maneuvers. This includes regular maneuvers, LOE for next year and critique on instructor techniques, briefings, debriefings and experience in both seats.

3.5.4 Other Factors and Future Considerations

It is important for airline managers who design or administer training programs to understand regulatory compliance. This allows them to design their training programs to be compliant. However, many airlines do not formally train their managers (Fleet Captains, Training Managers, etc.) with respect to the regulatory and compliance process, including advisory circulars, rulemaking processes, use of the Federal Register, regulations, inspector handbook material, etc. Rulemaking training that includes the process and associated considerations is available by independent providers. In addition, the FAA offers some training regarding the air-carrier and FAA interfaces.

The rapid changes expected in future airspace operations will provide challenges for maintaining both pilots' and instructors' knowledge and skills.

3.6 Flight Deck Equipment Design

Current flight deck designs and retrofit solutions have incorporated many safety and operational improvements in recent years, such as Terrain Awareness and Warning System (TAWS) among others. However, retrofitting some new ancillary systems to the numerous existing aircraft has resulted in complexity from the pilots' perspective because the new systems may be added without fully considering consistency or compatibility with the existing flight deck design. Additionally, the highly integrated nature of some new aircraft flight deck systems has resulted in consequences for complexity from the pilots' perspective because of the interdependencies among systems and the quantity of information and system behavior.

Also related to complexity from the pilots' perspective, the proliferation of new technologies and operations contributes to the variation across systems, including variation in the flightcrew interfaces with the systems and the system functionality (which affects operations within the airspace; e.g., the manner in which different aircraft perform curved path transitions in en route airspace).

The following sections address these areas of complexity, integration and standardization.

3.6.1 Equipment Design Complexity and Integration

Finding 14 – Flight Deck Equipment Design.
Current flight deck designs have incorporated many useful safety and operational improvements through new systems and technologies. However, the data suggest that the highly integrated nature of current flight decks, and additional "add-on" features and retrofits in older aircraft, have increased flightcrew knowledge requirements and introduced complexity that sometimes results in pilot confusion and errors in flight deck operations.

Airplanes have a very long life, spanning several decades, and during that life span, there are changes in regulatory requirements, available technologies, and other factors that result in changes to aircraft. In this context and relative to flight deck design, the term "complexity" is based upon the AC 25.1302 discussion as having several dimensions.[45] Relative to the "level of integration," complexity is referred to here as a result of a system (or group of systems) that is characterized by an involved arrangement of parts, operations or interrelationships such that it is difficult to understand (in general) and difficult to analyze in the event of a failure. The tightly-coupled nature of many of these systems, with extensive dependencies among the components, is a key aspect of their highly integrated nature.

As discussed in section 3.2.4, complexity may contribute to vulnerabilities in pilot interaction and understanding of some automated systems. Some of the characteristics that make these

[45] AC/AMC 25.1302 discusses complexity as follows: "Complexity of the system design from the flight crew's perspective is an important factor that may also affect means of compliance in this process. Complexity has multiple dimensions. The number of information elements the flight crew has to use (the number of pieces of information on a display, for instance) may be an indication of complexity. The level of system integration may be a measure of complexity of the system from the flight crew's perspective. Design of controls can also be complex. An example would be a knob with multiple control modes."

systems vulnerable to pilot errors may be complexity, as opposed to simply the automated nature of the system.

Complexity from the pilot's perspective has been the result of several factors, some of which include:

- Systems such as the FMS in many aircraft were originally designed several decades ago and the pilot interface in many of the older designs does not incorporate current human-computer interface knowledge. An example (as discussed above in section 3.2.4.4) is that FMS programming errors are partially a result of the complexity in operating the interface as well as understanding the system's behavior and underlying algorithms.
- System integration in the flight deck is intended to aid the flightcrew for normal and non-normal operations, but may introduce complexity from the flightcrew's perspective. An added benefit is that the new systems may reduce training for some operations. However, the data suggests that new flight decks that are based on highly integrated modern avionics (versus the older federated systems) also increase complexity from the pilot's perspective of understanding the total system operation. For example and as discussed above in section 3.2.3, despite robust failure modes testing for any system design, the highly integrated nature of some systems makes it even more difficult for manufacturers and regulators to test for all potential failures or combinations of failures and subsequently identify the detailed procedures needed by the pilots. It is well understood that all possible failure modes cannot be identified. Nonetheless, operators reported that flightcrews require additional training on highly integrated systems to better understand normal system operation as well as system relationships during failure conditions. As explained in 3.5.2., the level of training required to understand some integrated systems may fall short.
- Aftermarket alterations are common occurrences in existing flight decks since the life of an aircraft can span decades and include many equipment retrofits. These alterations are done to accommodate new technologies (such as GPS and ADS-B), safety improvements (such as TAWS), and operational and airspace changes (such as RNP). These changes represent improvements in some manner but may be incompatible with the original equipment manufacturers (OEM's) system design philosophy and can result in an approach not intended by the original manufacturer. Manufacturers take great care in their designs with respect to a methodological philosophy and "add-on" systems may not integrate well into that design. This may negatively affect the coherence of the design from the pilots' perspective.

The topic of flight deck equipment design process was discussed extensively in the 1996 FAA report. As noted above, flight deck systems designers have become more proficient at integrating flight deck systems and generally, those designs are logical, more elegant and efficient. Aircraft systems are becoming more integrated for very good technical reasons (e.g., a few central processors rather than hundreds of individual computers). One result is that the source of a problem or consequences of a component failure are often non-intuitive.

However, the flightcrew is now faced with controlling the operation through a multitude of interfaces, some of which may be prone to error. Operators reported that the sheer number of operations and the complexity of those systems have inundated the flightcrew, particularly in high workload or non-normal conditions. Flightcrew manuals and checklists have expanded in an attempt to mitigate the technology growth, but operators now question the effectiveness of those efforts and reported that they are uncertain on what to do to help their flightcrew members cope.

That increase in crew workload can in part be attributed to new technology and changes to airspace operations, each of which can be significant contributors to new flight deck system designs. Flight deck system design is uniquely affected by new operations such as RNP Authorization Required (RNP-AR) which are creating new avionics system requirements, new automation requirements, and subsequently adding complexity to flightcrew procedures. For example, stringent airspace requirements (low RNP values) have altered navigation system availability and integrity requirements that were not previously considered necessary beyond the current navigation system designs. Subsequently, flightcrew workload has increased in the form of additional procedures to perform the operation as well as monitor system performance during the respective operation.

Such new airspace operations tend to alter crew procedure requirements, particularly in cases where flightcrew procedures are required to mitigate perceived system shortfalls. In addition to special operations like RNP-AR noted above, RNAV departure and arrival procedure designs are becoming more complex. Instrument procedure designers have become increasingly creative by combining multiple components (such as en route transitions, runway transitions and others) onto a single procedure. In addition to adding more components and therefore complexity to the instrument procedure, the flightcrew is now increasingly exposed to potential flight planning errors because of FMS logic and an unintentional omission of transition waypoints. Such unintended consequences then become a flightcrew and Air Traffic problem. The flight deck system designer's new task then becomes one of exploring ways to accommodate the new airspace operations in the flight deck while maintaining acceptable crew workload and allowing recognition and management of flightcrew errors.

An interesting alternative that might appear counter to the theme that "complexity is bad" is the concept that a system "backplane" may require even more complexity so that the equipment design is simplified from the flightcrew perspective. For example, modern fly-by-wire system architectures are extraordinarily complex yet the flightcrew interface is simple. Notwithstanding the economics of engineering and producing such systems, the lesson here is that system design should more creatively consider the human operator. Therefore, the resulting architecture could focus not only on the system operation but also on the flightcrew's ability to operate the system and to easily and correctly maneuver through normal and non-normal events.

3.6.2 Equipment Design Standardization

Finding 15 - Flight Deck Equipment Standardization.
There is significant variation in flight deck equipment design, in both flightcrew interfaces and in system functionality. Such variations can have important consequences for flightcrews (pilot error, increased training time, negative transfer of learning, etc.) and airspace operations (potential differences in the flight paths within the airspace), especially considering future airspace changes. Although standardization can reduce such variations, comprehensive changes to standardize existing equipment may not be realistic and complete standardization may inhibit advances in technology.

This finding is based on interviews and WG expertise.

The term “standardization” can obviously apply to many aviation topics: terminology, phraseology, training, flightcrew procedures, regulatory practices, and many others. The Terms of Reference specifically tasked the WG to address variation in respect to equipment design. Some of the above standardization topics are also related to the WG study areas and therefore is addressed in other sections of the report.

Variation in aircraft equipage has been a point of interest within the industry for a very long time and it frequently surfaces when cost of equipage, aircrew training costs, or flight path differences are the topics of discussion. Most will agree that variation in flight deck systems is typically the result of continual advances in technology. On a positive note, variation in the flight deck has been created by a host of technology enhancements that have improved the flightcrew’s ability to function (location of controls, use of color coding, consistency of display formats, automated checklists, etc.) or improved safety operations (EGPWS, TAWS, and other alerting).

However, there have also been negative consequences of change and the resulting variation. For example, operators report that some flightcrews require increased training time associated with learning aircraft with corresponding system functions that operate differently than on their previous model. This issue was a frequent comment by those operators which allow frequent movement between models. Other operators that consider this a threat have opted to segregate those aircraft with unique or different FMSs and have dedicated crews to fly those aircraft. Such action is common in the industry today and serves to alleviate the threat and enhance safety.

Interestingly, one segment reported that they would like to see more flight deck compatibility across the industry since today’s pilot force is much more mobile than in previous years. Flightcrews migrate between models and between sectors (major airline, regional, business, etc.) and from their perspective, more commonality could significantly reduce training costs for all operators. As a result, OEMs are sometimes encouraged by operators to design a new airplane model or variant (and its flight deck systems) similar to previous models. Similar follow-on designs reduce the operator’s cost of training for the new aircraft as well as differences training from existing aircraft. It may also provide an avenue for type rating relief. However, this approach can also be a disincentive to introduce new technologies and design characteristics in an effort to limit the training impact.

The data on variation also suggests that there are higher frequencies of pilot error resulting from negative transfer of learning between multiple versions of the same function. Variations of the same function are highlighted in fleets that have multiple versions of the same FMS. Some operators have several different combinations of FMSs and software on the same airplane type. As a result, a flightcrew could fly several legs in one day and use different FMSs with different versions of the software on each leg. This taxes flightcrews to ensure they are operating the system correctly and when combined with the associated aircraft systems differences, higher rates of confusion and error can be expected. Some operators understand these operational and training issues and have subsequently taken aggressive action to address problems brought about by variation by standardizing the path management hardware and software within their fleets.

Operators also reported that technology advances have orphaned some system versions with no practical path to upgrade the older hardware. Avionics and aircraft manufacturers have endeavored to design and implement state-of-the-art equipment and sometimes will no longer support the older versions. As a result, operators can be faced with expensive changes to their existing aircraft to standardize with new deliveries of the same model. Some operators have managed to upgrade their older aircraft while others face the variation within their fleets and the subsequent flightcrew-related issues noted above.

Variation in aircraft systems can also have important effects on airspace operations. Air traffic service providers have reported many cases of traffic conflicts because FMSs do not perform consistently across all models in terms of how they function in the airspace. To support their position, several studies have recorded flight tracks and demonstrated that dissimilar aircraft will fly lateral and vertical curved path transitions (fly-by waypoints) differently. Similarly, various aircraft may treat the path following a "fly-over" waypoint differently or turn early to intercept a course leg, all of which results in a non-predictable flight path and complicates Air Traffic's task of providing separation. The cause of such path management differences is well known and emanates from slight variations in methodologies among Original Equipment Manufacturer (OEM) and FMS manufacturers.[46] Operators also play a role in this aspect since some of the variation is a result of specific customer requests. Nonetheless, as airspace requirements become more precise with RNP RNAV, it is this WG's position that flight management and flight guidance systems should control the aircraft consistently with respect to trajectory so that the air traffic service provider can expect a consistent and predictable aircraft behavior.

Variation in how aircraft comply with flight paths has also generated frequent discussion on flight management standardization from a regulatory perspective. Subsequently, regulators have proposed (for discussion) concepts to mandate standardization not only in function, but form and fit as well. Complete standardization may not be realistic, but as noted above, some operations could be considered for a degree of standardization such that:

- Flight path trajectories within the airspace are consistent across aircraft,
- Potential for crew error/confusion due to negative transfer of learning from one aircraft to another is reduced,
- Training costs are reduced, and
- Equipment costs are reduced by decreasing the quantity of part numbers, inventory, etc.

There are pros and cons to a regulatory concept but rigid standardization is seen as a negative influence on product discrimination and particularly technology advancement. The challenge is to discover the correct mix of guidance that addresses the adverse effects of variation noted above while allowing manufacturers to enhance the technology in their products.

3.6.3 Flight Deck System Design Processes

Design processes have increasingly incorporated HF expertise at some manufacturers with respect to increased HF involvement, formal incorporation of HF into the design teams and design processes, and early participation by the customers and operators. The flight deck design

[46] For detailed discussions of variation in FMS performance, see (Steinbach et al 2004), (Herndon et al 2005), (Herndon et al 2006), (Herndon et al 2007), (Herndon et al 2008), (Herndon et al 2009), (Herndon et al 2010), (Herndon et al 2011), and (Herndon et al 2012).

process at these aircraft manufacturers and suppliers has noticeably matured since the 1996 FAA report, as evidenced by greater attention to human factors and crew-centered design. Additionally, the crew-centered focus has also received greater emphasis on flight deck designs through regulatory and guidance material and through the certification process as well. For example, HF consideration in the design processes has been influenced by regulations and guidance material such as the following:

- AC 25.11A Electronic Flight Deck Displays
- 14 CFR/CS 25.1302 and AC/AMC 25.1302 Installed Systems And Equipment For Use By The Flightcrew
- 14 CFR 25.1322 and AC 25.1322-1 Flightcrew Alerting
- 14 CFR 25.1329 and AC 26.1329-1B Approval Of Flight Guidance Systems

However, concerns still exist about whether there is sufficient rigor of the design process, inclusion of appropriate human factors knowledge, and operator / customer inputs, especially within the smaller manufacturers and suppliers. The disparity in knowledge, experience, guidance material, and standardized design processes among organizations producing flight deck equipment suggests that crew-centered design "best practices" could be made more accessible to, and implemented in, those smaller manufacturers and suppliers which may not have the mature design processes as compared to the major manufacturers and larger suppliers.

Finding 16 - Human Factors in the Flight Deck Design Process.
Human factors expertise has been increasingly incorporated into the design process at most manufacturers, but is still inconsistently applied at some manufacturers. Furthermore, HF specialists may not exist in some organizations or are called upon (either in-house or at another manufacturer) to resolve or mitigate crew-centered issues that are discovered late in the design schedule.

Since the 1996 FAA report, Human Factors has experienced more influence on flight deck designs and noticeably at the larger aircraft manufacturers where HF has been well integrated into the design process at all stages. However, that same success is not apparent at the small manufacturers, both with respect to aircraft and avionics. For example, some manufacturers reported that HF specialists (if they exist) are called in to work "special projects" as opposed to being on the initial design concept team. Others reported that they rely upon the avionics supplier or test pilot expertise for an HF assessment. Consequently, some operators reported that their aircraft manufacturer could not explain the avionics design philosophy and some crew interface functions and subsequently referred the operator to the avionics manufacturer. In several cases, the manufacturer reported that the eventual design reflected the desires of one or more customers or flight test pilots and sometimes resulted in a design that was not necessarily well integrated into the overall flight deck operation. Some products were driven to relatively unique designs for each customer and the manufacturer's common design philosophy and principles were therefore not consistent. Also, in such cases the design rationale was sometimes not fully documented and only existed in the mind of the designer or avionics manufacturer.

Relative to the manufacturer's comment on flight test pilot input, it is important to note that human factors expertise should be combined with pilot experience throughout the design process. Although the two disciplines are frequently related and provide synergy to the design, they are quite distinct and should not be considered the same (although one individual may have both areas of expertise). The flight test pilot is an important part of the design process that can provide experience from the pilot/operator perspective. However, that expertise should not necessarily supplant a validated crew-centered concept. The 1996 FAA report noted that some design issues were the result of a strong flight test pilot or customer pilot preference. Although such events appear to be less prevalent now, some flight deck operations still reflect that influence.

Some smaller manufacturers also reported that they did not have adequate crew-centered design resource material to guide their designs. As a result, some equipment designs reflected a limited perspective on an effective human-machine interaction and interface. For example, the regional aircraft manufacturers reported that they would like to see data and / or guidance that would support their decision processes on flight path management. I.e., should more functions be automated to accommodate a desired reduction in training? Conversely, are there alternative approaches to integration and automation that might address issues like pilot error and the perceived deterioration of basic flying skills? Even though much literature exists on Human Factors and the importance of a crew-centered design, there are still many examples in aviation where manufacturers are producing equipment that does not necessarily reflect an effective human-machine interaction. During interviews, it was obvious that manufacturers have their own (sometimes limited) references but not necessarily a robust source of recommended practices for flight deck and equipment design. A frequent question was “where do we go for the best guidance?” Therefore, an accessible repository of references could be developed that identifies the core documents relevant to “recommended practices” for human-centered flight deck and equipment design.

Rapid advancements in technology further complicate the information resources and both directly and indirectly affect criteria, standards and the equipment design processes. In recent years, the aviation industry has experienced numerous innovations, some of which have been effectively incorporated into flight decks to enhance safe and efficient flight operations while others are still in question. Rapid advances have created pressure on regulators to “keep up” with appropriate guidance to ensure that implementations meet safety requirements and the intent of the desired operation. Unfortunately, the very conservative nature of the regulatory process has led to a perception by manufacturers that the regulator strives for a “lowest common denominator” perspective and in doing so severely limits the potential benefits of technology. For example, when a new feature is fielded, the true benefit of the feature may not be fully known or developed until some in-service experience and operator feedback is obtained. Subsequently, further advances in the technology are required to realize the full benefit. Often however, the guidance may be based upon the original implementation and may not accommodate further development until the guidance is changed. That obviously impedes benefits to the operators and the industry as a whole.

A recent effect of new technology on equipment design processes has been felt by the large transport category aircraft manufacturers. To better respond to customer requests and expertise, manufacturers are increasingly inviting higher levels of design participation by operators. Although frequently seen as a positive, customer involvement may sometimes alter or compromise the manufacturer’s design philosophy. During such cooperative design activities, the manufacturer is sometimes asked by customers to provide new “glitzy” features and functions which have been recently implemented by business jet or general aviation manufacturers. Cases were reported where independent supplier marketing efforts to operators sometimes resulted in pressure by the operator on the manufacturer to implement the new feature. Unfortunately, the operator may not fully understand the implications of the requested feature on the overall system integration or the potentially adverse effects on the flightcrew interface and subsequent operational considerations.

Other factors relating to design process considerations involve the changing pilot force. For example, operators and manufacturers believe that pilot experience and proficiency are declining globally. Worldwide, ab initio pilots are being introduced into transport category flight decks more frequently and operators report increased training loads and dropout rates. Operators report that the pilots entering the workforce have high levels of computer skills but some may not have the robust aviation background and aeronautical experience that current pilots have from actual flight experience. The manufacturers understand the changes in the pilot workforce but may not yet assess their flight deck designs to address these changes. In the interim, some of the proposed mitigations include proceduralization (by some operators or manufacturers) and increased automation of tasks and functions (by some manufacturers). Each of these mitigations has potential for unintended consequences.

English language proficiency has been a long-standing issue but English–as-a-second-language (ESL) is becoming more prominent as the transport industry expands in rapidly developing areas of the world. Aircraft manufacturers reported that potential customers had requested ESL considerations for their future fleet. As a result, some manufacturers are considering whether they should go further in their designs to accommodate ESL operations. English remains as the international aviation standard for traffic operations, but ESL considerations within the flight deck in the form of instrumentation placards, procedures and checklists potentially could reduce pilot confusion, error, and training time for ESL operators. However, this would introduce other significant vulnerabilities. Manufacturers and regulators expressed concern that it would be unmanageable to have multiple languages in the flight deck, and it would be difficult to decide what language to choose, in many cases. Many operators have multiple nationalities in the flight deck, so the language issue would still be a major problem.

Finding 17 – Knowledge and Skills of Flight Deck Designers.
The WG found different definitions of "human factors specialist" being used within the aviation industry and among regulators. In some cases, formal training or background in relevant areas was required (e.g., experimental psychology, industrial engineering, human/computer interaction), and in other cases, human factors expertise was related primarily to experience in piloting and flight test.

This finding is based on interviews and WG expertise.

The introduction of new regulatory requirements, (such as CS 25.1302, AC 25-11 Electronic Displays, updated 14 CFR 25.1322 and 25.1329), together with the widespread recognition of the importance of pilot performance to safety and efficiency, have led to an increasing amount of attention and resources being devoted to human factors as a discipline. All manufacturers stated that they include human factors expertise on design teams, but the WG saw varying amounts of authority, participation and expertise.

Many manufacturers use a combination of engineering designers, human factors specialists, engineering test pilots, and airline standards, training and technical pilots that work in parallel to develop and validate designs in mockups and engineering simulators to provide the link to the operational world. But the WG also found that, in some cases, design decisions continue to be based on an engineering design perspective, rather than how a flightcrew will use a system in an operational environment. This is likely to be a contributing factor to the difficulty pilots have in understanding the autoflight modes. Likewise, pilots express numerous concerns about the difficulty in using current flight management systems, and they often mention that these systems appear to be designed without considering important flightcrew operational needs, which leads to an increased potential for flightcrew errors.

3.7 Air Traffic and Airspace Considerations

Successful flight path management is done within the context of the airspace system, so airspace and air traffic integration is an important consideration. Implementation of RNAV and RNP-based procedures is expanding, with significant safety and operational benefits. As discussed in Section 3.1, PBN operations are a key component of the evolution of the NAS towards NextGen operations. RNAV and RNP procedures offer safety enhancements along with new levels of flexibility to negotiate terrain, airspace, and environmental considerations. More RNAV procedures, with and without RNP segments, are being developed each year to support PBN implementation.[47]

However, some of the RNAV arrival and departure procedures have been designed with characteristics that have proved challenging for the flight management system to accommodate and the pilots to fly. In this section, findings are provided on airspace/air traffic procedures, and on knowledge and skills of air traffic personnel, particularly with respect to consequences of changes in airspace operations on flightcrews and on aircraft.

3.7.1 Airspace/Air Traffic Procedures

Finding 18 - Complex And Unfamiliar Instrument Flight Procedures.
Complex or unfamiliar airspace flight procedures can be confusing and lead to errors involving flight path management. In addition, airspace design and associated airspace procedures are not always compatible with aircraft capabilities.

This finding is based on incident and interview data and WG expertise.

New arrival, departure and approach procedures based on performance-based navigation are increasingly being implemented within the NAS. These procedures have significant potential benefits for safety and flight operations, including reduced radio congestion, more efficient routing more efficient airspace utilization, and more operational value from aircraft equipage. Those benefits must be achieved through procedure design that takes into account pilot workload, controller workload, a wide range of aircraft capabilities and other factors. Although RNAV procedures have existed for many years, RNAV SIDs, STARs and enroute segments are becoming more common, complex and varied to take advantage of the benefits PBN can provide.

For ease of implementation, many new and amended IFPs are designed to fit within the existing airspace structure constraints which have evolved, usually incrementally, to safely meet the competing needs of various users. Efforts to optimize new procedures by leveraging aircraft capabilities are restrained by mixed equipage environments and existing airspace restrictions, resulting in additional complexity.

Implementations of airspace changes differ dramatically in degree of difficulty. Major airspace redesign projects are multi-year, multi-million-dollar propositions with uncertain outcomes due to legal and regulatory requirements, including environmental (especially noise) considerations.

[47] Federal Aviation Administration. (2013). *NextGen Implementation Plan 2013,* www.faa.gov/nextgen/implementation/plan.

The new designs are intended to optimize the integration of arrivals and departures, creating altitude "windows" (constraints both above and below at a particular waypoint).

IFP design complexity and data depicted on charts have tended to increase. Multiple lateral track transitions, altitude constraints, and airspeed restrictions can add complexity and tax automated system, aircraft and flightcrew capabilities. Complex procedures may require coupling to the autopilot and autothrust systems, reducing opportunities for manual flight operations. An example of a complex procedure with multiple constraints and short leg lengths is shown in Figure 24. Note: since this procedure was originally published, it has been revised to address some of the concerns reported by pilots.

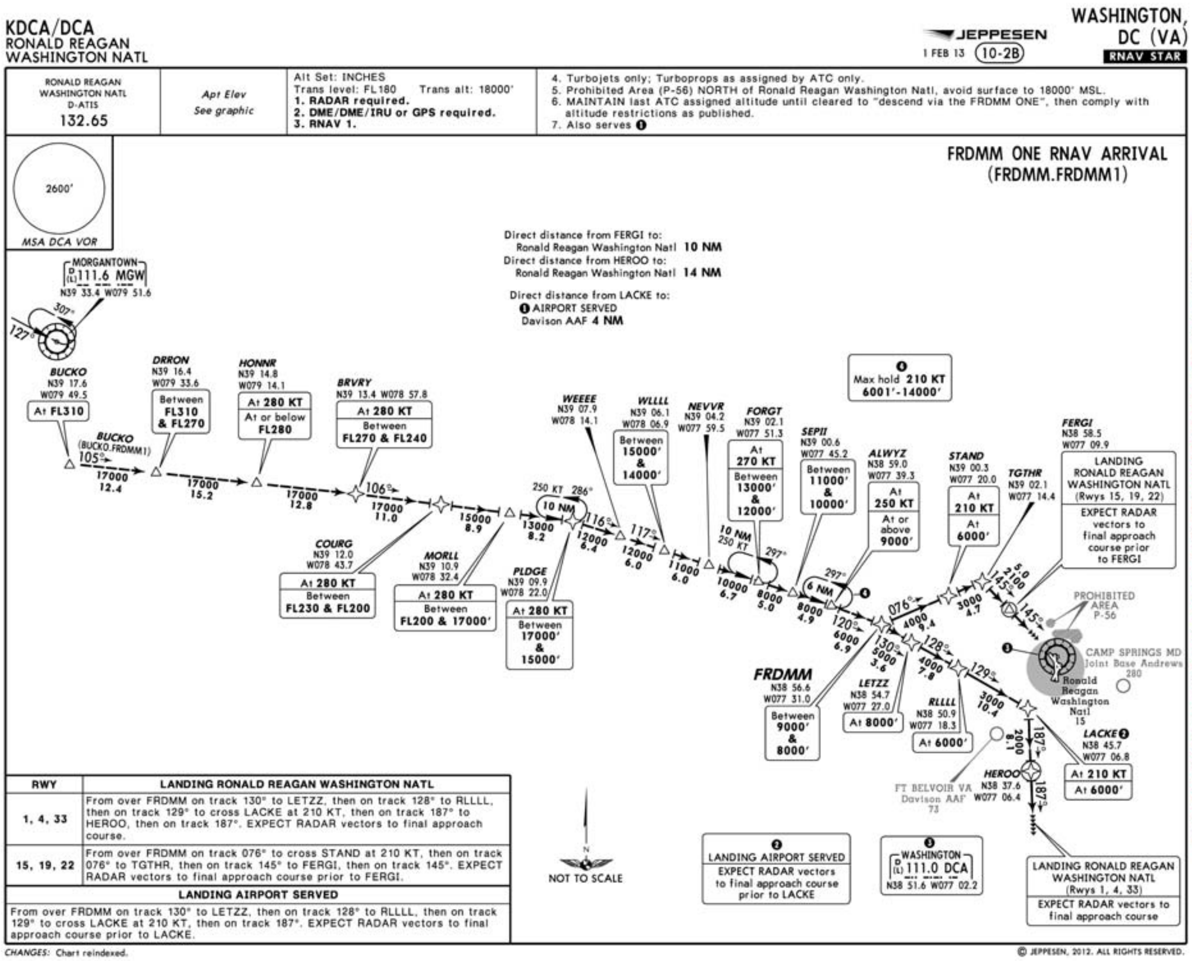


Figure 24. RNAV Arrival Procedure with Multiple Altitude and Speed Constraints.

These complex procedures provide great flexibility for air traffic personnel to make full use of airspace, but it is new to many pilots. The WG was told in the interviews with pilots and training organizations that pilots get relatively little formal instruction on these new types of procedures, particularly SIDs and STARs, which used to be simpler procedures. Familiarity with the new procedures typically is gained through operational experience, although some operators have found that extensively briefing the pilots on new, complex procedures can help reduce initial errors. In addition, company procedures and guidance vary widely among operators on how and when pilots should brief profile descents.

A recent issue of NASA Callback[48] identified that ASRS receives a significant number of reports every month related to difficulties with RNAV arrival procedures. Examples of reported issues include:

- Complexity of RNAV Optimized Profile Descents (OPDs),
- Flightcrew workload,
- Aircraft system compatibility or capability,
- ATC familiarity with aircraft performance and requirements, and
- Procedure interruption and phraseology.

Chart clutter characteristics are nebulous; most users will only agree that they know it when they see it and, when present, it's a problem. Based on interviews and other inputs provided to WG members, much of the "chart clutter" is additional data required to accurately convey the procedure design. Sometimes it is difficult to distinguish when the complexity is due to procedure design or the depiction of that procedure on a chart (or some combination).

Complexities also exist within conventional procedures. For example, in some cases, pilots conducting Instrument Landing System (ILS) approach procedures with numerous step-down altitudes may have assumed that, when they were within the service volume of the ILS and cleared for the approach, relief from further minimum crossing altitude requirements was provided by the electronic glideslope. In most cases this is true; however, minimum altitudes were imposed on approach procedures to facilitate air traffic flow that could result in the electronic glideslope being below the minimum altitude(s) within the ILS service volume. Chart depiction, procedural design and aircraft automation assumptions may be contributing factors to the misunderstanding.

In the profile view of an Instrument Approach Procedure, a flight path may be depicted on the chart that inadvertently gives the impression that the electronic glideslope is above the minimum crossing altitudes. Although different chart manufacturers depict glideslope in different ways, none appear to have intended to provide a scaled representation of the actual electronic glideslope relative to the minimum altitudes outside the Final Approach Fix in their profile views. A more accurate depiction of the electronic glideslope location and the glidepath imposed by the minimum altitudes could be one way to reduce misinterpretation.

This is just one example of a situation where the pilots are expected to mitigate any operational risk associated with instrument procedure design. Awareness training, consideration in procedure design, and the enhanced depiction of the electronic glideslope or glidepath with this real but infrequent scenario may benefit the pilot when encountering such procedures. Another area where pilot migration of risk is assumed is avoidance of obstacles in the visual segment of a procedure.

Airspace design and associated air traffic procedures and clearances are not always compatible with flight deck system capabilities, for a variety of reasons. These may include insufficient knowledge of aircraft capabilities on the part of the procedure designers. In addition, equipment differences exist in airplanes which affect the compatibility of airplanes and procedures. Flightcrew and airplane capabilities relative to Airspace/ATS requirements are not standardized and may not match air traffic services' expectations.

[48] NASA Callback, Issue 401, June 2013.

In addition to the complexity and feasibility issues mentioned previously, there are an increasing diversity of applicable criteria among the various controlled sectors, terminal areas, airports, and an increasing number of applicable documentations and rules. The multiple different types of procedures that are being implemented do not replace previous ones but are added to them, increasing the aforementioned diversity. This situation may result in increasing training needs inside the airline and potentially entails increasing risks of errors, especially for crews frequently operating in a large variety of environments.

To accommodate the increasing variety of needs at a given airport, the numbers of departure, arrival, and approach procedures also tend to increase. This can entail a long preparation time on the FMS to select and program the required procedure. For arrivals in complex terminal areas, selection and verification of some arrivals and runways can take more than one minute for the pilot working on the FMS (most often head down). Adding to the complexity, the names of some approaches on the FMS do not match the names of the approaches on the approach plates. Some airports are using tables to help pilots match approach names to available FMS approach selections to help save time and reduce error. In some circumstances, the required procedures cannot be selected in time. In addition, these multiple procedures also take up very limited FMS database memory.

Voice communications were described as so challenging in congested areas that the risk of confusion or omission is a concern. Therefore, airspace procedures are designed with the aim of reducing the need for voice communication, (and with RNAV operations, some notable reductions have been claimed).

Many of the issues discussed above are not new, and have been identified in previous implementations.[49] There have been many lessons learned about procedure design criteria, limitations of onboard systems and navigation system performance differences. At least in the case of PBN procedures, IFP developers must consider aircraft capabilities both by procedure design criteria and through established implementation processes. One concern that was expressed to the WG was that lessons learned from different implementations are not retained and used by subsequent implementations. There is no repository or other mechanism for making sure that the lessons learned, both positive and negative, are shared.

Aircraft onboard system capability, air traffic management automation, and modern airspace design offer the prospect of significantly enhanced operational efficiency and flexibility to the future aviation system. Before such technology is designed and implemented, industry and government must consider and incorporate measures to ensure that a human-centered design approach is used to develop the future aviation system. Such an approach takes into account human capabilities and limitations as well as aircraft capabilities, and allows the human operators to have the information and flexibility to manage the operation or intervene when required.

[49] Barhydt, Richard and Adams, Catherine. (2006) *Human Factors Considerations for Performance-Based Navigation*. NASA Technical Memorandum TM-2006-214531, National Aeronautics and Space Administration, 2006.

3.7.2 Air Traffic Personnel

<u>Finding 19 - Knowledge And Skills Of Air Traffic Personnel.</u>
Air traffic service personnel often do not have sufficient knowledge of how airspace procedure design and clearances affect flight deck operations and often lack knowledge of aircraft capabilities. As a result, the airspace procedures and clearances are sometimes not compatible with the aircraft operating in the airspace system.

This finding is based on interview data, WG expertise, and additional related reports.

Operators implementing new operations such as RNAV and RNP expressed concerns that air traffic personnel often lack knowledge of the new concepts and technologies. This comment was applicable to the management in the air traffic organization, to the personnel that design airspace and air traffic procedures, and to the front line air traffic personnel communicating directly with pilots.

As new procedures have been introduced into the airspace, concerns have been raised about knowledge of air traffic personnel. Specific concerns provided through voluntary reports include:

- Initial facility training does not adequately address issues such as aircraft flight profiles, the complexities of working differing types of aircraft, and procedures for vectoring aircraft off and then re-clearing them back on to the published procedure. Facilities are left without a clear understanding of the new procedures.
- Lack of training provided to controllers for handling the new OPD operations. OPD training is developed and provided by each individual facility. Facilities often have little to no knowledge base and are struggling to develop effective training. Only after implementation, and numerous real time issues, does the facility become aware of training needs.
- Lack of understanding by controllers and pilots as to expectations when alternate instructions, which are contrary to the published procedure, are issued. Examples include speed adjustments other than published speeds, vectors for additional spacing, and then resumption of the published OPD.

Potential consequences of insufficient knowledge of airspace procedure designers include airspace procedures that are prone to error, as discussed above. Potential consequences of controllers with insufficient knowledge or not understanding how clearances affect aircraft operations may result in undesired aircraft states.

3.8 Regulators’ Knowledge, Skills and Processes

The 1996 FAA report identified several areas for improvement in the knowledge, skills and processes within the regulatory system. This section presents the results of the WG analysis, first addressing knowledge and skills of the regulators, then addressing processes for approval of new technologies and operations.

Finding 20 – Knowledge and Skills of Regulators.
Regulators have improved their knowledge and expertise in human performance evaluation methods, criteria, guidelines, and research results; identification of research requirements; and operational knowledge about how the airplane will be flown, but the demand for such capabilities within the regulator is greater than the capabilities available.

This finding is based on interview data and WG expertise.

Regulatory personnel in both aircraft certification and flight standards are encountering new technologies and new operations that require knowledge of the technology and knowledge of how such capabilities affect pilot performance. In many cases, the FAA and other regulatory authorities and industry have increased the staffing of HF specialists and the overall knowledge of the staff in HF. Although there is great commitment by the organization and the individuals to address human factors appropriately, the demand exceeds the resources available, and that demand will continue to increase as new operations and new technologies increase.

In aircraft certification, the introduction of a new regulation to address design-related pilot error (Certification Specification 25.1302 Installed Systems and Equipment for Use by the Flightcrew, and 14 CFR Part 25.1302) and updated regulations and guidance material, such as 14 CFR Part 25.1329 Flight Guidance Systems, Part 25.1322 Flightcrew Alerting Systems, and AC 25-11 Electronic Displays, have resulted in increased awareness of, and attention to, HF issues in flight deck design and aircraft certification. Since 1996, the FAA has increased staffing of HF specialists, especially in Aircraft Certification. Industry, especially the design community, has also increased its staffing of HF specialists.

FAA regulatory personnel would benefit significantly from greater knowledge and expertise in human factors and, in some cases, from increased operational and technical knowledge about the airplane types for which they are responsible. Certification of modern automated aircraft and evaluations of flightcrews increasingly involve considerations related to the interaction between human(s) and machine(s). Members of teams who conduct certification evaluations, such as flight test pilots, inspectors, Aircrew Program Managers and Aircraft Certification Office engineers, are not necessarily trained human factors specialists, nor is human factors expertise necessarily part of these teams. This lack of training and expertise can contribute to insufficient quality and inconsistent regulatory results in the certification process with respect to flightcrew performance issues.

Certification flight test pilots and Aircraft Evaluation Group (AEG) pilots bear a large share of the responsibility for providing the flightcrew perspective during the flight deck certification process. Because of the lack of objective criteria and methods (or lack of knowledge of the methods and criteria that do exist) they must often base their assessment on subjective evaluation of the displays, controls, and system operation. While it is true that their subjective evaluation generally reflects good judgment, often it does not represent an objective, systematic evaluation of human performance for the target user population (i.e., the "typical" line pilot), nor does it always address the operational environment expected in service. Because most of these pilots are highly experienced, the results are generally very good. However, because experience varies, the results of the certification process may also vary. Manufacturers said that they saw differences and inconsistencies in certification results, depending on which individuals were making the decisions.

In addition, the regulator's pilots do not always evaluate some important aspects of flight deck operation from the perspective of a line flightcrew. They may evaluate operation for a pre-defined high-workload situation (such as one pilot incapacitated) but may not necessarily consider effects of pilot-flying/pilot-monitoring coordination used in service (e.g., monitored approach, International Relief Officer duties, etc.). As a result, designs are not always evaluated for flightcrew coordination in the operational environment in which they will be used.

Adequate training is not always available for the operational evaluations that AEG pilots are required to perform. For example, AEG pilots routinely are asked to provide operational judgments on characteristics such as non-normal procedures and related handling qualities when new or modified aircraft are proposed for US airline operations under Part 121. Yet, these same pilots may be lacking in recent experience on those types for which they are rated or they may not have experience with the aircraft in an operating environment using the new technologies or operational concepts. Also, AEG pilots have needs for required knowledge and skills in human factors similar to the certification test pilots.

The level of relevant technical expertise of inspector personnel in many Flight Standards District Offices is generally insufficient in HF. Unlike pilots in other aviation authorities worldwide, FAA inspectors no longer operationally fly in line operations even though regulatory authority exists for gaining valuable experience in this manner. In addition, inspectors may lack some specific relevant skills. For example, inspectors may not be familiar with operations (e.g., oceanic) or technologies for which they have responsibility. This may adversely affect their ability to assess and apply human performance considerations, even if HF training was provided.

Finding 21 - Regulatory Process for New Technologies or Operations.
The WG found the following concerns about the regulatory process:

- **Aircraft certification and operational approvals for new technologies take too long and are more burdensome than necessary.**
- **Standards and criteria to support new technologies sometimes are slow to be developed and approved.**
- **Regulators are sometimes reluctant to change existing policies and procedures to eliminate unnecessary, preexisting, requirements.**
- **Integration with existing systems and consequences from an operational/crew-centered perspective are not always sufficiently considered, possibly introducing unanticipated risks to the integrated type design or operation.**

This finding is based on interview data and WG expertise.

Technology innovations continue to occur at a fast pace and many have positively contributed to enhancing safe and efficient flight operations. However, there have been instances where a new "after-market" product or feature has been developed, approved via a Supplemental Type Certificate (STC) or field approvals, and installed on aircraft without a thorough understanding of the effects of the addition on a highly integrated flight deck. Similarly, there have been instances where some aircraft manufacturers have added functions to existing fleets at the request of customers which did not necessarily fit well into the original integrated flight deck design.

In addition, sometimes there is reluctance to change regulatory policy and procedures. Challenges to making changes include:

- Lack of stakeholder understanding of the rationale for existing policy/procedure (why was it put in place?).
- Making a safety case for the changes (perhaps against a higher bar) in an SMS environment.
- Stakeholders combining disparate issues and procedures (e.g., GPS is accurate; therefore I don't need a procedure that enhances situation awareness).
- Risk aversion and limited field of view.
- Document coordination and production/publication processes/timelines.

Future Considerations

The following information is provided as part of a Working Paper for the ICAO Twelfth Air Navigation Conference:[50]

> "Civil Aviation Authorities' personnel play an important role in support of safety assurance through the identification and mitigation of specific and systemic safety risks. Further, given their responsibilities and knowledge concerning operational approvals, participation of regulatory personnel is critical to successful planning and implementation of Performance Based Navigation (PBN) and other applications of aircraft technology. In order to properly accomplish these duties, regulatory organizations need to ensure proper investments are made to 1) adequately train their personnel using practical application scenarios of Aviation System Block Upgrade (ASBU) technologies and policies; 2) participate during implementation planning efforts; and 3) provide necessary oversight and assistance with ongoing operations."

The paper identifies that implementation of PBN across all phases of flight has improved operational safety and efficiency worldwide. It says that progress with global implementation of PBN has been hampered by difficulties of Civil Aviation Authorities (CAA) concerning operational approvals and continuing oversight. It also identifies that significant challenges remain for continued implementation. A collaborative decision making process and coordination among regulatory authorities, operators, service providers, and other stakeholders are essential to successful PBN implementations, whether a limited-scale trial or one broader in scope, as is the accrual of the requisite knowledge by representatives of each expertise. CAA personnel must

[50] United States (2012). "The Importance of Civil Aviation Authorities Involvement in the Implementation of the Global Air Navigation Plan," Working Paper for Agenda Item 6: Future Directions, Twelfth Air Navigation Conference, 19 to 30 November 2012, Montreal, Quebec, Canada.

receive a suitable amount of training to provide foundational and specialized knowledge for production of regulations, guidance materials, and approval mechanisms. Similar education and training is also necessary to properly evaluate and, as appropriate, approve various PBN (RNAV and RNP) operations.

Although the paper tends to focus on PBN implementation, the same concerns apply to other aspects of airspace changes, including upcoming changes to communication, surveillance, and air traffic management.

3.9 Data Collection and Analysis

In addition to the operational data analysis, the WG was asked to identify lessons learned from analyzing multiple data sources, as part of a prognostic (versus forensic) approach to safety data analysis. As the analysis progressed and findings were developed, the lessons learned were retained into a set of findings related to the data collection and analysis process. These findings also address two of the 1996 FAA report recommendations, Measures-1 and Measures-2.[51]

Since 1996, there has been an expansion of data collected beyond incident and accident reports through programs such as LOSA, ASAP, and FOQA. The WG spent considerable effort to collect, organize, and analyze the data available that was within the scope of the WG Terms of Reference. In these efforts, the WG experienced gaps in the accessibility of the data, in the organization of the data, and in the characteristics of data that hampered evidence-based assessment of the safety and operational issues related to flight path management and the use of related automated systems.

This section describes the lessons learned by the WG from these experiences and challenges. It is organized by these related topics: data availability; data characteristics; and data organization, analysis, and use.

3.9.1 Data Availability

Finding 22 – Availability of Flight Operations Data.
The amount and types of data collected for analysis of flight operations have increased significantly since 1996, and utilization of these data has resulted in substantial benefits for safety.

Since 1996, significant improvements have been made in data collected from operational experience, especially within individual operator organizations. Increased airline implementation of voluntary safety reporting programs (e.g., ASAP) and digital data gathering programs (e.g., FOQA) have improved the ability to identify safety related events and trends that occur in their operations. The frequency of operators requesting LOSAs or similar programs is also increasing. Many airlines have conducted multiple LOSAs (several years apart), allowing them to compare results with previous data and determine the effects of changes in training or operations.

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[51] Recommendation Measures-1: The FAA should lead the aviation community to use accident precursors increasingly and consistently as an additional measure of aviation safety; work with industry to establish systems/processes for collecting precursor data and for tracking the influence of system changes (e.g., design changes, training changes) on safety; and work with industry to investigate other means of assessing or communicating safety (e.g., ways of measuring errors intercepted, incidents or accidents prevented).
Recommendation Measures-2: In accident/incident investigations where human error is considered a potential factor, the FAA and the National Transportation Safety Board should thoroughly investigate the factors that contributed to the error, including design, training, operational procedures, the airspace system, or other factors. The FAA should encourage other organizations (both domestic and foreign) conducting accident/incident investigations to do the same. This recommendation should apply to all accident/incident investigations involving human error, regardless of whether the error is associated with a pilot, mechanic, air traffic controller, dispatcher, or other participant in the aviation system.

In addition to these operator-related data sources, the data received by airplane and avionics manufacturers based on in-service experience with their airplanes and products has also increased. However, data collection alone does not make a difference for improved safety and operations. There are also increasing challenges with the data being available to those who can use it to improve safety.

Data availability can be addressed in three areas: within the organization, to other organizations for their application, and to the public and industry at large. Fears about misuse of the data can overshadow the valuable contribution that analyzing such data can bring. This is illustrated by a point that resulted from WG discussions with manufacturers that concerns about product liability sometimes provide a disincentive for making data available about design-related vulnerabilities. Such concerns can heighten sensitivity to gathering information about design characteristics and potential changes to existing systems and their operations. Sometimes system changes or enhancements are not implemented because the change could be interpreted as an admission of a defective product. Sensitivity to make data available to others is also an issue with airlines and pilot groups because of adverse publicity in the media, public perception, airline competition, and protecting the identity of the individual pilots who voluntarily provide the safety information.

As noted above, many of these concerns are related to making the data available to the industry at large with the possibility of misuse by the media and others. Unfortunately, policies for addressing those concerns could also reduce the availability within the organization for its own safety use and sharing with other similar organizations in the industry to improve safety.

In regard to sharing with others in the industry, the Aviation Safety Information Analysis and Sharing (ASIAS) program is working to make many safety data sources available. The vision for ASIAS is to gather a broad variety of available safety data sources and provide means and methods to analyze the data separately and in combination and to overcome the sensitivities to sharing those data, because the data are aggregated or made anonymous before they are shared. ASIAS is making significant progress towards this vision, but the data and their analysis are available primarily to the ASIAS members and are not yet widely accessible.

The WG was told during interviews that there are very few venues in which to learn about and share data across the industry. It was said that having access to the lessons others have learned, including identification of risks and associated successful mitigations would have a significant positive effect on safety and operations.

The WG had a challenge getting access to some data because some operators were reluctant to share their ASAP data following an accident that resulted in the use of ASAP data for a civil lawsuit. Self-reported safety data rely on the confidentiality agreements made with those who respond. When these agreements are misunderstood or violated, the entire industry is affected. The WG had a goal to use as many of these data sources as possible but was not able to get broad access to ASAP or FOQA data, due to these industry challenges present at the time of the WG requests.

In spite of the reluctance on the part of many operators to provide individual data reports from such sources, the WG did receive some such data, usually in the form of aggregated ASAP reports from several operators, individual FOQA examples, and various anecdotes from worldwide sources (pilots and airline managers in various positions). Generally, when such data were provided, it was with the agreement that complete confidentiality would be assured.

3.9.2 Data Sources

Finding 23 - Data Source Strengths and Limitations.
Each data source has characteristics, limitations and strengths that affect its usefulness for addressing intended safety and operational questions.

Different data sources have different characteristics. Data source strengths and limitations were described earlier in the report and are expanded upon in the following paragraphs.

ASRS reports: Voluntary self-reported events like ASRS and ASAP reports can give insightful first-person accounts of events, although such reports can be biased because of the inherent difficulty in observing one's own behavior. The ASRS incident reports cannot be assumed to be representative of all operations because many reasons motivate a reporter to file (or not file) an ASRS report. It cannot be assumed that all of a particular type of event will be reported. Therefore, no definitive statements can be made about the proportions of such events in overall operations based on these data. Care is to be taken when using them, but it is often the case that first-person voluntary reports like ASRS reports provide the only means of identifying complex issues that are not easily measured by technology-based sensors like FOQA. Another challenge with voluntary reports is that they are only submitted at the motivation of the reporter, and they do not have a standard enacted for level of detail or type of information to include.

Aviation Safety Action Program (ASAP) reports: ASAP reports are also voluntary self-reports and, therefore, have similar strengths and limitations to ASRS reports based on those qualities. However, some airlines have given more structure to forms used to submit ASAP reports, and some request reports on particular safety topics of interest. This can provide more rich and consistent reports being submitted within those airlines and to the ASRS program (if the same reports are sent to ASRS as well). Another value that can be seen with ASAP is based on the airline's structure of their Event Review Committee (ERC) and how they process, resolve, and communicate the events that are submitted. The WG learned about some programs that provide a lot of value to their organization by intentionally addressing and investigating issues that are raised in ASAP reports, recording the actions taken, and communicating about the issues to other areas of the operation for them to build on the knowledge developed (e.g., incorporation of particular events into training scenarios or substantiation for policy or procedures changes).

Accident reports: Accident reports are developed by trained investigators and experts as part of their work on investigation boards. These reports usually include both objective and subjective data and analyses. Multiple data sources are used to reconstruct events and develop conclusions. These reports typically provide a thorough description of events and information that lead to their development of findings and conclusions. However, the information included in investigations and subsequently in the accident reports is dependent on the backgrounds, experience, and focus of the investigators. This leads to a broad range of quality of reports from the perspective of using their information for safety and operations studies. As mentioned earlier, the information included in the report is also dependent on the process used by the investigating board to gather and process information. This lack of a globally consistent process leads to variability in the factors and underlying details investigated and included in the reports.

Line Operations Safety Audit (LOSA): The International Civil Aviation Organization (ICAO) describes LOSA as a program for the management of human error in aviation operations. It is a tool used by the airlines requesting the audit to identify threats to aviation safety, minimize the risks such threats may generate, and implement measures to manage human error in operational contexts. LOSA provides a data-driven approach to prioritize and implement actions to enhance safety by enabling operators to assess their level of resilience to systemic threats, operational risks and front-line personnel errors. LOSA data can be used to provide an accurate snapshot of a particular airline's operations because they are based on a random sampling of flights that are observed by trained observers who document a standard set of events and other operational characteristics. Many airlines have used LOSA data to provide direction for improvements and have then requested a subsequent LOSA a few years later to measure the effects of those improvements. LOSA data are proprietary to the requesting airline and are not available to others without the permission of the airline. The LOSA Collaborative conducts most LOSAs and maintains a proprietary database of all LOSA data collected. This allows them to query for information across many airlines and develop insights based on aggregated information. It was this aggregated information that was used by the WG to compare across common categories used in review of the accident and incident reports. This was very valuable especially because LOSA data can be considered to represent day-to-day or "normal" operations. Comparing these "normal" operations data in the threat and error categories with the same categories for accidents and incidents provided many safety and operations insights for the WG.

Combining data sources: Combining several data sources for a particular purpose can be effective, if the sources are complementary and if they address the questions being investigated. Using multiple sources of data has been beneficial for the work of the WG because each source has its strengths that can be combined to provide a broad look at operations and safety issues. Although the use of these varied data are very valuable, collection and analysis of the data is quite labor intensive. It is important to intentionally choose the full set of data that will be used and consider the benefits each will bring for addressing the issues of focus for the study.

When choosing data sources, the strengths and limitations of each source are important, but there are also other considerations based on the purpose of the study. One is related to how the data source is intended to generalize the study findings (e.g. to a particular airline, to major US airline operations, to all US operations, to worldwide operations). As mentioned earlier, voluntary self-reports like ASRS cannot be used to generalize to any type of broader operations for understanding the numbers of similar events. It is important to determine whether the data to be used can be considered representative of the types of operations or geographical areas intended to be addressed. Often studies or reports are intended to address the state of safety in the US, another country, or worldwide. Very few data sources currently available have the characteristics to be generalized in this manner. This is why accident rates are most often used for this purpose – they can represent the state of safety during a particular time period if all reports that were published describing accidents within that period are considered. However, the infrequency of accidents makes it difficult to identify and address a broad range of issues. When describing a study it is important to clearly state the intended scope of the study and how the data represent that scope. For the WG, the Terms of Reference defined the scope in terms of time (since 1996) and operations. The accident and incident reports chosen for review were those that fell within that scope and not the full set of accidents within that time period.

Today's methods for data collection and analysis have made tremendous progress related to developing indicators of individual component level factors. However, due to the characteristics of data available there remains the inability to cope with latent emergent factors related to the complex interdependencies and interactions central to all modern industries leaving gaps for effectively addressing safety concerns as described in the next section.

3.9.3 Data Organization, Analysis, and Use

Finding 24 - Organizing and Analyzing Operations Data.
The increased availability of operations data has resulted in a large quantity of those data. Effectively identifying and addressing the issues from these data require sophisticated means to organize and analyze the data and appropriate resources and expertise. The review and analysis of narrative-intensive safety data can be very labor intensive and require expertise in the analysis process and operations being addressed.

The increase in the operations data that are collected for safety purpose has resulted in a "data wave."[52] Having the data is necessary but not sufficient to meet the desired safety and operational objectives. Generally, when considering how to analyze data, the first step must be to define the purpose for which the data will be used. Without determining this, using data sources that are available and convenient may dictate how they are summarized and used. For example, the metric most commonly used to understand the state of aviation safety is accident rate; however, because accidents are infrequent, it is difficult to develop a broad understanding of the state of safety and effectively develop changes or mitigations based only on accident rates. Using only accident data may result in reactive changes to the system and the generation of point solutions that may not address underlying or related challenges or vulnerabilities.

Another important element is to describe the intended users of the analysis results. For example, is it intended for use by one organization's management, multiple airlines and manufactures, other safety groups addressing worldwide issues, or others?

Often data collection and analysis are limited to tracking individual events and behaviors that have been associated with errors and risks that have previously been identified. One common approach to analyzing such data is simply to count these negative events and behaviors to guide interventions and assess progress. This approach to analyzing the safety data is limited in its ability to:

- Identify interactions or combinations of factors that can combine to increase risk and to challenge flightcrews,
- Provide detailed diagnoses of factors that contribute to errors (e.g., factors that contribute to poor communication),
- Move past surface categorizations of errors by pilots and controllers or minor breakdowns of specific equipment to identify underlying factors such as complexity or organizational contributors to safety, or
- Assist in anticipating new or emerging threats by recognizing early signs of such threats.

[52] Captain Don Gunther, *Emergency and Abnormal Situations in Aviation Symposium,* 2003.

The ASIAS program is making significant progress in providing access to data from multiple sources, which should prove beneficial for safety. However, the WG observed that data from most of these operational data sources indicate that some sort of an event of interest has occurred but do not have information related to the underlying factors that lead to the event. Knowing what happened is necessary, but few current data sources provide information that would help analysts develop an understanding about *why* events happened or the mitigations that prevented safety consequences. When the primary information available about something is that it occurred, the only analysis option is to tabulate event frequencies individually or in combination. This may be efficient, but it is inadequate for identifying interacting factors or underlying factors or for anticipating emerging safety threats (see below for further discussion of this topic).

One key goal of the efforts to build data sharing mechanisms should be to support targeted assessment of new safety questions. Safety analysts need the ability to ask new questions of the data to provide an evidence-based assessment of potential risks, including identification and resolution of data gaps and the ability to direct data gathering resources to assess trends. This seems particularly important as the US is developing plans and technology for implementing NextGen.

The WG found many successful programs for tracking and tabulating specific negative events or behaviors. There is also much motivation for implementing programs or other interventions to reduce these specific events or behaviors. However, the WG experienced in its own work, and observed in other organizations, an overload of detailed data that was often organized for efficiency of collection and storage rather than organized to help ask and answer key safety questions. In some cases airlines and other organizations are “data rich” but don’t have a good process to organize and analyze the data in a meaningful way. This made it challenging for the WG to carry out evidence-based assessments of high-level safety questions just as it does for the organizations that collect the data.

Proactive safety management is necessary to continue to advance safety across the industry. This is recognized in the movement toward implementing safety management systems. Proactive safety management requires the ability to examine how multiple small problems (when considered individually) may combine in ways that produce a cascade of complications and difficulties that together increase risk and degrade safety.

As mentioned earlier, it is important to understand the intent for reviewing and analyzing the data and find the analysis tools and review categories that support the intended purpose. This means that one size won’t fit all, either in categorization schemes or analysis tools. This observation may imply that spending a lot of time working on global taxonomies to be used across many data sets may not be an effective solution. Some questions that are useful to address when deciding on categorization schemes for data review and analysis are the following:

> (1) What categories are already being used by others in similar areas, especially those who will be using the results of the analysis?
> (2) Are there datasets that would be useful to integrate the results after completion and will the categories used by those efforts work for the review and analyses being planned?

The key question is, “do the data collection, organization, analysis and synthesis mechanisms help an analyst answer new questions or test possible ways to improve safety?” Depending on a global common taxonomy has proven incompatible with the above test. Categorizations tend to focus on components and miss interactions and possible emergent factors. Categorizations also tend to focus on operator error and miss underlying factors, including the effects of complexity.

Categorization schemes need to be designed for data review and analysis. For example, the WG considered the broad use and understanding of the Threat and Error Management (TEM) framework and its compatibility with the LOSA data results when deciding to use TEM categories in the review and analysis process. The WG did add some categories to the TEM framework that addressed some areas of WG interest. This allowed a direct comparison with LOSA results, as well as insight into some more specific threats and errors related to the scope of the WG.

Just as data sources each have strengths and weakness, so do different taxonomies and categorization schemes. See Mumaw et al 2005 for a discussion on this issue with respect to error taxonomies.[53] This supports the concern that no single taxonomy or categorization scheme can address all aspects of a topic area, and that there may be benefit to using multiple taxonomies (as with multiple data sources) to help.

Another challenge faced by the WG, as it is by organizations throughout the industry, was that of data collection and analysis to identify positive behaviors that are important to safety so that they can be understood and strengthened. This often includes a desire for understanding behaviors that should intentionally be included in training and protected from being removed during any changes to the training or procedures. Another example would be when a new procedure is being developed. It is important to understand the behaviors of pilots who are exceptional at accomplishing the tasks so their positive behaviors can be used as a model when developing the new procedures.

Finding 25- Sources of Data about Positive Behaviors.
The majority of safety and operational data come from a negative perspective and describe negative events that have occurred, such as incidents or accidents. There are very few data sources that capture the positive aspects of the aviation system, such as those aspects that describe when pilots or controllers overcome adverse situations or successfully mitigate operational or safety risk.

The WG had a strong desire to understand positive behaviors that occur in operations that affect safety. Developing an understanding of positive behaviors allows the determination of aspects of the safety systems that need to be protected as changes are made for enhancing operations in the future. The only data source that the WG could identify that explicitly collects data that include positive behaviors while understanding normal operations were those from LOSA. Although major incidents often involve positive behaviors where pilot actions prevent a serious situation from becoming an accident, the investigations into these events rarely describe the details of those behaviors and instead focus on what when wrong.

[53] Randall J. Mumaw, Richard J. Kennedy, Hans-Juergen Hoermann (2005). “Task 1B Report: Review of Human Error Frameworks. A Deliverable for the Project: Human Factors Tools for Accident Investigation,”Boeing, Seattle, WA. June 29, 2005.

During LOSA observations, all aspects of the operations are noted: normal, non-normal, positive, and negative. Coupled with the fact that the LOSA observations are made from a random sample of the operations of the airline being audited, LOSA data provide a unique snapshot of the operation as a whole. When combined with data from other airlines, such data may provide a unique view of the broad aviation system as represented by those airlines. The WG was able to compare the LOSA results, such as the proportion of flights with malfunctions, with the proportion that occurred in the accident flights, major incidents, and ASRS incidents. This comparison can be very interesting and was helpful to inform the WG analyses.

Finding 26 - Variability in Safety Event Investigations.
There is significant variability in the topics covered or emphasized by different accident investigation agencies around the world.

Besides the challenges in addressing positive behaviors, there are also challenges due to the varying characteristics of data gathered and reported for different events even when they are investigated in detail. Various investigating boards differ in their methods, scope, and detail of investigations. There is also quite a bit of variability from report to report from the same investigating board. This variability can make it difficult to gather consistent information across reports. It also can be difficult to draw fact-based conclusions across reports if there is a possibility that some aspect of the event or situation was not included in one investigation that was included in another. Unless it is stated that a factor was included in the investigation and was not present, it is difficult to know whether it was present and just not reported or that it was indeed not present.

The absence of information about a particular aspect of the event does not necessarily mean that it was not involved or present in that event. For example, many accident investigations do not look at the role of organizational culture or other cultural aspects. There are many reasons for this, including lack of access to data about these aspects, or lack of methods for analyzing such data when available. This results in these types of underlying or “latent factors” not being identified as present for those events. The investigation process details are often dictated by the topics of interest at that point in time and not based on a systematic process that is consistently used by one investigating board or across investigating boards.

Many investigations do not put the crew’s individual actions in context for that organization (e.g., how generalizable is that crew’s actions for the company or for a broader set of operators?). Similarly, training deficiencies are often identified but specifics about those deficiencies are rarely included in the report.

Another investigation process issue that was identified is that only shorter reports are available for some serious incidents even though the details and analysis of those incidents could be as important as the details and analysis of accidents.

The majority of work conducted by the WG entailed reviewing and analyzing information from the chosen data sources. The analysis included primarily review of report narratives because of the nature of the data (accident reports, ASRS incident reports, and LOSA narratives and aggregated reports). Narrative analysis is very different from quantitative analysis and tends to be much more time and labor intensive. In addition, it requires operational expertise to effectively review and analyze these types of data. However, even though the review and analysis requires expertise, it is important to write up the results in a form that can be understood by those without such expertise. These are challenges faced by all groups working with these types of data and desiring to produce reports to be used by the industry at large.

Choosing the appropriate metric for describing the data is also important. For example, as described earlier, using frequency of events alone is not appropriate for some of the data sources because of the nature of the data (e.g., voluntary reports do not represent the full set of operations and therefore cannot be generalized to describe frequency of event types in the industry as a whole). However, using proportions of events within a particular data set can be useful when describing a set of data. Using proportions of the reviewed data can also allow comparison across data sources if those data were all gathered to address the same scope of operations. The WG found it very useful to compare proportions of the reviewed data across the data sources. This practice does require some caution, however, because the data still are not completely one-to-one-to-one comparisons due to the varied nature of the sources and perspectives of the data sets as described earlier. The conclusions drawn from the data must carefully consider these differences.

It is difficult to make general observations across accidents (or other sources of safety data, including incidents and normal operations) and often requires a great deal of expertise and judgment. It can be difficult to develop objective criteria that can be applied by a variety of team members in a timely manner. Intentionally defining the process to use for review can reduce some of these challenges.

There are some ongoing efforts looking at data mining algorithms and ways to determine whether natural language processing methods can be developed to reduce the initial review and categorization time required for review of narrative intensive documents. This would allow the subsequent review by the working group or other team members to be focused on particular areas of interest and involve more efficient and effective use of their time and expertise. Although progress is being made in this area, no tools were available at the time of the WG efforts and still are not available at the time of this report.

Finding 27 – Interactions and Underlying Factors in Accidents and Incidents.
Current practices for accident and incident investigation are not designed to enable diagnoses of interactions between safety elements and underlying or "latent" factors that are increasingly recognized as important contributors to safety risks. One reason is because there is a lack of data available addressing such factors. When developing safety enhancements, such factors (e.g., organizational culture or policies) are just as important to understand as the human errors that occur.

Data are collected primarily about "front line" operations. Attempts to diagnose safety-related problems in analyses and investigations are dominated by categorizing events as due to "pilot error" and "controller error," and the WG found this is no different when addressing flight path management and use of automated systems. The persistence of this attitude reduces the ability to understand the factors that create the conditions for, or lead to, these errors (Woods et al., 2010). One class of latent or underlying factors is that of organizational factors related to organizational culture, including policy, procedures and economic pressures. Another class of latent factors relates to effects of complexity - increases in the degree and kinds of interdependencies across factors (including tighter coupling of systems). Unfortunately, very little information about these classes of latent factors is gathered at all (what is gathered is not done so in a consistent way), and little of the available data is utilized to assess the effects of such factors.

The further away an event report gets from the specific line operational details, the more judgment is required to review and analyze the data and understand it. The statements in event reports about other aspects that led up to events often lack the depth needed to understand them and to make observations and recommendations related to those areas. The WG found that it was very difficult to find data and information to understand the factors that lead up to accidents or underlie pilot errors or other errors (e.g., areas such as organizational culture). Indeed it is difficult to find investigations or analyses that look in depth at any type of error besides those that occur on the front line. It is going to be important to find ways to begin gathering this type of information to effectively find safety and operations implementations for the future. Finding methods to identify, mitigate, and recover from errors throughout the system will become more critical as systems throughout the NAS evolve to become more interdependent and automated.

The WG also found that the general nature of many categories that are typically used when reviewing safety reports were not specific enough to allow useful conclusions to be drawn that could lead to recommendations about actions that could be taken to address specific areas of concern. For example, simply knowing the category of pilot error that occurred in the accidents was not detailed enough. The WG took the reports that referenced each category of error (e.g., manual handling/flight control errors or programming errors) and documented the details about those errors to help understand them and develop conclusions and recommendations. It was much more informative to know that manual handling errors were actually errors such as inappropriate control inputs and incorrect upset recovery. These more specific categories are much more likely to lead to effective recommendations.

Finding 28 - Precursors to accidents.
The relationship between incidents and accidents is complex. The characteristics of this relationship should be understood when using incidents (or other data sources) as precursors or predictors of more serious safety events. Mitigations to one risk factor can create other, unanticipated risks.

The WG results comparing data across data sets has made it clear that there is no simple relationship between the number of incidents that include particular events and the number of accidents related to those types of events. Typically, incidents are considered to be precursors to accidents. However, the WG found that the relationship between incidents and accidents is much more complex than that, depending on many factors. The factors include the following:

- Different definitions of incident are used. Depending on the definition, an incident may be more of a precursor to accidents than others. For example, ASRS-reported events may not be “near misses.”
- There may be different mitigations or defenses in the system for some categories than for others. For example, lateral deviations have different mitigations (or sensitivity of mitigations) in the system (surveillance by air traffic personnel) than vertical or speed deviations.
- Different categories may have different potential safety consequences. For example, ground navigation has different potential safety consequences than incorrect aircraft configurations.

It became evident in the WG review that accidents may not be preceded by incidents or errors that would have pointed to them. Due to this, the frequency or type of incidents or errors cannot always be used to predict accidents. This means that traditional “iceberg” or pyramid concept is not supported by the WG data in the way is has been typically used. While the “iceberg model” may be useful and accurate in the aggregate, it may not apply to specific categories of accidents or errors. This implies that predicting accidents based on specific categories must take into account characteristics such as type of data source, mitigations or defenses in the aviation system, and other factors.

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4 Recommendations

The recommendations to address the findings are proposed below. For each recommendation, information is included about the findings being addressed, any related recommendations, discussion of the recommendation itself, and any related recommendations from the 1996 FAA report that are still relevant, based on the WG analysis.

The recommendations are written to address vulnerabilities identified in the findings. Any particular recommendation may address one or more findings, and several of the recommendations are interdependent. When implementing the recommendations, it is important that an integrated approach be taken to address that interdependence. In many cases, the vulnerability will not be fully corrected if a partial approach is taken to the solution. They are written to provide sufficient information so that tasking for appropriate implementation can be done that addresses the relevant findings.

In some of the recommendations, there is a short-term and a long-term part. This is intended to recognize that some types of mitigation, such as improved flight deck equipment design, may be the most desirable, but may take a long time to implement. Many of the aircraft currently flying will still be flying in ten years or more, so changes in equipment design may have little effect during that time period. Therefore, mitigations that assume the use of existing equipment designs are necessary to address the issues or vulnerabilities.

It should be noted that the recommendations generally are listed in order of the findings they address, and are not listed in order of priority.

Recommendation 1 – Manual Flight Operations.

Develop and implement standards and guidance for maintaining and improving knowledge and skills for manual flight operations that include the following:

- Pilots must be provided with opportunities to refine this knowledge and practice the skills;
- Training and checking should directly address this topic; and
- Operators' policies for flight path management must support and be consistent with the training and practice in the aircraft type.

This should be done in an integrated manner with related recommendations.

Finding(s) addressed:
Finding 2 – Manual Flight Operations.
Finding 7 – Standard Operating Procedures.
Finding 9 – Operator Policies for Flight Path Management.
Finding 11 – Pilot Knowledge and Skills for Flight Path Management.
Finding 12 – Current Training Time, Methods and Content.
Finding 13 – Flight Instructor Training and Qualification.

Related recommendations:
Recommendation 9 – Operator Policies for Flight Path Management.

Recommendation 13 – Pilot Training and Qualification.

Discussion:
As part of achieving the list of items above, the term "manual flying skills" and the associated knowledge and skills should be agreed upon. It involves more than "stick and rudder" skills. It also involves cognitive skills and knowledge on how to handle situations that arise and how to keep the pilot engaged with the flight path management operation and ready to take over manually.

The vulnerability in manual flight operations is a critical area that must be addressed in an integrated fashion. Training is an important part of the solution, but training alone would not be sufficient to address this area. A comprehensive approach that includes training, operational policy with respect to use of automated systems and opportunities to use and practice manual flying skills in operation, and associated flightcrew procedures that enable the practice, development and retention of manual flying skills are necessary. During flight operations, pilots should have opportunities to practice manual flight operations when appropriate, as recommended in Safety Alert for Operators 13002.[54]

Manual flight operations should be included as part of the recommendation for updating training and qualification (see Recommendation 13).

The 1996 FAA report expressed the following concerns:

> One area is the degradation of manual flying skills of pilots who use automation frequently, or who participate in long-haul operations, and therefore do not have the opportunity to perform manual takeoffs and landings more than a few times a month. It is also rare for pilots to experience the edges of the flight envelope, or receive training on special issues such as high altitude stability and handling qualities. Yet there have been incidents in both the MD-11 and the A300-600 of high-altitude upsets where the autopilot disengaged for various reasons, including turbulence, resulting in pilots taking over control of an out-of-trim aircraft in a flight regime with which they were not very familiar.[55] A second area of concern is in the skills needed to perform recovery from unusual aircraft attitudes.

Future operations using even more complex airspace procedures are expected to require or encourage more use of automated systems. This recommendation is necessary to enable pilots to maintain the necessary manual flight operations knowledge and skills.

Recommendation 2 - Autoflight Mode Awareness.

For the near term, emphasize and encourage improved training and flightcrew procedures to improve autoflight mode awareness as part of an emphasis on flight path management. For the longer term, equipment design should emphasize reducing the number and complexity of

[54] SAFO 13002 was written based on preliminary results of this Working Group. See http://www.faa.gov/other_visit/aviation_industry/airline_operators/airline_safety/safo/all_safos/media/2013/SAFO13002.pdf

[55] This quote refers to two incidents reviewed for the 1996 FAA report. Since the 1996 FAA report was completed, similar high altitude upsets have occurred on many types of aircraft, and the issue is not limited to just these two aircraft.

autoflight modes from the pilot's perspective and improve the feedback to pilots (e.g., on mode transitions) while ensuring that the design of the mode logic assists with pilots' intuitive interpretation of failures and reversions.

Finding(s) addressed:
Finding 4 – Automated Systems.
Finding 5 – Pilot-to-Pilot Communication and Coordination.
Finding 14 – Flight Deck Equipment Design.

Related recommendations:
Recommendation 6 – Flight Deck System Design.
Recommendation 8 – Design of Flightcrew Procedures.
Recommendation 9 – Operational Policies for Flight Path Management.
Recommendation 13 – Pilot Training and Qualification.

Discussion:
Training and procedures are used as mitigations for existing design, but may not be sufficient for the long term in all cases, as complexity increases in airspace operations. With few exceptions, design of autoflight modes and their use have not decreased in complexity. Therefore, as longer term mitigation, equipment design emphasis should address this situation. This must be done in the context of the changes in airspace operations, and as described below in Recommendation 4, coordination should be done between equipment design and airspace requirements to enable decrease in complexity.

In the 1996 FAA report, recommendations were made to help address this topic. It continues to be an issue, and this is an updated approach to addressing the vulnerability.

Recommendation 3 – Information Automation.

Develop or enhance guidance for documentation, training, and procedures for information automation systems (e.g., EFBs, moving map displays, performance management calculations, multi-function displays) or functions:

- Describe what is meant by Information Automation and what systems, equipment are included,
- Define terms associated with Information Automation,
- Develop guidelines concerning the content and structure of policy statements in Flight Operations Policy Manuals for Information Automation, and
- Develop operational procedures to avoid information-automation-related errors.

Finding(s) addressed:
Finding 4 – Automated Systems.
Finding 5 – Pilot-to-Pilot Communication and Coordination.

Related recommendations:
Recommendation 8 – Design of Flightcrew Procedures.

Discussion:
Operators requested policy guidance regarding information management and information automation (automation devoted to the management and presentation of relevant information to flightcrew members; this category includes communications automation). The discussion also included the terminology, use of displays, integration of new technologies (EFB, etc.), and the need to cross verify differing sources of information. Such policy should include topics such as: use of uplinked data (direct to FMS or Aircraft Communications Addressing and Reporting System (ACARS) Weather, etc.) and any cross verification required by the flightcrew.

Implementation of this recommendation should address the concern that replacing paper with electronic media does not simply bring over the same paper-based issues (although it may duplicate some such issues). New issues may occur and fundamental change may be required.

The 1996 FAA report addressed this topic in recommendations (SA-6, SA-7) but did not describe them as or use the phrase information automation. The 1996 FAA report encouraged the redesign and modernization of the information provided to the flightcrew in notices to airmen (NOTAMs), charts, approach plates, instrument procedures, meteorological data, etc. It said that the information should be prioritized and highlighted in terms of urgency and importance, and presented in a clear, well organized, easy-to-understand format suitable for use with information management systems in current and future airplanes.

The 1996 FAA report also addressed the modernization of information provided to aircrew in recommendation Comm/Coord-5. While the SAE G10 has a subgroup addressing a portion of this topic, more work needs to be done since much of this information will be presented to the crews via some sort of information management/automation system on the flight deck.

Recommendation 4 – FMS Documentation, Design, Training, and Procedures for Operational Use.
In the near term, develop or enhance guidance for flightcrew documentation, training and procedures for FMS use. For the longer term, research should be conducted on new interface designs and technologies that support pilot tasks, strategies and processes, as opposed to machine or technology-driven strategies.

Finding(s) addressed:
Finding 4 – Automated Systems.
Finding 16 – Human Factors in the Flight Deck Design Process.

Related recommendations:
Recommendation 8 – Design of Flightcrew Procedures.
Recommendation 12 – Flight Deck Equipment Design Process and Resources.
Recommendation 13 – Pilot Training and Qualification.

Discussion:
Consideration should be given to a new, much simpler flight path management system design from the pilot’s perspective. Current flight path management systems appear to be more complex than in the past, in part because new functions are added to the existing functions, a process that may have evolved over decades.

Any efforts on FMS design must be closely integrated with airspace requirements, current and future. As discussed below, the airspace procedure design should account for, and support the capabilities of onboard systems, including FMSs.

The 1996 FAA report addressed the topic of FMS design and operation in several of its recommendations (AutomationMgt-5, SA-1, SA-2, Knowledge-2) and the recommendations are still relevant.

Recommendation 5 – Verification and Validation for Equipment Design.

Research should be conducted and implemented on processes and methods of verification and validation (includes validation of requirements) during the design of highly integrated systems that specifically address failures and failure effects resulting from the integration.

Finding(s) addressed:
Finding 3 – Managing Malfunctions.
Finding 14 – Flight Deck Equipment Design.

Related recommendations:
Recommendation 7 – Guidance for Flightcrew Procedures for Malfunctions.

Discussion:
As mentioned in the discussion of Finding 3 on managing malfunctions, the highly integrated avionics systems being implemented in current airplanes make it very difficult, if not impossible, to anticipate all possible equipment failures and their consequences. Yet the pilots are responsible for managing any such situations that arise. This situation is expected to continue, and must be addressed from the pilot's perspective. The research should include operational aspects of failures, to help guide pilot training and procedures during non-normal situations.

It is likely to be impossible to anticipate all possible equipment failures and their consequences, but improvements should be made. In acknowledgement of the need to do more, the FAA has published AC 20-174, which cites Aerospace Recommended Practice (ARP) Development 4754a, Development of Civil Aircraft and Systems. The AC says "This AC addresses the concern of possible development errors due to the ever increasing complexity of modern aircraft and systems. In order to address this concern, a more structured methodology to mitigate development errors is described in SAE ARP 4754A."

The 1996 FAA report did not specifically address this issue, which has emerged since the report was published.

Recommendation 6 - Flight Deck System Design.

Flightcrew training should be enhanced to include characteristics of the flight deck system design that are needed for operation of the aircraft (such as system relationships and interdependencies during normal and non-normal modes of operation for flight path management for existing aircraft fleets). For new systems, manufacturers should design flight deck systems such that the underlying system should be more understandable from the flightcrew's perspective by including human-centered design processes.

Finding(s) addressed:
Finding 14 – Flight Deck Equipment Design.

Related recommendations:
Recommendation 5 – Verification and Validation for Equipment Design.
Recommendation 12 – Flight Deck Equipment Design Process and Resources.

Discussion:
Accident data showed that flightcrews were sometimes unaware of system behavior brought about by failures in other systems that were related to or integrated into the respective system function. Although not definitive, it is practical to assume that the accident may have been prevented if the flightcrew understood the failure modes and effects or had appropriate alerting and checklist resources to mitigate the anomaly. Complex system design could be construed as a contributing factor in such events but a large number of related events, albeit not catastrophic, have also occurred in daily revenue operation as highlighted in ASRS, ASAP and ATSAP reports.

The complex nature of system integration becomes apparent when the flightcrew attempts to operate the respective system in a high workload environment and either errs or responds in a fashion "believed" to be correct because the condition is not fully understood. Operators reported that they did not have available time to train such systems issues and many such explanations are not provided to them by the OEM in the form of crew literature or training materials. Some independent documentation has been produced with "tribal knowledge" but that information may not contain viable solutions for the respective failure.

Since the existing fleets will be operational for many years, focused training may be the only practical mitigation for integrated systems knowledge in those existing fleets. Training an overarching flight path management philosophy, which includes system relationships and interdependencies during normal and non-normal modes of operation, would also be useful. Part of this training should include how to interface with and use the automated systems to help manage the airplane's flight path.

As stated previously, aircraft systems are becoming more integrated for very good technical reasons. One result is that the source of a problem or consequences of a component failure are often non-intuitive. The emphasis should be on providing the pilot the information necessary to perform the tasks (and presenting it in a usable form). The full understanding of the system may not be a requirement.

Complexity can be considered from several perspectives. In this case, the WG was concerned about the flightcrew's perspective in operating the aircraft. A good example is the fly-by-wire flight control system mentioned earlier, in which the system is internally very complex but the crew operation of the system is usually simple, to include simple alternative actions should the primary system fail.

Newer designs should focus on the flightcrew's ability to understand normal system operations and their ability to function effectively without error, especially when failures occur. New approaches to system design may be required. In similar fashion, the integration of multiple systems should be designed such that the flightcrew has clear, definitive and well understood actions in the event of failures or degraded modes. Consideration should be given to reducing functionality in new designs to the required applications and discarding obsolete functions remaining in “updated” software.

The 1996 FAA report discussed how the pilots could be surprised by subtle behavior or overwhelmed by the complexity embedded in the systems. The importance of crew-centered design was discussed extensively. Recommendations from the report that continue to be relevant include SA-5, SA-7, Criteria-1, and Knowledge-2.

Recommendation 7 – Guidance for Flightcrew Procedures for Malfunctions.
Develop guidance for flightcrew strategies and procedures to address malfunctions for which there is no specific procedure.

Finding(s) addressed:
Finding 3 – Managing Malfunctions.

Related recommendations:
Recommendation 8 – Design of Flightcrew Procedures.

Discussion:
The intent of this recommendation is to provide support to pilots for dealing with malfunctions for which there are no procedures or where current procedures exist, but do not properly address the situation or are inadequate. The goal is not to have line pilots perform the functions of test pilots, but to support them with information on how to address such situations.

Some operators have implemented general procedures when there is no checklist for the specific situation. The operational experience with such procedures should be reviewed and incorporated into appropriate guidance material.

The 1996 FAA report identified such malfunctions as an issue, as well, and recommended training for such events (Recommendation Knowledge-2).

Recommendation 8 – Design of Flightcrew Procedures.
For the near term, update guidance (e.g., AC 120-71A) and develop recommended practices for design of SOPs based on manufacturer procedures, continuous feedback from operational experience, and lessons learned. This guidance should be updated to reflect operational experience and research findings on a recurring basis. For the longer term, conduct research to understand and address when and why SOPs are not followed. The activities should place particular emphasis on monitoring, cross verification, and appropriate allocation of tasks between pilot flying and pilot monitoring.

Finding(s) addressed:
Finding 7 – Standard Operating Procedures.
Finding 8 – Data Entry and Cross Verification Errors.

Related recommendations:
Recommendation 13 – Pilot Training and Qualification.

Discussion:
Currently, the guidance for SOPs[56] provides templates for typical flightcrew procedures. When updated, this guidance should be updated to:

- Validate that SOPs are written at an appropriate level of detail.
- This should also capture the anticipatory nature of effective cross-verification; i.e., the notion of staying ahead and having an expectation of what the performance should be and not merely verifying aircraft performance matches what the flight path management system has scheduled.
- Support the task/workload management, and the monitoring by PF/PM.
- Support research on this topic as necessary.

More guidance should be provided on how to develop and manage flight path management SOPs, including how to safely implement SOP changes. This has been highlighted with the increased use of ASAP reporting systems as well as the recent wave of industry mergers. A robust SOP management program should include developing flight path management SOPs based on manufacturer procedures, and include continuous feedback from operational experience and lessons learned. To ensure SOPs and SOP changes are effective, guidance for managing SOPs and SOP changes may include defining assessment measures to show SOP effectiveness, what data should be collected to measure this effectiveness, and guidance on how to analyze the data.

The 1996 FAA report identified the concern about pilots not following procedures, and made Recommendation AutomationMgt-4 to conduct analyses about why pilots do not follow procedures. Progress has been made in understanding the reasons, but improvements are needed in designing the procedures and in other mitigations.

Recommendation 9 - Operational Policy for Flight Path Management.

Operators should have a clearly stated flight path management policy as follows:

- The policy should highlight and stress that the responsibility for flight path management remains with the pilots at all times. Focus the policy on flight path management, rather than automated systems.
- Identify appropriate opportunities for manual flight operations.
- Recognize the importance of automated systems as a tool (among other tools) to support the flight path management task, and provide operational policy for the use of automated systems.
- Distinguish between guidance and control.
- Encourage flightcrews to tell Air Traffic "unable" when appropriate.
- Adapt to the operator's needs and operations.
- Develop consistent terminology for automated systems, guidance, control, and other terms that form the foundation of the policy.
- Develop guidance for development of policies for managing information automation.

[56] FAA Advisory Circular 120-71A, Standard Operating Procedures for Flight Deck Crewmembers, 2/27/03.

Finding(s) addressed:
Finding 1 – Pilot Mitigation of Safety and Operational Risks.
Finding 2 – Manual Flight Operations.
Finding 4 – Automated Systems.
Finding 7 – Standard Operating Procedures.
Finding 9 – Operator Policies for Flight Path Management.

Related recommendations:
Recommendation 1 – Manual Flight Operations.
Recommendation 8 – Design of Flightcrew Procedures.
Recommendation 13 – Pilot Training and Qualification.

Discussion:
The implementation of this recommendation should build on the work of the SE-30 team and report,[57] and operators' experience. The following items represent suggested 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 flight path management, rather than automated systems. Note that this policy would contain what has previously been named an "automation policy" and would be broader, to emphasize flight path management.
- The policy should state that automated systems should be viewed as important tools (among other tools) to support the flight path management tasks. Build on the lessons learned.
- The operator's policy should provide guidance on the operational use of automated systems Include the following information, based on the 1996 FAA report recommendation Automation-Mgt-2:
    - 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).
- Make a clear distinction in the policy between guidance and control.
- The policy should reflect the operator's own circumstances, operating environment, culture and expectations of the crew.
- The policy should be an integral part of the operator's own policies and procedures and not be included as an add-on or something different from, or inconsistent with other policies.
- The policy should be dynamic and may need to be adapted as the operator's circumstances and operational challenges change—e.g., new equipment, routes, changing flightcrew demographics.
- The operator should also regularly review feedback from training, line experience, and incident and accident data when considering changes.

[57] Commercial Aviation Safety Team, *"Mode Awareness and Energy State Management Aspects of Flight Deck Automation"* Final Report, Safety Enhancement 30, August, 2008.

- The policy needs to be cognizant of the manufacturer's own "automation" philosophy. However, simply adopting the manufacturer's recommended policies may not meet the operator's own requirements or reflect their own philosophy of operations.

The operational policies need to be developed in conjunction with the approach taken to training. Training programs should complement the policy and associated line operations. Consider using "levels of automation" as a communication mechanism, but recognize the lessons learned that prescriptive and detailed levels of automation are difficult to operationalize.

Operational policies should also address information automation and its management. Information automation should be addressed in philosophy, policies, procedures and practices. Guidance material provided for policy should address benefits/disadvantages and potential mitigations depending on type of policy adopted. Examples of differing policies and associated benefits, disadvantages and mitigations should be presented.

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 1996 FAA report recommended that operators have a clearly stated automation policy. The data and analysis of this WG suggests that it is important to build on that experience and revise it to have a stronger focus on the flight path management task.

Recommendation 10 - Pilot-Air Traffic Communication and Coordination.

Discourage the use of regional or country-specific terminology in favor of international harmonization. Implement harmonized phraseology for amendments to clearances and for re-clearing onto procedures with vertical profiles and speed restrictions. Implement education and familiarization outreach for air traffic personnel to better understand flight deck systems and operational issues associated with amended clearances and other air traffic communications. In operations, minimize the threats associated with runway assignment changes through a combination of better planning and understanding of the risks involved.

Finding(s) addressed:
Finding 6 – Communication and Coordination between Pilots and Air Traffic Services.
Finding 19 – Knowledge and Skills of Air Traffic Personnel.

Related recommendations:
Recommendation 11 – Airspace Procedure Design.

Discussion:
Phraseology by pilots and controllers continues to be a concern, especially with implementation of new airspace procedures.[58] Pilots are expected to use different phraseology in different parts of the world, adding to the potential for error. There is a desire for flexibility in airspace operations, but the need to intervene brings with it different elements of complexity, and the

[58] IFALPA Safety Bulletin 13SAB003, SID/STAR Phraseology Issues, 6 December 2012.

need for phraseology to support this desired flexibility is representative of the challenges that this complexity introduces for pilots and air traffic personnel.

It will be important to extend this consistency and harmonization to future capabilities for communication and surveillance. In particular, there needs to be consistency among voice communications phraseology, datacomm message sets, and the wording of clearances in pre-departure clearances.

The 1996 FAA report addresses this topic in several recommendations that are still relevant, including Culture-3, Culture-4, and Comm/Coord-1.

Recommendation 11 - Airspace Procedure Design.
Continue the transition to PBN operations and drawdown of those conventional procedures with limited utility. As part of that transition, address procedure design complexity (from the perspective of operational use) and mixed equipage issues. Standardize PBN procedure design and implementation processes with inclusion of recommended practices and lessons learned. This includes arrivals, departures, and approaches.

Finding(s) addressed:
Finding 6 – Communication and Coordination between Pilots and Air Traffic Services.
Finding 18 – Complex and Unfamiliar Instrument Flight Procedures.
Finding 19 – Knowledge and Skills of Air Traffic Personnel.

Related recommendations:
Recommendation 4 – FMS Documentation, Design, Training, and Procedures for Operational Use.
Recommendation 9 – Operational Policy Flight Path Management.
Recommendation 10 – Pilot-Air Traffic Communication and Coordination.

Discussion:
Air traffic services should continue the transition to PBN operations and drawdown of those conventional procedures with limited value or potentially higher risk (e.g., those procedures that lack vertical guidance). The processes for designing airspace procedures must be coordinated between air traffic services and the aircraft operational perspective, addressing the issues identified in the findings. This is challenging because it involves multiple organizations with very different perspectives and incentives. However, the resulting human performance issues for both pilots and air traffic personnel have potential consequences for both safety and operational effectiveness.

To aid in the transition from conventional to PBN operations, the FAA is developing a repository that documents the lessons learned and can be used for improved procedure design and reduced operational issues for new PBN operations. These lessons learned are very important and should be made widely available.

Airspace improvement efforts should incorporate airspace optimization objectives with integrated procedure design. Ideally, entire terminal airspace systems and associated feeder/departure routes should be considered for redesign and optimization during PBN procedure projects. The consequences for flight operations (including phraseology and other pilot-air traffic communication issues) should be considered during the procedure design process.

The 1996 FAA report addressed this topic with Recommendations Comm/Coord-1 and Comm/Coord-2.

Recommendation 12 – Flight Deck Design Process and Resources.
Ensure that appropriate human factors expertise is integrated into the flight deck design process in partnership with other disciplines, with the goal of contributing to a human-centered design. To assist in this process, an accessible repository of references should be developed that identifies the core documents relevant to "recommended practices" for human-centered flight deck and equipment design. Early in the design process, designers should document their assumptions on how the equipment should be used in operation.

Finding(s) addressed:
Finding 16 – Human Factors in the Flight Deck Design Process.
Finding 17 – Knowledge and Skills of Flight Deck Designers.

Related recommendations:
Recommendation 16 – Flight Deck Equipment Standardization.

Discussion:
The 1996 FAA report addressed this topic extensively and made several recommendations. This WG was tasked to provide an update based on implementation of the 1996 FAA report recommendations. Although extensive progress has been made in improving the consideration of human factors in the flight deck design process, there are still many examples where manufacturers are producing equipment that does not necessarily reflect an effective human-machine interaction.

A great deal of literature exists on Human Factors and the importance of a crew-centered design. During interviews, it was obvious that manufacturers have their own (sometimes limited) references but not necessarily a robust source of recommended practices for flight deck and equipment design. A frequent question was "where do we go for the best guidance?" That question is valid since HF information is spread across multiple sources and not easily found. Additionally, some resources which offer approaches to crew-centered design are not as useful as other, well-validated sources.

A list of references could be easily formulated to provide information of accepted, recommended practices. That resource could be something similar in concept to the "Starting Point to Learn About Safety and Human Error Risks" (SPLASHER) resource developed by the JAA Human Factors Steering Group in 2001. Such a resource list would include those guidance sources which are generally viewed as recommended practices and could include, for example, more resources like the Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 4033, "Pilot-System Integration," August 1995, current regulatory guidance, and others.

Relevant recommendations from the 1996 FAA report include Processes-1, Processes-2, Knowledge-1, and Knowledge-9.

Recommendation 13 - Pilot Training and Qualification.
Revise initial and recurrent pilot training, qualification requirements (as necessary), and revise guidance for the development and maintenance of improved knowledge and skills for successful flight path management. As part of the implementation of this recommendation, improve the oversight of air carriers and Part 142 Training Centers.

Finding(s) addressed:
Finding 1 – Pilot Mitigation of Safety and Operational Risks.
Finding 2 – Manual Flight Operations.
Finding 3 – Managing Malfunctions.
Finding 4 – Automated Systems.
Finding 5 – Pilot-to-Pilot Communication and Coordination.
Finding 6 – Communication and Coordination between Pilots and Air Traffic Services.
Finding 7 – Standard Operating Procedures.
Finding 8 – Data Entry and Cross Verification Errors.
Finding 9 – Operator Policies for Flight Path Management.
Finding 10 – Task/Workload Management.
Finding 11 – Pilot Knowledge and Skills for Flight Path Management.
Finding 12 – Current Training Time, Methods and Content.
Finding 13 – Flight Instructor Training and Qualification.

Related recommendations:
Recommendation 1 – Manual Flight Operations.
Recommendation 2 – Autoflight Mode Awareness.
Recommendation 3 – Information Automation.
Recommendation 4 – FMS Documentation, Design, Training, and Procedures for Operational Use.
Recommendation 5 – Verification and Validation For Equipment Design.
Recommendation 7 – Flightcrew Procedures for Malfunctions.
Recommendation 8 – Design of Flightcrew Procedures.
Recommendation 9 – Operational Policy for Flight Path Management.
Recommendation 10 – Pilot-Air Traffic Communication and Coordination.
Recommendation 11 – Airspace Procedure Design.
Recommendation 14 – Instructor/Evaluator Training and Qualification.

Discussion:
Regulatory guidance and requirements that determine content and length for training and certification should include:

- Flight path and energy management throughout the flight regime;
- Management and use of automated systems, including achieving and maintaining mode awareness;
- Handling known automated system anomalies or situations known to cause crew difficulties in line operations or in training;
- The decision-making process concerning the selection of applicable modes;

- Recovery from off-path circumstances;
- The use of alternative modes to meet air traffic clearances/requirements;
- The conduct of normal go-arounds;
- Task/workload management, including managing distractions;
- Manual handling skills and associated decision making;
- Upset prevention, recognition and recovery training;
- Decision making, including unanticipated event training;
- Pilot monitoring skills;
- Malfunction management, to include partial failures and failures across systems;
- Training to meet the operators' operational policies;
- Required pilot tasks and skill sets for flight path management;
- A training and evaluation plan using appropriate flight simulation training devices as outlined in ICAO document 9625, manual of Criteria for the Qualification of Flight Simulation Training Devices;
- New skill sets and training devices that may be required by NextGen that do not exist yet;
- Actions to be taken when the desired aircraft performance does not match that provided or scheduled by the automated systems. Include actions and the requirement to advise air traffic when applicable;
- Training in scenario-based, line operational environments where threat and error management skills and crew resource management skills are essential.
- Training needed during the introduction of new technology and NextGen operations, procedures, phraseology or practices (such as, PBN procedures). Note that these may be amended following the integration of these new elements into normal operations;
- Operational experience performance measures that would be used by regulators, air carriers and 142 Training Centers in the training and evaluation of pilots to evaluate the pilot's ability to deal with complex operational events and anomalies;
- Approved training programs to actively incorporate structured feedback from several sources such as line operations and training results (ASAP, instructor observations, evaluations);
- Assurance that flight safety and training managers are appropriately educated about human factors considerations, particularly with regard to automated systems and new operations; and
- Allowance of air carriers and 142 Training Centers to develop training programs based on core competencies such as flight path and energy management while being permitted to exercise the benefits of proficiency based training and customize training as necessary around those core competencies.

These should be addressed regardless of whether the training is conducted under AQP or traditional training programs; or whether it is done at an air carrier or through a Part 142 training center. The FAA should work with industry to develop guiding principles and associated advisory material for training, operational procedures, and flightcrew qualification for the areas listed above. Note that the WG does NOT recommend an automation training aid, because the focus of the training needs to be on flight path management, with the use of automated systems as a subset of the flight path management tasks. This is consistent with the philosophy recommended for the operational policy for flight path management.

Regulators should address how the following areas are specified in the syllabus, content and conduct of training/qualification in flight path management systems:

- The levels of skill and knowledge to be demonstrated,
- The mix of training required with particular emphasis on the elements to be addressed during line training, and
- The promotion and retention of knowledge and skills for manual flight operations, which should include reassessment of recency requirements for flightcrews.

The FAA should reassess the airman certification criteria to ensure that pilots are released with a satisfactory level of skills for managing and using automated systems for flight path management. Since current training is often oriented toward preparing pilots for checkrides instead of the knowledge and skills necessary for pilot competency, the airman certification criteria should be reassessed to ensure appropriate coverage of the topics listed in the discussion above.

The industry should define the knowledge, skills, and abilities associated with "airmanship" for current and future operations and develop procedures and training methods for training these knowledge and skills, including decision making abilities for current and future pilots to use in modern and future aircraft and airspace operations. In addition, the industry needs to develop procedures and training guidance on how pilots should monitor and cross-verify automated systems.

In the past pilots were taught to monitor their instruments and were taught an "instrument crosscheck." An effective instrument cross verification is one of the fundamental skills that pilots need to manually fly any aircraft, automated or not. But the instrument verification and monitor functions become more difficult as automated systems are added and the items that must be monitored are increased. Pilots are taught how to interface with the automated systems, make inputs to achieve the desired result, and then told to monitor, but they are usually not taught how to monitor or what to monitor. For example, when a pilot makes a change to the MCP, what are they required to look at in order to confirm that the automated systems received and then made the inputs? Then how does the pilot monitor the automated systems to ensure that the desired flight path result will be achieved? Pilots are told to monitor, but many don't know the best way to accomplish the task. These skills need to be updated for today's modern airplanes and airspace.

To address some of the complexity and human performance issues with RNAV arrivals, several operators have recently established guidance and requirements for briefing RNAV arrivals during cruise flight, similar to how an instrument approach is briefed. Training programs spend many hours having the pilots briefing and conducting instrument approaches in simulators, which always require a full brief of the procedure. This, historically, has not been the case with RNAV arrivals.

Most of the knowledge-related recommendations from the 1996 FAA report are re-included in this recommendation because the WG analysis shows that they are still issues and have not been completely resolved.

Recommendation 14 - Instructor/Evaluator Training and Qualification.
Review and revise, as necessary, guidance and oversight for initial and recurrent training and qualification for instructors/evaluators. This review should focus on the development and maintenance of skills and knowledge to enable instructors and evaluators to successfully teach and evaluate airplane flight path management, including use of automated systems.

Finding(s) addressed:
Finding 1 – Pilot Mitigation of Safety and Operational Risks.
Finding 2 – Manual Flight Operations.
Finding 3 – Managing Malfunctions.
Finding 4 – Automated Systems.
Finding 5 – Pilot-to-Pilot Communication and Coordination.
Finding 6 – Communication and Coordination between Pilots and Air Traffic Services.
Finding 7 – Standard Operating Procedures.
Finding 8 – Data Entry and Cross Verification Errors.
Finding 9 – Operator Policies for Flight Path Management.
Finding 10 – Task/Workload Management.
Finding 11 – Pilot Knowledge and Skills for Flight Path Management.
Finding 12 – Current Training Time, Methods and Content.
Finding 13 – Flight Instructor Training and Qualification.

Related recommendations:
Recommendation 13 - Pilot Training and Qualification.

Discussion:
In the WG interview data, many instructors stated they would benefit from better instructor training on how to teach the use of automated systems as well as instruction on the underlying principles and intricacies of how the automation works. Many instructors stated that this improved training would improve the quality of the training they provided and increase pilot proficiency using flight path management automated systems during line operations.

Operators should provide a method of ensuring that instructors are prepared to properly train the flight path management elements included in the training program. Instructors should also have current line experience so they can provide realistic scenario-based training of the use of automated systems for flight path management, incorporating known issues facing pilots in line operations. This should include specific training and experience on stall and upset prevention and recognition so instructors can provide effective training on recognizing and managing situations that could result in a stall or upset while using automated systems for flight path management.

The 2011 Boeing study on worldwide airline pilot perspectives on training effectiveness also revealed that improved instructors/evaluators are part of the solution for creating more positive experiences in training. The study mentions train the trainers, standardize trainers, and monitor/assess trainers as possible solutions. Instructors and Evaluators need to be trained to have a common way to look at evaluation – expanded standard that needs to be met. This will vary based on airline culture and needs, where and how they operate. This is related to recommendation 13 and addresses training for using operational performance measures.

Familiarity with line operations is critical to instructor /evaluator as new automated systems and airspace changes are introduced with the implementation of NextGen. Current experience is especially important for new instructors that have never been in the airplane. Instructors without line experience or observations can teach the facts but cannot teach the experience, if they do not have it.

This is particularly important with new technologies and for NextGen. Instructors need to have experience at least in observing operations on the line not just flying the simulator. Observations provide experience so that instructors can simulate a realistic operational environment. There are certain attributes that are lost if observations are not done on the line such as realism, unexpected anomalies that occur on almost every flight, distractions, changes that affect situation awareness, understanding how pilots are flying versus how they are trained. Such observations can also be structured to provide feedback back into the system.

Based on the above information, regulatory guidance and requirements for training and certification should be expanded to address:

- Identify required instructor skills and experience for training the use of automated tools for flight path management.
- Guidance for training instructors (train the trainer) on "how to teach" automation skills.
- Integrated scenario-based training with CRM/TEM.
- Training and qualification requirements for trainers, including recurrent training, for the areas listed in Recommendation 12 above.
- Require air-carriers and 142 Training Centers to provide advanced training to instructors and evaluators that include the evaluation of a pilot's ability to deal with complex operational events and anomalies that are aircraft centric.
- Instructor training for how to provide stall and upset prevention, recognition and recovery training, especially when using automated systems for flight path management.
- Develop operational experience performance measures that would be used by regulators, air carriers and 142 Training Centers in the training and evaluation of pilots to evaluate the pilot's ability to deal with complex operational events and anomalies.
- Reinforce the importance of Line Observation programs for instructors/evaluators that do not fly the line.

The 1996 FAA report did not specifically address instructor training.

<u>Recommendation 15 - Regulatory Process and Guidance for Aircraft Certification and Operational Approvals.</u>

Improve the regulatory processes and guidance for aircraft certification and operational approvals, especially for new technologies and operations, to improve consideration of human performance and operational consequences in the following areas:

- Changes to existing flight deck design through STCs, TSOs, or field approvals, and
- Introduction of new operations or changes to operations, to include implications for training, flightcrew procedures, and operational risk management.

Finding(s) addressed:
Finding 20 – Knowledge and Skills of Regulators.

Finding 21 – Regulatory Process for New Technologies or Operations.

Related recommendations:
None.

Discussion:
Improve the current TSO, STC and field approval processes so that the airplane manufacturer's original design philosophy and operating assumptions (considered during the original type certification process) are not adversely affected. This is intended to preclude adverse effects on flightcrew operations by equipment changes that may not fully consider the original design intent, assumptions or characteristics.

Another consideration is that changes to the flight deck should address design-related pilot error. Although 14 CFR Part 25.1302 has been introduced, it may or may not be applied, depending on the Changed Product Rule (CPR) 14 CFR 21.101 applicability (this is true for EASA, as well). The guidance for CPR should also highlight, with the use of appropriate examples, that human performance aspects may also be part of the areas potentially affected by a change to the flight deck. This may be particularly important to address for aircraft updates to implement NextGen capabilities.

As new systems and technologies are developed, regulatory guidance should respond such that the benefits of the technology and operations can be further exploited by subsequent advances and not strictly limited to the original implementation methodology.

This regulatory guidance should explicitly address pilot performance considerations, including updates necessary in training, recency of experience, and flightcrew procedures.

Education of regulatory personnel will be a critical part of making these improvements, especially for NextGen In addition, these personnel need to stay informed about operational experience as new capabilities and operations are implemented.

The 1996 FAA report addressed this topic in several recommendations, including Comm/Coord-3, Comm/Coord-6, Knowledge-9, Knowledge-10, and Knowledge-11.

Recommendation 16 – Flight Deck Equipment Standardization.

Develop standards to encourage consistency for flightcrew interfaces for new technologies and operations as they are introduced into the airspace system. Standards should be developed which establish consistency of system functionality (from an airspace operations perspective) for those operations deemed necessary for current and future airspace operations.

Finding(s) addressed:
Finding 15 – Flight Deck Equipment Standardization.

Related recommendations:
Recommendation 12 – Flight Deck Equipment Design Process and Resources.

Discussion:
Several groups are working on standards for future operations, including RTCA, SAE, etc. As new flightcrew interfaces are developed, or existing flightcrew interfaces are modified to include new functionality for new operations, standardization of those interfaces should be encouraged to avoid the further proliferation of interfaces for the pilots to use.

For FMS functionality, the FMS Standardization subgroup of the CNS Task Force worked on this general topic, and has turned over their work to the RTCA Special Committee 227. This work should be encouraged, with recommendations to be provided to the PARC. Most of the work is simply updating the language in DO-236B to reflect more recent activities in RNP. However, there are several new initiatives being considered which would warrant a common implementation method that would provide air traffic services with predictable aircraft performance while providing flightcrews with a consistent operation across aircraft platforms. For example, here is a subset of those operations being proposed:

- Continuous LNAV – provides lateral path guidance shortly after takeoff and during go-arounds.
- Speed constraints on terminal procedures – implements AT, AT-OR-BELOW and AT-OR ABOVE speeds at waypoints.
- Lateral turn performance – specifies turn performance for fly-by turns and also implements fixed radius transitions for the enroute segment.
- Wrong Runway alert – alerts the flightcrew if beginning a takeoff on the incorrect runway.
- Temperature compensation – automatically adjusts for cold and hot temperatures in the terminal area.
- Parallel offsets – standardizes the entry and exit of offsets.

The 1996 FAA report made the following related recommendations: SA-6, SA-7, Culture-4.

<u>Recommendation 17 – Monitor Implementation of New Operations and New Technologies.</u>
Encourage the identification, gathering, and use of appropriate data to monitor implementation of new operations, technologies, procedures, etc. based on the specified objectives for safety and effectiveness. Particular attention should be paid to human performance aspects, both positive and negative.

Finding(s) addressed:
Finding 24 – Means of Organizing and Analyzing Safety Data.

Related recommendations:
Recommendation 18 – Methods and Recommended Practices for Data Collection, Analysis, and Event Investigation That Address Human Performance and Underlying Factors.

Discussion:
As NextGen applications are implemented, data should be collected to encourage timely implementation of changes to address issues as they arise. ASIAS is a mechanism to allow this to be done, but timely access to results of data collection and analysis will be important, for monitoring of safety and operational effectiveness.

In addition, any information pertinent to pilots associated with changes to existing operations or new operations such as those proposed above should be published in the appropriate FAA pilot document so all pilots have access to the background information to help promote system understanding

The 1996 FAA report addressed this area in Recommendation Measures-1.

Recommendation 18 – Methods and Recommended Practices for Data Collection, Analysis, and Event Investigation That Address Human Performance and Underlying Factors.

Develop methods and recommended practices for improved data collection, operational data analysis and accident and incident investigations. The methods and recommended practices should address the following:

- When reviewing and analyzing operational, accident and incident data, or any other narrative-intensive dataset, ensure that the team has adequate expertise in the appropriate domains to understand the reports and apply appropriate judgment and ensure that the time allotted for the activity is adequate.
- Explicitly address underlying factors in the investigation, including factors such as organizational culture, regulatory policies, and others.
- Provide guidance on strengths and limitations of different data sources and different methodologies and taxonomies.
- Encourage the use of multiple, dissimilar data sources to provide better coverage of events.
- Encourage the wide sharing of safety related information and analysis results, especially lessons learned and risk mitigations.
- Encourage the wide sharing of safety related information and analysis results especially lessons learned and risk mitigations.

Finding(s) addressed:
Finding 1 – Pilot Mitigation of Safety and Operational Risks.
Finding 23 – Data Sources Strengths and Limitations.
Finding 24 – Organizing and Analyzing Safety Data.
Finding 25 – Sources of Data about Positive Behaviors.
Finding 26 – Variability in Safety Event Investigations.
Finding 28 – Precursors to Accidents.

Related recommendations:
None.

Discussion:
Ensure that when groups are gathering and analyzing safety data, clear objectives are developed and that those objectives guide the choices of data to collect and analyses to be accomplished. The strengths and weaknesses of data sources and categorization schemes should be considered when making these decisions.

This recommendation refers to the latent or underlying factors (such as, organizational culture, equipment design, or policies). As discussed previously, there is a lack of data available on most aspects of an accident or incident, since data are collected primarily from “the front line.”

The 1996 FAA report addressed this topic in Recommendations Measures-1 and Measures-2.

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5 Concluding Remarks

The Working Group found that the aviation system is very safe, and identified numerous areas that contribute to safety and operational effectiveness. However, vulnerabilities within the aviation system relating to the operational use, equipment design, and management and training of flight path management systems were identified from the accident, incident and operational data reviewed by the Working Group.

Since the Working Group completed its data collection and analysis, several accidents have occurred where the investigative reports identified vulnerabilities in the events that are similar to those vulnerabilities identified in this report. These vulnerabilities represent systemic issues that continue to occur. Examples of accident reports that were published after the WG stopped its data collection include Colgan 3407 (NTSB 2010a); Air France 447 (BEA 2012); Turkish Airlines 1951 (Dutch Safety Board 2010), and others.

Some underlying themes that the Flight Deck Automation Working Group has identified include complexity (in systems and in operations); concerns about pilot skill degradation; and integration and interdependence of the components of the overall aviation system. As discussed in the report, complexity in airspace operations is increasing, and as the flexibility increases, as enabled by future changes, so does the complexity and potential for unexpected events. Pilots must be prepared for dealing with the unexpected, and the equipment design, training, procedures and operations must enable them to do so.

The recommendations represent both short term and long term approaches to addressing the issues. These recommendations address the immediate vulnerabilities, as well as the characteristics of the aviation processes that enable the vulnerabilities to exist. The Working Group believes that implementing these recommendations is necessary to make improvements in safety and operational effectiveness, especially considering the expected changes in future operations.

Regardless of how low the accident rate gets, all stakeholders must remain vigilant to ensure that risks are continuously evaluated. The ongoing evolution in airspace operations will require careful attention to managing change to maintain or improve safety and achieve the operational improvement that is desired.

Acronyms and Abbreviations

AAIB	Aircraft Accident Investigation Board
AC	Advisory Circular
AMC	Acceptable Means of Compliance
AQP	Advanced Qualification Program
AR	Authorization required
AEG	Aircraft Evaluation Group
ANSP	Air Navigation Service Provider
ASAP	Aviation Safety Action Program
ASIAS	Aviation Safety Information Analysis System
ASBU	Aviation System Block Upgrade
ASRS	Aviation Safety Reporting System
ATIS	Automatic Terminal Information Service
ATS	Air Traffic Services
ATSB	Australian Transportation Safety Board
ATM	Air Traffic Management
BEA	Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile
CAA	Civil Aviation Authority
CAST	Commercial Aviation Safety Team
CDU	Control Display Unit
CFIT	Controlled Flight Into Terrain
CFR	Code of Federal Regulations
CPR	Changed Product Rule
CRM	Crew Resource Management
CS	Certification Specification
EASA	European Aviation Safety Agency
EFB	Electronic Flight Bag
EFVS	Enhanced Flight Vision Systems
ERC	Event Review Committee
ESL	English as a Second Language
FAA	Federal Aviation Administration
FCU	Flight Control Unit
FGS	Flight Guidance System
FMS	Flight Management System
FOQA	Flight Operations Quality Assurance
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GS	Glide Slope
HF	Human Factors
HUD	Heads-up Display
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFP	Instrument Flight Procedure

ILS	Instrument Landing System
JIMDAT	Joint Implementation Measurement Data Analysis Team
JPDO	Joint Program Development Office
LOC	Loss of Control
LOE	Line Oriented Evaluation
LOSA	Line Operations Safety Audit
MCP	Mode Control Panel
NAS	National Airspace System
NDB	Non-Directional Beacon
NTSB	National Transportation Safety Board
OEM	Original Equipment Manufacturer
OEP	Operational Evolution Partnership
PARC	Performance-based Operation Aviation Rulemaking Committee
PBN	Performance-Based Navigation
PF	Pilot Flying
PM	Pilot Monitoring
PNT	Position, Navigation, and Timing
RA	Resolution Advisory
RNAV	Area Navigation
RNP	Required Navigation Performance
SAAAR	Special Aircrew-Aircraft Authorization Required
SESAR	Single European Sky ATM (Air Traffic Management) Research
SMS	Safety Management System
SID	Standard Instrument Departure
SOP	Standard Operating Procedure
STC	Supplemental Type Certificate
TA	Traffic Advisory
TAWS	Terrain Awareness and Warning System
TBO	Trajectory-Based Operations
TCAS	Traffic Collision Alert System
TEM	Threat and Error Management
TSB	Transportation Safety Board
TSO	Technical Standard Order
VNAV	Vertical Navigation
VOR	Very High Frequency Omni-directional Range
WG	Working Group

Appendix A Terms of Reference

PARC/CAST Flight Deck Automation Working Group
Terms of Reference

1.	**Statement of Objective, i.e. what is the problem/requirement:** In the past decade, major improvements have been made in the design, training, and operational use of onboard systems for flight path management (autopilot, flight director, flight management systems, etc. and their associated flightcrew interfaces). In spite of these improvements, incident reports suggest that flightcrews continue to have problems interfacing with the automation and have difficulty using these systems. But appropriate use of automation by the flightcrew is critical to safety and effective implementation of new operational concepts, such as RNAV and RNP. The objective of this joint PARC/CAST working group is to review operational experience with modern flight deck systems and recommend and prioritize actions to address the safety and efficiency-related aspects of their use in current and projected transport aircraft operations.
2.	**Statement of scope of task/activity:** PARC and CAST will establish a joint working group that will recommend and prioritize actions to address, for current and projected operational use, the safety and efficiency of modern flight deck systems for flight path management (including energy-state management). These systems include autopilot, flight director, autothrottle/autothrust, and flight management systems and associated flightcrew interfaces in the following: • Part 121 transport aircraft operations, • Jet transport aircraft operating with two-pilot "121-like" operations, including air carrier operations under Part 135, Part 91 Subpart K, or Part 91 that use Part 142 training schools. This will include equipment design, operational policies, flightcrew procedures, and flightcrew qualification and training.
3.	**What is the expected deliverable/product:** • Review relevant accident/incident data from the past 5 to 10 years to identify human performance issues associated with the use of automation for flight path management. This activity can be used to refine and evolve, as appropriate, CAST's proposed proactive incident analysis process. • Compilation and analysis of relevant accident / incident reports involving the use of this equipment for flight path and energy state management. • Analysis of current and projected operational use with flight deck systems for flight path and energy-state management, to identify potential safety vulnerabilities. This will include a review of current experience and current practices embodied in training programs and operational procedures for the use of automation for flight path and energy-state management. • A review of the outstanding recommendations issued in the 1996 FAA HF Team Report, and update/revision of these recommendations, as appropriate. • Automation management training aid for flight path and energy-state management, as appropriate. • Operational guidelines for use of automation for flight path and energy-state management, including policies and procedures. • As appropriate, recommended revisions to relevant FAA Advisory Circulars, such as AC 120-51 on CRM Training, or the creation of, or revision to, other applicable ACs and other guidance, to incorporate information on automation training and procedures for automation management. • Specific recommendations for relevant industry standards documents to communicate recommended practices for use of flight deck systems for flight path and energy-state management. • Recommendations for improved standardization for flightcrew interfaces with these

	systems in Part 25 aircraft, as appropriate.
4.	**Special Considerations: None**
5.	**What is the schedule of activities:** Tasks A-C should be completed in nine months; the remainder to be complete in 30 months (the exact time period will depend on the results of the initial analysis). A. Review incident/accident data and relevant research B. Review current state of automation training and operational usage C. Review outstanding recommendations issued in FAA HF Team Report, and recommend ways to have those implemented, as appropriate. D. Identify automation training topics E. Develop automation training content F. Develop guidance for operational use of automation G. Develop recommendations for industry and other standards. H. Review applicability of the WG products for other portions of the operational community (e.g., general aviation, including single-pilot very light jets, rotorcraft, Part 125 operators) I. Based on information gathered during the above activities, investigate other automated systems that indicate potential safety hazards.
6.	**Related Activities:** This is a joint activity with CAST (Commercial Aviation Safety Team). 1. CAST is working with the carriers (with ATA's assistance) and manufacturers to identify automation aspects of mode awareness and energy state management current business practices for training automation mode awareness and energy state management as a short-term tactical solution to CAST Safety Enhancement-30. Appropriate findings from this activity will be provided to the PARC/CAST Working Group. 2. The PARC/CAST WG products will be provided to the CAST for the development and implementation of safety enhancements, using the CAST process and to the PARC for appropriate PARC action. It is desirable that CAST and PARC coordinate their recommendations to ensure they are not at cross purposes. 3. The PARC/CAST WG will use the supporting info from CFIT, LOC, and approach and landing, etc. to enable the effort to review the causal analysis event sequence spreadsheets to look for automation related issues that are crosscutting so that data may be combined with incident/event data. Additionally this WG will coordinate with other external and PARC Working Groups and Action Teams, as appropriate.
7.	**What are the resource requirements and commitments (e.g. who will be able to do it):** Each member of the core group is expected to spend up to an average of one week a month for 30 months, with meetings every other month (on average). This may vary depending on the findings of the initial data analysis.
8.	**What is the urgency/criticality:** Experience in RNP/RNAV implementation shows that appropriate use of flight deck systems by the flightcrew for flight path is critical for conducting safe RNP/RNAV operations.
9	**Who are the customers for the product/deliverable:** 121/135 air carriers, Part 91 Subpart K operators, the FAA, and manufacturers.
10.	**Will this result in PARC Recommendations or is this coordination to keep PARC aware of significant related activities:** The Working Group will provide input for PARC/CAST recommendations and keep the PARC and CAST aware of significant events and related activities.

Appendix B Topics for Discussion with Manufacturers and Operators

This Appendix contains the topics for manufacturers and the topics for operators that guided the structured interview discussions.

Topics to Guide the Discussions with the Manufacturers

Please be prepared to discuss the following topics. Include, as applicable, the specific supporting studies, data, etc.

Design and Operations Philosophy

1. Please describe your overall design philosophy and how it has evolved, especially over the last 10 years.
   - How do you decide which tasks get automated?
   - How are different operating environments (e.g., air traffic systems, operator practices, cultures) taken into account?
   - What specific studies, data sources, etc. have affected your design philosophy and in what way?
   - What operations philosophy do you recommend to your customers, if any?

2. When you learn of difficulties in service, how do you decide whether to introduce a design change, an operators bulletin, or a product improvement?

3. What changes in flight deck functionality and interface design do you see occurring in the future (five-, ten- and twenty years)?

Design Process

1. Please describe your flight deck design process, particularly in terms of the flight path management functions and the interfaces between the flightcrew and the onboard systems for flight path management..

2. In what ways do your customers influence the design, both in terms of the functions provided and how they are implemented?

3. How are human factors considerations identified and addressed?
   - At what point(s) in the design process does this occur?
   - What standards and methods do you use to test and evaluate human performance?

4. How are training considerations taken into account or anticipated during design?

5. How are flightcrew procedures developed and how does the development relate to the design process?

Design Features

1. How do you decide what flight path management modes to include?

2. How do you allocate tasks between crew members, and how do you incorporate that into the design?

Service Implementation

1. What training philosophy (or philosophies) do you recommend in regards to using the onboard systems to manage the airplane flight path?

2. Are there any generic issues involving crew qualification (e.g., training, checking, recency of experience) that should be addressed for either for all types or for a particular type of airplane?

3. What processes do you use to ensure the adequacy and accuracy of training tools and manuals?

4. How do you obtain and incorporate feedback from your customers?

In-Service Issues

1. What do you consider to be the most significant operational issues seen in service you're your aircraft or systems?

2. Please address the following areas of interest:

A. Crew awareness/feedback
- Mode awareness
- Mode changes
- Flight control positions
- Failures of the onboard systems for flight path management
- Behavior of the onboard systems for flight path management
- Trim setting and trim changes
- Thrust setting and thrust changes

B. Standardization of the flight path management interfaces

C. Envelope protection

D. Autopilot/Autothrottle/Autothrust
- Methods of engaging and disconnecting
- Mode selection (direct and indirect)
- Autopilot trim authority
- Force disconnects

E. Use of Heads-up Displays

F. Vertical Navigation

G. Crew Workload/Boredom/Complacency/Fatigue

H. Potential for manual flying skill degradation

I. Introduction of new technologies and new operations

Future Operations

1. What should this Team assume about future operations?
2. How will these future operations affect how pilots will manage the flight path of the airplane?

Standards, Policies, Processes, and Research

1. In what areas, if any, should the regulatory authorities change the current standards, policies, or processes in order to assure safe operation of present and future airplanes?

2. In what areas, if any, should the industry (including manufacturers and operators) change the current standards, policies, or processes in order to assure safe operation of present and future airplanes?

3. What areas, if any, should be addressed by research in order to assure safe operation of present and future civil airplanes?

4. What else do you think this Team should consider about the design, training, and operation of glass flight deck airplanes?

5. Do you have any additional suggestions for the Team in this or other areas?

Questions To Guide The Discussion With Operators

Operations

1. Do you have an overall philosophy for the use of flight deck automation*?* If so, what is it? How has it evolved over the last 10 years?

2. Did you develop this philosophy from the equipment that you had, or did you acquire equipment that fit this philosophy?

3. What issues do you see, if any, in the need to create operating policies, procedures, or checklists to supplement or compensate for design characteristics of your glass flight deck airplanes?

Training

1. Please describe your overall training environment and how it has changed over the last 10 years.

    1.2. What Type of Training do you provide? (Appendix H, AQP, other)?

    1.3. Describe the background/experience level of your typical training pilot?

    1.4. How are instructors trained to "teach" automation?

    1.4. What changes do you expect to see in the future?

2. Please describe your overall automation training philosophy and how it has evolved, especially over the last 10 years.

    2.1. What training philosophy do you adhere to, with respect to the use of automation and flight path management in glass flight decks?

    2.2. Do Captains and First Officers receive the same automation and flight path management training?

    2.3. Have there been modifications to training to accommodate different automation designs?

    2.4. If you have a mixed fleet of airplanes, have you experienced any automation training issues due to different types of aircraft?

3. Please comment on the *level of difficulty* pilots have in the following areas

    3.1. Understanding basic principles of the FMS.

    3.2. Learning to program the FMS (flight plans, holds, approaches, etc.)

    3.3. Learning proper selection of flight director modes

    3.4. Understanding the flight director and the Flight Guidance System

3.5. Learning to interpret information from EFIS and EICAS displays

3.6. Understanding and correctly using the autopilot

4. Which area(s) of flight deck automation takes the *most amount of time* in training to reach an acceptable level of understanding and performance? Why?

5. What element(s) of flight deck automation training do you feel you do not have time to adequately address during the initial training phase?

   5.1. Do you have sufficient time to address these carry-over training requirements during recurrent?

6. What are the biggest problems or failings in current training regarding flight deck automation?

7. What are the automation problem areas that keep appearing during training and line operations?

8. If you could change the way you teach automation, what changes would you make?

9. Can you identify any generic issues that affect crew qualification (e.g. training, checking, or recency of experience) that may need to be addressed industry-wide for all glass flight deck aircraft, or industry-wide for a particular type of glass flight deck airplanes?

10. Has your company done any research or studies on how to properly teach automation? If so, have the results been used to improve automation training?

11. What level of assistance / support do you receive from the manufacturer of the avionics suite for the solving of these problem areas?

12. Have you seen any effects of automation use affecting pilots maintaining their manual flying skills?

13. What do you think you do well in teaching Flight Path Management and Energy Management?

14. What would you like to see in future flight deck designs?

15. What else do you think this Team should consider about design, training and operation of glass flight deck airplanes?

<u>Design</u>

1. Have your crews experienced automation or flight path surprises, or mode confusion? What design characteristics, if any, have contributed to these?

2. In terms of flight deck design, do you have concerns about:

    2.1. Any specific aircraft type?

    2.2. Transfer of pilots between particular types?

    2.3. Particular types in certain settings, (e.g., at certain airports, or certain ATC systems, or certain weather conditions)?

3. What design issues or characteristics are you aware of, generically or by specific airplane type, that may be unduly contributing to difficulties regarding safe flight path management?

Standards, Policies, Processes And Research

1. What areas do you believe the Authorities should change in the standards, policies or processes to assure safer operation of present and future glass flight deck airplanes?

2. What areas do you believe the industry (manufacturing, operating, etc.) should change in the standards, policies or processes to assure safer operation of present and future glass-flight deck airplanes?

3. What areas do you think should be addressed in research to improve design and operation of present and future glass flight deck airplanes?

4. What else do you think this Team should consider about design, training and operation of glass flight deck airplanes?

5. Do you have any additional suggestions for the Team in this or other areas?

Appendix C Keywords used for ASRS Event Retrieval

Purpose of incident review and analysis:

To identify human performance issues associated with the use of automation for flight path and energy-state management

Data needs as described in Terms of Reference:

Review of modern flight deck systems for safety and efficiency-related aspects of use of flight path management (including energy-state management) in current transport operations. This includes:

- Autopilot
- Flight director
- Autothrottle/autothrust
- Flight management systems
- Associated flightcrew interfaces of:
    - Part 121 transport aircraft operations
    - Transport aircraft operating with two-pilot “121-like” operations including air carrier operations under
        - Part 135
        - Part 91 Subpart K
        - Part 91 that use Part 142 training schools

Timeframe: past 5 to 10 years

ASRS Query Criteria:

Date of Occurrence - Date as Year/Month: >=9601

Textual Information:
Incident Synopsis: ALL
Reporter Narrative: ALL

Aircraft One Detail:
Aircraft Advanced Flight deck: EFIS or HUD or Integrated NAV
Aircraft Operator Org: Air Carrier or Corporate
Aircraft mission: Passenger (one report), Cargo (another separate report with all the other search criteria the same)
Aircraft Handle: A1

Personnel One Detail:
Personnel Affiliation: Air Carrier
Role: Flightcrew
Person Number: P1

Aircraft types:
Heavy Transport
Large Transport
Light Transport
Med Large Transport
Medium Transport
Small Transport
Wide Body

Appendix D Accident and Major Incident Reports Used in Flight Deck Automation Working Group Analyses

Accident Investigation Board Finland (1996, July 10). *Aircraft accident at Kajaani Airport, Finland, 3 November 1994, DC-9-83 registered as F-GHED operated by Air Liberte Tunisie.* Translation of the Finnish original report. Major Accident Report Nr 2/1994. Helsinki, Finland: Multiprint. Retrieved from http://www.onnettomuustutkinta.fi/text/en/1279613867445.

> ***Summary:***
> "On Thursday November 3, 1994 at 06.57 local time an aircraft accident took place at Kajaani airport in which a Douglas DC-9-83 (MD-83) aircraft, registered F-GHED, owned by Gie Libellule 1 and operated by Tunisian Air Liberte Tunisie was severely damaged. … The accident was caused by a chain of flightcrew errors in the use of the auto throttle system and ground spoilers. The touchdown occurred approximately 600 m further than normal with substantial overspeed. The immediate brake application after touchdown without ground spoiler deployment, the main landing gear vibration characteristics and the overspeed led to the main landing gear vibration and damage during the landing roll. The left main landing gear brakes were lost. Reverse was applied only 10 s after touchdown and with a low thrust setting. As a result it was not possible to stop the aircraft on the remaining runway. The aircraft turned right and sideslipped of the runway mainly because only the right main landing gear brakes were effective."
>
> "Factors contributing to the accident were:
>
> 1. The 100 % high intensity approach and runway lights which possibly caused a visual illusion to captain's height observation just before he took the controls. According to the captain's statement the aircraft was above the glide slope at that time. The approach and runway lights were disturbingly bright in the prevailing conditions.
> 2. A change of duties between the piloting pilot and the monitoring pilot during the final phase of the final approach at a height of approximately 150 ft for which the pilots had no training nor the company established procedures.
> 3. An inadvertent TOGA button push which immediately caused engine thrust to increase towards go-around thrust setting and the flight guidance system mode to change to go-around mode.
> 4. The first officer did not perform the duties of the monitoring pilot after the change of duties, for example the ground spoiler operation was not monitored nor were the spoilers deployed manually. The flight guidance and auto throttle system mode changes were not observed and called out.
> 5. In general, the flight deck crew co-operation during the final phase of the final approach and landing was non-existent. The company practices, procedures and training did not support the team work of the flight deck crew." (Accident Investigation Board Finland, 1996)

Aeronautica Civil of the Republic of Colombia (1996, November 6). *Controlled Flight Into Terrain, American Airlines flight 965, Boeing 757-223, N651AA, Near Cali, Colombia, December 20, 1995*. Santafe de Bogota, DC, Colombia: Aeronautica Civil of the Republic of Colombia.

Summary:
"At 2142 eastern standard time (est) [l], on December 20, 1995, American Airlines Flight 965 (AA965), a Boeing 757-223, N651AA, on a regularly scheduled passenger flight from Miami International Airport (MIA), Florida, USA., to Alfonso Bonilla Aragon International Airport (SKCL), in Cali, Colombia, operating under instrument flight rules (IFR), crashed into mountainous terrain during a descent from cruise altitude in visual meteorological conditions (VMC)."

"Aeronautica Civil determines that the probable causes of this accident were:

1. The flightcrew's failure to adequately plan and execute the approach to runway 19 at SKCL and their inadequate use of automation.
2. Failure of the flightcrew to discontinue the approach into Cali, despite numerous cues alerting them of the inadvisability of continuing the approach.
3. The lack of situational awareness of the flightcrew regarding vertical navigation, proximity to terrain, and the relative location of critical radio aids.
4. Failure of the flightcrew to revert to basic radio navigation at the time when the FMS-assisted navigation became confusing and demanded an excessive workload in a critieal phase of the flight.

"Contributing to the cause of the accident were:

1. The flightcrew's ongoing efforts to expedite their approach and landing in order to avoid potential delays.
2. The flightcrew's execution of the GPWS escape maneuver while the speedbrakes remained deployed.
3. FMS logic that dropped all intermediate fixes from the display(s) in the event of execution of a direct routing.
4. FMS-generated navigational information that used a different naming convention from that published in navigational charts."

(Aeronautica Civil of the Republic of Colombia, 1996, November 6)

Aeronautical Accident Investigation and Prevention System (2008). *Aircraft Accident Involving PR-GTD and N600XL, Mid-Air Collision within the Amazonic Flight Information Region (FIR), 29 September 2006.* Final Report A-00X/CENIPA/2008. Brazil: Aeronautical Accident Investigation and Prevention System (SIPAER).

Summary:
"This Final Report refers to the accident of 29 September 2006, typified as MID-AIR COLLISION, an occurrence that involved one regular air transport and one executive aircraft. The regular air transport airplane was a Boeing 737-8EH, manufactured in the United States and registered in Brazil as PR-GTD, operated by the Brazilian airline company 'Gol Transportes Aéreos S.A.'. The executive airplane, an Embraer-135 BJ Legacy, manufactured in Brazil and registered in the United States as N600XL, was

operated by the American company 'ExcelAire Services, Inc.' … At 19:56 UTC, the two aircraft collided head on at flight level FL370, striking each other on their left wings, next to NABOL position, within the Amazonic Flight Information Region (FIR). They had been flying in opposite directions along airway UZ6, which connects Manaus and Brasilia terminal areas. ... The evidence collected during this investigation strongly supports the conclusion that this accident was caused by N600XL and GLO1907 following ATC clearances which directed them to operate in opposite directions on the same airway at the same altitude resulting in a midair collision. The loss of effective air traffic control was not the result of a single error, but of a combination of numerous individual and institutional ATC factors, which reflected systemic shortcomings in emphasis on positive air traffic control concepts. Contributing to this accident was the undetected loss of functionality of the airborne collision avoidance system technology as a result of the inadvertent inactivation of the transponder on board N600XL. Further contributing to the accident was inadequate communication between ATC and the N600XL flightcrew." (Aeronautical Accident Investigation and Prevention System, 2008)

Air Accidents Investigation Branch (1999, April). *AAIB Bulletin: Loss of altitude following takeoff, Airbus A310, 5Y-BFT on November 8, 1998.* AAIB Bulletin No: 4/99. Ref: EW/C98/11/01. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

Summary:
"The aircraft was departing Heathrow for Nairobi Airport on a Midhurst 3G Standard Instrument Departure (SID). It appeared to take off normally and climb to about 600 feet agl before the nose dropped and the aircraft lost height. After a few seconds the aircraft regained a normal climbing flight path and continued the departure. The visibility was reported as 10 km with few at 1,200 feet and overcast at 1,700 feet. The manoeuvre was seen by people who reported the aircraft's abnormal behaviour to air traffic control. Later during the departure, when the flightcrew were asked if they had encountered a problem after take off, the reply was "we had a problem with our landing gear, it refused to go up and we had a slight problem with the flight director". The AAIB were informed whereupon relevant radar and RTF tapes were impounded for analysis." (Aircraft Accident Investigation Branch, 1999, April)

"In this incident reversion to SPD - V/S - HDG took place on the runway and so when the FCC reset, it produced demands for SPD (V2) on the A/THR and zero vertical speed in pitch on the Flight Director. The commander quite rightly ignored the FD pitch-down command and because the A/THR clutches were disengaged, the thrust levers did not retard to satisfy the V2 command until the gear lever was first raised. When the lever was raised the aircraft was most probably flying faster than V2 and so the thrust levers were retarded at much the same time as the ECAM warning was triggered. It is quite probable that the during the next few seconds, both pilot focused their attention on resolving the gear problem and neither noticed the thrust levers being retarded. With the commander holding a climbing pitch attitude instead of satisfying the FD demand for level flight, the airspeed was bound to reduce rapidly. Although thrust should have been restored when the aircraft decelerated to V2, the time required for the engines to accelerate from low power to high power may have resulted in a speed excursion below V2 from which the commander recovered by lowering the aircraft's nose and trading height for airspeed." (Aircraft Accident Investigation Branch, 1999, April)

Air Accidents Investigation Branch (2000, October). *AAIB Bulletin: Uncommanded pitch-down on landing, Boeing 747-236B, G-BDXJ on 15 May 2000.* AAIB Bulletin No: 10/2000. Ref: EW/G2000/05/16. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

Summary:
On 15 May 2000, a Boeing 747-236B aircraft registered as G-BDXJ "was operating a scheduled return flight from Miami to London Heathrow Airport. The weather conditions on arrival at Heathrow were dry with light winds and good visibility. The crew were carrying out an automatic landing on Runway 27L for practice purposes. The aircraft was configured during the approach for an automatic landing with all three autopilots engaged. (The three autopilots are designated 'A', 'B' and 'C' channels for identification purposes). At 1,000 feet radio height the 'A' channel autopilot disengaged itself, but the approach was continued as the aircraft retains full automatic landing capability with two autopilot channels engaged. The approach down to the flare was satisfactory and the automatic flare manoeuvre was correctly initiated by the autopilot at 50 feet radio height, when the control column moved backwards to raise the nose of the aircraft and slow the rate of descent before touchdown. At about 30 feet radio height however, the control column moved forward unexpectedly and the aircraft began to pitch nose down. The pilot rapidly intervened by disengaging the autopilot and pulling back sharply on the control column, but there was insufficient time to arrest the high rate of descent which had developed and the aircraft landed very firmly. There were no injuries to passengers or crew, but the aircraft sustained minor airframe damage." (Air Accidents Investigation Branch, 2000, October)

Air Accidents Investigation Branch (2001, June). *AAIB Bulletin: AIRPROX, Airbus A330 C-GGWD, Airbus A340 TC-JDN on 2 October 2000.* AAIB Bulletin No: 6/2001. Ref: EW/C2000/10/2. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

Summary:
On 2 October 2000, an Airbus A340 aircraft registered as TC-JDN and an Airbus A330 registered as C-GGWD were flying the North Atlantic Track E. "The A340 was en-route from Istanbul to New York and the A330 was en-route from London to Ottawa. Both aircraft were assigned to North Atlantic (NAT) Track E with an entry point into Oceanic Airspace of 58°North 10°West and a next reporting point of 59°N 20°W. Both aircraft were cleared by the Scottish Oceanic Area Control Centre to cruise at Mach 0.82 with the A340 at Flight Level (FL) 360 and the A330 1,000 feet above at FL 370. The vertical separation distance of 1000 feet was in accordance with RVSM (Reduced Vertical Separation Minima) used by approved aircraft within NAT MNPS (Minimum Navigation Performance Specification) Airspace. … The incident began when both aircraft deviated from their assigned flight levels whilst the lateral separation between them was less than nautical two miles triggering TCAS RA warnings in both aircraft. Initially the risk was minimal because when TCAS RAs were issued, the aircraft were about 800 feet vertically

separated with transient variations in vertical speed due to the turbulence; at that stage the A340 had not begun its 'zoom climb'. The incident became serious about 10 seconds later when the A340's flight control system captured alpha prot and commenced a vigorous climb which resulted in the A340 climbing through the A330's assigned flight level whilst both aircraft were laterally separated by a few hundred feet." (Air Accidents Investigation Branch, 2001, June)

Air Accidents Investigation Branch (2001, November). *AAIB Bulletin: Autoflight failure, Airbus A319-131, G-EUPV on 9 August 2001.* AAIB Bulletin No: 11/2001. Ref: EW/G2001/08/10. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

Summary:
On 9 August 2001, an Airbus A319-131 aircraft registered as G-EUPV on approach to London Heathrow Airport experienced an "uncommanded disengagement of both the Autopilot and Autothrust systems. The commander took positive manual control of the aircraft. The disengagements were coincident with multiple Warnings and Cautions on the Electronic Centralised Aircraft Monitoring (ECAM) display. Multiple crew procedures were therefore displayed for action. The commander reported that the pattern and sequence of these failure messages, which included ADR Disagree, ADR Fault, Auto Flight Rudder Travel Limit and Flight Augmentation Computer (FAC)2 amongst others, did not indicate a single recognisable failure. … The commander issued a PAN call to advise ATC and the crew carried out the appropriate ECAM actions as displayed. … The approach was continued with the aircraft in 'Alternate Law' flight control mode. … The commander carried out an uneventful landing in 'Direct Law' using configuration 3, with an approach speed appropriately increased in accordance with the manufacturer's recommended procedures. … After landing, the crew halted the aircraft when clear of the runway to fully assess the situation prior to taxiing to the parking stand. Once parked, the passengers deplaned normally." (Air Accidents Investigation Branch, 2001, November)

Air Accidents Investigation Branch (2004, December). *AAIB Bulletin: Acceleration to speed well above VMO, Airbus A320-232, G-TTOA on 15 April 2004.* AAIB Bulletin No: 12/2004. Ref: EW/G2004/04/14. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

Summary:
On 15 April 2004, an Airbus A320-232 aircraft registered as G-TTOA was "commencing the approach for Malaga Airport. … On passing FL220 the aircraft was descending at 4,800 ft/min and maintaining a speed of between M 0.78 and M 0.79. The CAS had increased to 349 kt and the Mach number was approaching VMO with the speed trend arrow indicating a continued acceleration to a speed well above VMO. The commander called "speed" to the co-pilot and a lower Mach number, equivalent to 320 kt CAS, was selected on the FCU although the autopilot and autothrottle were kept in the MACH mode. One second later the autopilot was disconnected and a further second later both pilots simultaneously applied aft stick demands of approximately 10° each in an attempt to prevent an overspeed. This resulted in the aircraft experiencing a sudden increase in

normal acceleration, peaking at 2g, before returning to about 1g. For a further eight seconds both pilots continued to make inputs on their respective side stick controllers, with neither pilot pressing their sidestick take-over button. The autothrust remained engaged throughout and no speedbrake was used. … After the incident the aircraft continued to make a normal landing at Malaga where medical assistance was provided." (Air Accidents Investigation Branch, 2004)

Air Accidents Investigation Branch (2005). *AAIB Special Bulletin S2/2005: Instrument failure, Airbus A319-131, G-EUOB on 22 October 2005.* AAIB Bulletin No: S2/2005. Ref: EW/C2005/10/05. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

Air Accidents Investigation Branch (2006). *AAIB Special Bulletin S3/2006: Instrument failure, Airbus A319-131, G-EUOB on 22 October 2005.* AAIB Bulletin No: S3/2006. Ref: EW/C2005/10/05. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

Summary:
On 22 October 2005 an Airbus A319-131, registration G-EUOB "departed London Heathrow at 1918 hrs on a scheduled flight to Budapest. At 1926 hrs, as it approached FL200 in clear weather conditions, the crew reported that there was an audible 'CLUNK' and the flight deck became dark with a number of electrical systems and flight information displays were lost.… The primary flight instruments and most other systems were restored after selection of the 'AC ESS FEED' push button switch, in accordance with the ECAM procedure. The aircraft was in the degraded condition for a period of about two minutes. … After landing all the remaining affected systems were successfully reset by a maintenance engineer and the aircraft continued in operation for six days with no further electrical failures reported." (Air Accidents Investigation Branch, 2005)

Air Accidents Investigation Branch (2005). *AAIB Special Bulletin S1/2005 Airbus A340-642, G-VATL serious incident en-route from Hong Kong to London Heathrow on 08 February 2005.* AAIB Bulletin No: S1/2005. Ref: EW/C2005/02/03. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

Air Accidents Investigation Branch (2006, February). *AAIB Bulletin: Multiple system failures, Airbus A340-642, G-VATL on 8 February 2005.* AAIB Bulletin No: 2/2006. Ref: EW/C2005/02/03. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

Summary:
On 8 February 2005 an Airbus A340-642, registration G-VATL flew from Hong Kong to London Heathrow. "FMC failures, engine failure, and a possible fuel leak affected this Airbus A340 flight and ended up in the declaration of a Mayday." (Air Accidents Investigation Branch, 2006, February)

After declaring 'MAYDAY', the aircraft diverted to Amsterdam. "When the diversion commenced the total fuel on board was in excess of 25,000 kg but there were significant quantities of fuel located in the trim, centre and outer wing fuel tanks. Manual fuel transfer was started by the flightcrew but they did not see immediately the expected indications of fuel transfer on the ECAM. Consequently, the flightcrew remained uncertain of the exact fuel status. The diversion to Amsterdam continued and the aircraft landed there without further technical problems." (Air Accidents Investigation Branch, 2005).

"Although a low fuel level in the engine feeding fuel tanks should normally never occur (when the system is operating correctly) this investigation has shown that when the system fails to operate correctly and if the crew are not aware of the situation, they are unable to act in an appropriate manner and prevent engine fuel starvation." (Air Accidents Investigation Branch, 2006, February)

Air Accidents Investigation Branch (2006, January). *AAIB Bulletin: ILS interference with autoland, Boeing 757-3CQ, G-JMAA on 23 November 2004.* AAIB Bulletin No: 1/2006. Ref: EW/C2004/11/05. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

Summary:
On 23 November 2004, a Boeing 757-3CQ aircraft registered as G-JMAA "rolled unexpectedly during the flare phase of an automatic landing at Manchester International Airport. The commander disconnected the autopilots and landed safely. The aircraft rolled in response to temporary interference of the ILS localiser signal caused by a departing Embraer 145 aircraft; this aircraft took off immediately prior to the Boeing 757's landing. Low Visibility Procedures (LVPs), which are intended to protect aircraft carrying out automatic landings, had been cancelled a short time before the incident but this information was not communicated to the Boeing 757 crew. … Communications within the ATC unit were central to the incident. About one hour before the incident the decision was taken to introduce LVPs on account of the rapidly deteriorating weather conditions. However, when LVPs were introduced, neither the Approach nor the Director controllers placed LVP reminder strips into their displays. … This incident identified several anomalies in the system by which LVP information was communicated to pilots. ATIS is used not only to communicate LVP status, but also other safety-critical information such as runway in use, meteorological conditions, and Essential Aerodrome Information." (Air Accidents Investigation Branch, 2006)

Air Accidents Investigation Branch (2006, June). *AAIB Bulletin: Loss of two ADIRUS, Airbus A320-200, I-BIKE on 25 June 2005.* AAIB Bulletin No: 6/2006. Ref: EW/C2005/06/03. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

Summary:
On 25 June 2005 an Airbus A320-200, registration I-BIKE "departed on a scheduled passenger flight from Milan to London Heathrow Airport, with an unserviceable No 3 Air Data Inertial Reference Unit (ADIRU). On final approach to Runway 09L at London Heathrow, in Instrument Meteorological Conditions (IMC), the Inertial Reference (IR) part of the No 1 ADIRU failed, depriving the commander (the pilot flying) of much of

the information on his Primary Flight and Navigation Displays. ATC required the aircraft to go-around from a height of 200 ft on short final approach due to another aircraft still occupying the runway. The co-pilot, who had been handed control, performed the go-around and the aircraft was radar vectored for a second approach. The crew then turned off the No 1 ADIRU whilst attempting to diagnose the problem, contrary to prescribed procedures. As a result, additional data was lost from the commander's electronic instrument displays, the nosewheel steering became inoperative and it became necessary to lower the landing gear by gravity extension. The aircraft landed safely. … During this investigation, it was apparent that the operator's training organisation train their flightcrews to a high standard and that nothing in the training of the I-BIKE crew should have led them to deviate from the checklist displayed on the ECAM. The operator's training organisation took the view that the commander had correctly elected to carry out a go-around and deal with the failure of the navigation equipment in a holding pattern. However, the reducing cloudbase, combined with being limited to a CAT 1 ILS approach, then became the main consideration of the crew to land the aircraft without unnecessary delay. The incorrect action by the crew of selecting the No 1 ADIRU to OFF, rather than following the ECAM checklist, was carried out from memory at a time of relatively high workload, and led to further loss of aircraft systems. By not adopting the usual protocol for declaring a MAYDAY, the commander may have contributed to ATC not being fully aware that the crew had declared an emergency situation. His heavy accent may also been a factor. This resulted in the airport RFFS not being brought to a Local Standby state of readiness for the landing." (Air Accidents Investigation Branch, 2006)

Air Accidents Investigation Branch (2007, January 30). *Report on the serious incident to Boeing B737-800, registration EI-DCT, at Cork Airport on 4 June 2006.* AAIU Synoptic Report No: 2007-002. AAIU File No: 2006/0051. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

Summary:

On 4 June 2006 a Boeing B737-800, registration EI-DCT "aircraft was on a routine scheduled passenger flight between London Stansted (EGSS) and Cork Airport (EICK). Weather conditions at EICK that afternoon were clear and sunny. The aircraft Commander was the Pilot Flying (PF), with the First Officer as the Pilot-Non-Flying (PNF) or the monitoring pilot. Approaching the South coast, the PNF asked Air Traffic Control (ATC) for permission to carry out a visual approach to Runway (RWY) 17. The aircraft was cleared by ATC for an unrestricted visual approach to RWY 17 at 4 NM from touchdown. As the final part of this approach was too high the PNF asked ATC, at the PF's request, for permission to carry out a right hand orbit. This was approved by ATC. During this orbit manoeuvre the aircraft flew low over the Bishopstown area of Cork City on its base leg. As the aircraft turned onto finals the Enhanced Ground Proximity Warning System (EGPWS) "Glide Slope" CAUTION sounded twice. In addition, the EGPWS alert activated. The aircraft landed normally at 16.53 hrs. The Operator advised the AAIU of this Serious Incident on 13 June 2006. … This serious incident was precipitated by the PF not adhering to the Operators explicit SOP's in the two approaches to RWY 17 and also by not conforming to established CRM principles in relation to the PNF." (Air Accidents Investigation Branch, 2007, January 30)

Air Accident Investigation Commission of the Interstate Aviation Committee (2007, February 12). *Final Report on the accident on 3 May 2006 in the Black Sea, off the coast of Sochi, to the Airbus 320-211 registered EK-32009 operated by Armavia Airlines.* Translation of the Russian original report. Moscow, Russia: Interstate Aviation Committee.

> ***Summary:***
> "On 2 May 2006 … the A320 registered EK-32009, operated by Armavia Airlines of the Republic of Armenia, was undertaking a passenger flight from Yerevan to Sochi at night in instrument meteorological conditions (IMC) and crashed into the Black Sea near Sochi airport. …
> "The fatal crash of the "Armavia" A-320 EK-32009 was a CFIT accident that happened due to collision with the water while carrying-out a climbing manoeuvre after an aborted approach to Sochi airport at night with weather conditions below the established minima for runway 06. While performing the climb with the autopilot disengaged, the Captain, being in a psychoemotional stress condition, made nose down control inputs due to the loss of pitch and roll awareness. This started the abnormal situation. Subsequently the Captain's inputs in the pitch channel were insufficient to prevent development of the abnormal situation into the catastrophic one. Along with the inadequate control inputs of the Captain, the contributing factors to development of the abnormal situation into the catastrophic one were also the lack of necessary monitoring of the aircraft descent parameters (pitch attitude, altitude, vertical speed) by the co-pilot and the absence of proper reaction by the crew to the EGPWS warning". (Air Accident Investigation Commission of the Interstate Aviation Committee, 2007)

Air Accidents Investigation Branch (2008). *Report on the accident to Boeing 737-300, registration OO-TND, at Nottingham East Midlands Airport on 15 June 2006.* Aircraft Accident Report No: 5/2008 (EW/C2006/06/04). Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

> ***Summary:***
> On 15 June 2006 a Boeing 737-300 being operated by Belgian Airline TNT was "on a scheduled cargo flight from Liège Airport to London Stansted Airport [when] the crew diverted to Nottingham East Midlands Airport due to unexpectedly poor weather conditions at Stansted. ... On approach, at approximately 500 feet agl, the crew were passed a message by ATC advising them of a company request to divert to Liverpool Airport. The commander inadvertently disconnected both autopilots whilst attempting to reply to ATC. He then attempted to re-engage the autopilot in order to continue the approach. The aircraft diverged to the left of the runway centreline and developed a high rate of descent. The commander commenced a go-around but was too late to prevent the aircraft contacting the grass some 90 m to the left of the runway centreline. The aircraft became airborne again but, during contact with the ground, the right main landing gear had broken off. …

The investigation determined the following:
Causal factors:

1. ATC inappropriately transmitted a company R/T message when the aircraft was at a late stage of a CAT III automatic approach.
2. The commander inadvertently disconnected the autopilots in attempting to respond to the R/T message.
3. The crew did not make a decision to go-around when it was required after the disconnection of both autopilots below 500 ft during a CAT III approach.
4. The commander lost situational awareness in the latter stages of the approach, following his inadvertent disconnection of the autopilots.
5. The co-pilot did not call 'go-around' until after the aircraft had contacted the ground.

Contributory factors:

1. The weather forecast gave no indication that mist and fog might occur.
2. The commander re-engaged one of the autopilots during a CAT III approach, following the inadvertent disconnection of both autopilots at 400 ft aal.
3. The training of the co-pilot was ineffective in respect of his understanding that he could call for a go-around during an approach."

(Air Accidents Investigation Branch, 2008)

Aviation Safety Council (2006). *GE 536 Occurrence Investigation Report on Runway Overrun During Landing On Taipei Sungshan Airport, Transasia Airways Flight 536, A320-232, B-22310 on October 18, 2004.* Report No: ASC-AOR-06-03-002. Taipei, Taiwan: Aviation Safety Council.

Summary:
"On October 18, 2004, at 1959 Taipei local time, TransAsia Airways (TNA) flight GE 536, an A320-232 aircraft, registration No.B-22310, departed from Tainan Airport (RCNN), rolling off from the stopway in the end of Runway 10, stopped with its nose gear trapped in a ditch during landing roll on Taipei Sungshan Airport (RCSS). ...

Findings Related to Probable Causes

1. When the aircraft was below 20 ft RA and Retard warnings were sounded, the pilot flying didn't pull thrust lever 2 to Idle detent which caused the ground spoilers were not deployed after touchdown though they were at Armed position, therefore the auto braking system was not triggered. Moreover, when the auto thrust was changed to manual operation mode automatically after touchdown, the thrust lever 2 was remained at 22.5 degrees which caused the Engine 2 still had an larger thrust output (EPR1.08) than idle position's. Thereupon, the aircraft was not able to complete deceleration within the residual length of the runway, and deviated from the runway before came to a full stop, even though the manual braking was actuated by the pilot 13 seconds after touchdown.
2. The pilot monitoring announced 'spoiler' automatically when the aircraft touched down without checking the ECAM display first according to SOP before made the announcement, as such the retraction of ground spoilers was ignored. ...

Findings Related to Risk

1. After touchdown, when the thrust lever 2 was not pulled back to Idle position and the Retard warning sounds have ceased, there were no other ways to remind pilots to pull back the thrust lever.
2. The diminution of Runway Safety Zone proclaimed by Sungshan airport, and the fixed objects of non auxiliary aviation facilities and uncovered drainage ditch within the area do not meet the requirements of Civil Airports Designing and Operating Regulations."

(Aviation Safety Council, 2006)

Civil Aviation Authority of Bahrain (2002, July 10). *Gulf Air Flight GF-072 Airbus A320-212, REG. A40-EK on 23 August 2000 at Bahrain.* Manama, Kingdom of Bahrain: Civil Aviation Authority of Bahrain.

Summary:

"On August 23, 2000, about 1930 Bahrain local time (1630 UTC), Gulf Air flight 72, an Airbus A320-212, Sultanate of Oman registration A40-EK, crashed in the Arabian Gulf near Muharraq, Bahrain. Flight 72 departed from Cairo International Airport, Cairo, Egypt, with 2 pilots, 6 flight attendants, and 135 passengers on board. The airplane had been cleared to land on runway 12 at Bahrain International Airport, Muharraq, Bahrain, but crashed about 3 miles northeast of the airport during a go-around. The airplane was destroyed by impact forces, and all persons on board were fatally injured. ... The factors contributing to the … accident were identified as a combination of individual and systemic issues. The individual factors during the approach and final phases of the flight were: non-adherence to standard operating procedures (SOPs) by the captain; the first officer not drawing the attention of the captain to the deviations of the aircraft from the standard flight parameters and profile; the spatial disorientation and information overload experienced by the flightcrew; and, the non-effective response by the flightcrew to the ground proximity warnings. The systemic factors that could have led to these individual factors were: a lack of a crew resources management (CRM) training programme; inadequacy in some of the airline's A320 flightcrew training programmes; problems in the airline's flight data analysis system and flight safety department which were not functioning satisfactorily; organisational and management issues within the airline; and safety oversight factors by the regulator. The investigation showed that no single factor was responsible for the accident to GF-072. The accident was the result of a fatal combination of many contributory factors, both at the individual and systemic levels."
(Civil Aviation Authority of Bahrain, 2002)

Danish Aircraft Accident Investigation Board (n.d.). *Summary Report: Failure to become airborne, Incident, Boeing 767-383, OY-KDN.* Report No: HCL 49/99. Denmark: Accident Investigation Board.

Summary:

On 24 August 1999, a Boeing 767-383 aircraft registered as OY-KDN failed to become airborne on takeoff at the Copenhagen Airport. "During take-off on runway 22R, the flightcrew initiated the rotation. The nose wheel was lifted off the runway, but the aircraft main wheel remained on the runway. The commander took over the control of the aircraft, lowered the aircraft nose and aborted the take-off. After the aircraft reached taxi speed near the end of runway 22R, the aircraft taxied into the taxiway AK. The aircraft was parked on taxiway AK and the Fire & Rescue Brigade was alerted in case of a brake fire and in order to cool down the brakes. The passengers were disembarked via the normal doors and were afterwards transported to the terminal. The investigation revealed the following causal factors: The flightcrew used a wrong and too low value as input take-off weight (ACT TOW). The result was that the values for V1, Vr and V2 were too low. The aircraft was rotated at the wrong and too low Vr and the aircraft never got airborne. … The take-off performance calculation was based on a too low ACT TOW. As a result of the wrong value for ACT TOW, the values for V1, Vr and V2 were too low. The wrong values of Vr resulted in the aircraft being rotated at a too low speed. The check of the take-off performance data was not sufficient." (Danish Aircraft Accident Investigation Board, n.d.)

Dutch Safety Board (2006, April 6). *Runway overrun after rejected take-off of the Onur Air MD-88, registration TC-ONP, at Groningen Airport Eelde on 17 June 2003.* Investigation number 2003071. The Hague: Dutch Safety Board.

Summary:
On 17 June 2003, a Boeing McDonnell Douglas MD-88 aircraft registered as TC-ONP scheduled for "a domestic flight from Groningen Airport Eelde to Maastricht Aachen Airport as OHY 2264" overran the runway after a rejected takeoff. … During take-off at a speed of approximately 130 knots the captain, who was pilot flying, rejected the take-off above the decision speed because he experienced a heavy elevator control force at rotation. The stabilizer warning sounded during the entire take-off roll. The aircraft overran the runway end and came to a stop in the soft soil. During subsequent evacuation one cabin crew member and a few passengers sustained minor injuries. The aircraft sustained substantial damage. …

Probable cause(s)
- The crew resumed the take off and continued whilst the take off configuration warning, as a result of the still incorrect stabilizer setting, reappeared.
- The actual center of gravity during take-off (TO-CG) was far more forward than assumed by the crew. As a consequence the horizontal stabilizer was not set at the required position for take-off.
- The far more forward TO-CG - contributed to an abnormal heavy elevator control force at rotation and made the pilot to reject the take-off beyond decision speed. This resulted in a runway overrun.

Contributing factors
- By design the aircraft configuration warning system does not protect against an incorrect TOCG insert.
- The aircraft was not equipped with a weight and balance measuring system.

- Deviations of operational factors accumulated into an unfavorable aircraft performance condition during take-off.
- Flight deck crew showed significant deficits."

(Dutch Safety Board, 2006, April 6)

German Federal Bureau of Aircraft Accidents Investigation (2004, August). *Investigation Report: Autopilot malfunction, Serious incident occurring on December 3, 2002 near Munich, involving an Airbus A300-600*. Report No: 5x011-0/02. Braunschweig, Germany: German Federal Bureau of Aircraft Accident Investigation.

Summary:

On 3 December 2002, an Airbus A300-600 aircraft took off from "Munich for a scheduled flight to Frankfurt. While climbing to cruise level with autopilot (AP2) engaged the crew noticed during a routine check of the instruments that the allowed airspeed (VMO) would be exceeded. As a countermeasure the preset speed was reduced and a higher climb rate selected on the AP panel. The AP was disengaged after it was noted that the airspeed increased further and the nose started to drop. Once the pilot took control of the airplane it was trimmed nose down. It was no longer in climb and the maximum allowed airspeed was exceeded by 16 kt. A great amount of control forces had to be applied until the wrong trim could be correct by means of the electrical trim device. Vertical acceleration was so great during the re-establishment of the original flight attitude that one crew member fell and injured herself slightly. The flight was continued with disengaged AP and no further incidents. …

Causes for the serious incident

- As a result of the deferred elimination of a fault on PTS 1 the AP could be operated with PTS 2 only.
- There was a fault on PTS 2 for which there was no confirmation or elimination
- At a certain airspeed the signal interruption between engaged AP 2 and PTS 2 caused a continuous change of the THS in direction of pitch down.
- Because of a system deficiency caused by the software error in FAC 2 the continuous change of the THS did not result in a warning and the self-deactivation of the system.
- The prescribed procedure for abnormal functions (AOM) of the trimable horizontal stabilizer was not executed in time.

Systemic causes contributing to the serious incident:

- Approval of the MMEL did not take into consideration that during AP operations there is no redundancy once one PTS in inoperable.
- The MMEL of the aircraft manufacturer and the resulting MEL of the operator did not contain clear criteria for resource scheduling; especially whether an aircraft with inoperable systems and equipment can be released for flight by the maintenance base.

- The MMEL did not take into consideration that by surrendering PTS 1 normally both APs use this system and an unhindered function of PTS 2 with both APs was not ensured.
- The maintenance instructions and operation procedures contained no or insufficient regulations how to deal with such a situation where a PTS 2 complaint could not be reproduced on ground.
- Design and certification procedures of EUROCAE dated 1982 regarding software for aircraft in the scope of the certification process of changes did not included a function check for the whole system or module.
- Neither schooling nor periodic training educated pilots sufficiently on how difficult it is to recognize abnormal system functions during auto flight operations (pitch up/down).” German Federal Bureau of Aircraft Accidents Investigation, 2004, August)

National Transportation Safety Board (1995, August 30). *Factual Report of In-flight upset, MarkAir flight 308, Boeing 737-3M8(300),* N681MA, *Anchorage, Alaska, December 11, 1994.* Factual Report Aviation NTSB/ANC95FA019. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (1995, October 13). *Probable Cause of In-flight upset, MarkAir flight 308, Boeing 737-3M8(300),* N681MA, *Anchorage Alaska, December 11, 1994*. Probable Cause Aviation NTSB/DCA04MA082. File No. 2001. Washington, DC: National Transportation Safety Board.

Summary:

“On December 11, 1994, at approximately 1435 Alaska standard time (AST), a Boeing model 737, series 3M8 airplane, US registration N681MA, SN:24376, registered to and operated by MARKAIR Inc., as flight No. 308, with a flightcrew of two, a cabin crew of three, and 116 revenue passengers, experienced an uncommanded pitch up during a cruise climb from the Anchorage International Airport, Anchorage, Alaska…The scheduled 14 CFR Part 121 flight departed Anchorage on an instrument flight plan at 1425 and was en route to Seattle, Washington when the accident occurred.” (National Transportation Safety Board, 1995, August 30)

“The National Transportation Safety Board determines the probable cause(s) of this accident as follows. The failure of the B system channel autopilot elevator actuator.” (National Transportation Safety Board, 1995, October 13).

National Transportation Safety Board (1996, November 13). *Collision with trees on final approach, American Airlines flight 1572, McDonnel Douglas MD-83, N566AA, East Granby Connecticut, November 12, 1995.* Aircraft Accident Report NTSB/AAR-96/05. Washington, DC: National Transportation Safety Board.

Summary:

"On November 12, 1995, at 0055 eastern standard time a McDonnell Douglas MD-83, N566AA, owned by American Airlines and operated as flight 1572, was substantially damaged when it impacted trees in East Granby, Connecticut, while on approach to runway 15 at Bradley International Airport (BDL), Windsor Locks, Connecticut. The airplane also impacted an instrument landing system antenna as it landed short of the runway on grassy, even terrain. Flight 1572 was being conducted under Title 14 Code of Federal Regulations, Part 121, as a scheduled passenger flight from Chicago, Illinois, to Bradley International Airport. … The National Transportation Safety Board determines that the probable cause of this accident was the flightcrew's failure to maintain the required minimum descent altitude until the required visual references identifiable with the runway were in sight. Contributing factors were the failure of the BDL approach controller to furnish the flightcrew with a current altimeter setting, and the flightcrew's failure to ask for a more current setting. … The safety issues in the report focused on tower shutdown procedures, non-precision approach flight procedures, precipitous terrain and obstruction identification during approach design, the issuance of altimeter settings by air traffic control, low level windshear alert system maintenance and recertification, and emergency evacuation issues." (National Transportation Safety Board, 1996, November 13)

National Transportation Safety Board (1998, February 2). *Factual Report of Electrical system anomalies incident, Martinair Holland flight 631, Boeing 767-31AER, PHMCH, Boston, Massachusetts, May 28, 1996.* Factual Report Aviation NTSB/ NYC96IA116. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (1998, April 28). *Probable Cause of Electrical system anomalies incident, Martinair Holland flight 631, Boeing 767-31AER, PHMCH, Boston Massachusetts, May 28, 1996.* Probable Cause Aviation NTSB/ NYC96IA116. File No. 5048. Washington, DC: National Transportation Safety Board.

Summary:
"On May 28, 1996, at 1421 eastern daylight time, a Boeing 767-31AER, with Dutch registry PH-MCH, and operated by Martinair Holland as flight 631, received minor damage during an unscheduled landing at Logan Airport, Boston, Massachusetts. There were no injuries to the 3 pilots, 8 flight attendants, or 191 passengers, and visual meteorological conditions prevailed. The flight had departed Schiphol Airport, Amsterdam, The Netherlands, at 0649, destined for Orlando, Florida (MCO), and was operated on an instrument flight rules (IFR) flight plan under 14 CFR 129." (National Transportation Safety Board, 1998, February 2).

"The National Transportation Safety Board determines the probable cause(s) of this incident as follows. Numerous electrical anomalies as a result of a loose main battery shunt connection and undetermined electrical system causes." (National Transportation Safety Board, 1998, April 28).

National Transportation Safety Board (1997, July 28). *In-flight upset following TCAS maneuvers, D-AIBE, Lufthansa Airlines flight 436, Airbus A340-200, DAIBE, Dallas/Fort Worth Airport, June 21, 1996.* Factual Report Aviation NTSB/FTW96LA269. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (1998, March 31). *In-flight upset following TCAS maneuvers, D-AIBE, Lufthansa Airlines flight 436, Airbus A340-200, DAIBE, Dallas/Fort Worth Airport, June 21, 1996.* Probable Cause Aviation NTSB/FTW96LA269. File No. 1751. Washington, DC: National Transportation Safety Board.

> ***Summary:***
> "On June 21, 1996, at 1428 central daylight time, the flightcrew of an Airbus A340-200, German Registration D-AIBE, en route from Dallas/Fort Worth Airport (DFW), Texas, climbing to 17,000 feet MSL, responded to a Traffic Alert and Collision Avoidance System (TCAS) alert Traffic Advisory (TA) at 13,800 feet MSL, with a descent maneuver. Operated by Lufthansa Airlines as Flight 436, a Title 14 CFR Part 129 scheduled passenger flight, the airplane was en route to Houston Intercontinental Airport (IAH), Houston, Texas." (National Transportation Safety Board, 1997, July 28)
>
> "The National Transportation Safety Board determines the probable cause(s) of this accident as follows. The flightcrew's abrupt maneuver/descent in response to a TCAS RA. Factors were the company assignment of the captain to the crew position with a lack of captain training." (National Transportation Safety Board, 1998, March 31)

National Transportation Safety Board (1997, February 25). *Factual Report of Uncommanded pitch-up, American Airlines flight 107, McDonnel Douglas MD-11, N1768D, Westerly, Rhode Island, July 13, 1996.* Factual Report Aviation NTSB/NYC96LA148. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (1999, March 17). *Probable Cause of Uncommanded pitch-up, American Airlines flight 107, McDonnel Douglas MD-11, N1768D, Westerly, Rhode Island, July 13, 1996.* Probable Cause Aviation NTSB/NYC96LA148. File No. 1447. Washington, DC: National Transportation Safety Board.

> ***Summary:***
> "On July 13, 1996, about 2040 eastern daylight time, an McDonnell Douglas MD-11, N1768D, operated by American Airlines as flight 107, experienced an abrupt maneuver during a descent, while operating near Westerly, Rhode Island. The airplane was not damaged. There were 180 occupants onboard the airplane, of which, one passenger received serious injuries, and one passenger and two flight attendants received minor injuries. Visual meteorological conditions prevailed, and flight 107 which had departed London, England, at 1354, was operated on an Instrument Flight Rules (IFR) under 14 CFR Part 121." (National Transportation Safety Board, 1997, February 25)
>
> "The National Transportation Safety Board determines the probable cause(s) of this accident as follows. … insufficient information from the manufacturer in the airplane flight manual and flightcrew operating manual regarding the hazards of applying force to

the control wheel or column while the autopilot is engaged and adjusting the pitch thumbwheel during a level off. Also causal was the flightcrew's lack of understanding of these items and the captain's improper decisions to overpower the engaged autopilot and then to disconnect the autopilot while holding back-pressure on the control yoke." (National Transportation Safety Board, 1999, March 17)

National Transportation Safety Board (1997, May 12). *Factual Report of Inflight loss of control, American Airlines flight 903, Airbus A300B4-605R,* N90070*, West Palm Beach, Florida, December 1, 1999.* Factual Report Aviation NTSB/DCA97MA049. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (1997, May 12). *Probable Cause of Inflight loss of control, American Airlines flight 903, Airbus A300B4-605R,* N90070*, West Palm Beach, Florida, February 11, 2000.* Probable Cause Aviation NTSB/DCA97MA049. File No. 1889. Washington, DC: National Transportation Safety Board.

Summary:
"On May 12, 1997, about 1529 eastern daylight time, an Airbus A300B4-605R, N90070, flight 903, registered to Wilmington Trust Company Trustee, operated by American Airlines Inc., as a 14 CFR Part 121 scheduled domestic passenger flight, experienced an inflight loss of control, about 10 miles north of HEATT intersection in the vicinity of West Palm Beach, Florida. Instrument meteorological conditions prevailed and an IFR flight plan was filed…The flight originated from General Edward Lawrence Logan International Airport, Boston, Massachusetts, about 2 hours 16 minutes before the accident." (National Transportation Safety Board, 1997, May 12).

"The National Transportation Safety Board determines the probable cause(s) of this accident as follows. … The flightcrew's failure to maintain adequate airspeed during leveloff which led to an inadvertent stall, and their subsequent failure to use proper stall recovery techniques. A factor contributing to the accident was the flightcrew's failure to properly use the autothrottle." (National Transportation Safety Board, 1997, May 12)

National Transportation Safety Board (1999, December 29). *Factual Report of Tail strike on landing, Delta Airlines, McDonnell Douglas MD-11, N801DE, Portland, Oregon, November 11, 1998.* Factual Report Aviation NTSB/SEA99LA014. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (2000, September 28). *Probable Cause of Tail strike on landing, Delta Airlines,. McDonnell Douglas MD-11, N801DE, Portland, Oregon, November 11, 1998.* Probable Cause Aviation NTSB/SEA99LA014. File No. 20896. Washington, DC: National Transportation Safety Board.

Summary:

"On November 11, 1998, at 1120 Pacific standard time, a McDonnell Douglas MD-11, N801DE, operated by Delta Air Lines as a 14 CFR Part 121 scheduled passenger flight, experienced a tail strike while landing at Portland International Airport, Portland, Oregon. The flight was landing on runway 10R after arriving from Cincinnati, Ohio. Visual meteorological conditions prevailed, and an instrument flight plan had been filed. There were no injuries to the 11 crew members or 113 passengers, but the aircraft sustained substantial damage to the belly skin and stringers. The flightcrew stated that they were unaware the aircraft had experienced a tail strike until maintenance personnel at the arrival gate advised them that there was damage to the number 3 VHF antenna and the skin aft of the antenna mount. After the passengers were deplaned normally through the jetway, the damage was further evaluated, and it was determined that the aircraft would need to be ferried to Atlanta for permanent repair." (National Transportation Safety Board, 1999, December 29)

"The National Transportation Safety Board determines the probable cause(s) of this accident as follows. The flightcrew's entry of an incorrect weight figure in the Flight Management System (FMS) computer, resulting in the approach being flown at an improper (low) Vref speed and an excessively nose-high attitude through the landing flare." (National Transportation Safety Board, 2000, September 28)

National Transportation Safety Board (2001, September 6). *Factual Report of In-flight upset during descent, British Airways as Flight 179, Boeing B747-236, G-BDXL, Providence, Rhode Island, February 27, 2000.* Factual Report Aviation NTSB/NYC00LA085. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (2001, September 27). *Probable Cause of In-flight upset during descent, British Airways as Flight 179, Boeing B747-236, G-BDXL, Providence, Rhode Island, February 27, 2000.* Probable Cause Aviation NTSB/NYC00LA085. File No. 10607. Washington, DC: National Transportation Safety Board.

Summary:
"On February 27, 2000, about 2100 Eastern Standard Time, a Boeing 747-236, G-BDXL, operated by British Airways, PLC., as flight 179, experienced an in-flight upset during a descent in the vicinity of Providence, Rhode Island." (National Transportation Safety Board, 2001, September 6).

"The airplane was in cruise flight when it began a descent from flight level 350. At the same time, the flight engineer was reconfiguring the airplane's electrical system from a Category III landing to a Category I landing. When the flight engineer closed the 'number one bus-tie-breaker,' the airplane experienced an uncommanded pitch-up, accompanied by numerous momentary instrument failures. Twelve occupants were injured. The airplane was utilizing the 'A' autopilot system, which remained engaged. The pilot disconnected the autopilot, leveled the airplane, re-engaged the autopilot, and continued to an uneventful landing. … The National Transportation Safety Board determines the probable cause(s) of this accident as follows. Maintenance personnel's failure to reconnect the pitot connections to the elevator feel computer which resulted in an elevator control surface deflection which was outside of the normal autopilot elevator authority. The uncommanded autopilot input to the elevator control surface resulted from an undetermined electrical source. A factor in this accident was that the section of the 747 Maintenance Manuel utilized by company maintenance personnel did not contain an 'elevator feel light test.'" (National Transportation Safety Board, 2001, September 27).

National Transportation Safety Board (2004, April 13). *Factual Report of Abrupt maneuver on descent, Delta Airlines as Flight 1669, Boeing B757-232, N644DL, San Francisco, California, July 11, 2001.* Factual Report Aviation NTSB/LAX01LA307. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (2004, June 2). *Probable Cause of Abrupt maneuver on descent, Delta Airlines as Flight 1669, Boeing B757-232, N644DL, San Francisco, California, July 11, 2001.* Probable Cause Aviation NTSB/LAX01LA307. File No. 15531. Washington, DC: National Transportation Safety Board.

Summary:
"On July 11, 2001, approximately 1830 Pacific daylight time, a Boeing 757-232 transport category airplane, N644DL, operated by Delta Airlines as Flight 1669, experienced an abrupt maneuver during descent over eastern California en route to San Francisco, California. Delta Airlines, Inc., was operating the airplane as a scheduled domestic passenger flight…" (National Transportation Safety Board, 2004, April 13)

"The captain initiated the descent and the first officer began programming the flight management system. The first officer looked up as the airplane was flying past FL330 and queried the captain. The captain then immediately pulled the aircraft out of the descent and leveled off at FL330. Shortly thereafter, the flightcrew was notified of a passenger injury resulting from the event. The captain reported to the passengers that they encountered turbulence. All of the flight attendants reported a smooth flight prior to the event. … The National Transportation Safety Board determines the probable cause(s) of this accident as follows. the captain's excessive use of the flight controls to level off from a descent, which resulted in a passenger injury." (National Transportation Safety Board, 2004, June 2).

National Transportation Safety Board (2002, September 18). *Factual Report of Loss of control on landing incident, JetBlue Airways as Flight 88, Airbus A320-232, N509JB, Jamaica, New York, January 21, 2001.* Factual Report Aviation NTSB/NYC01IA068. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (2002, October 23). *Probable Cause of Loss of control on landing incident, JetBlue Airways as Flight 88, Airbus A320-232, N509JB, Jamaica, New York, January 21, 2001.* Probable Cause Aviation NTSB/NYC01IA068. File No. 12437. Washington, DC: National Transportation Safety Board.

Summary:

"On January 21, 2001, at 0808 eastern standard time, an Airbus A320-232, N509JB, operated by JetBlue Airways, Inc., as flight 88, departed the left side of Runway 4R during landing roll, at John F. Kennedy Airport (JFK), Jamaica, New York. There was no damage to the airplane, and there were no Injuries…" (National Transportation Safety Board, 2002, September 18).

"On final approach to runway 4R, the control tower gave the pilots winds from 340 degrees at 15 knots, and braking action poor. About 1 second after nose wheel touchdown, the airplane deviated left and the auto-pilot system corrected back. About 11 seconds after touchdown, the airplane deviated left again, did not correct back, and the pilot disconnected the autopilot to regain directional control. He was unable to restore runway heading, and kept the airplane straight as it departed the runway on the left side. … The National Transportation Safety Board determines the probable cause(s) of this incident as follows. The pilot's decision to perform an auto rollout on a snow contaminated runway, which had not been demonstrated, and which resulted in a loss of directional control, when the capability of the autoland system to maintain directional control was exceeded. Factors were the failure of the control tower to ensure that the results of the latest MU reading were available to the pilots, the crosswind, and the snow covered runway." National Transportation Safety Board, 2002, October 23)

National Transportation Safety Board (2003, October 16). *Factual Report of Runway overrun on takeoff, Northwest Airlines as Flight 985, Airbus A320-200, N357NW, Detroit, Michigan, March 17, 2001.* Factual Report Aviation NTSB/CHI01FA104. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (2003, November 25). *Probable Cause of Runway overrun on takeoff, Northwest Airlines as Flight 985, Airbus A320-200, N357NW, Detroit, Michigan, March 17, 2001.* Probable Cause Aviation NTSB/CHI01FA104. File No. 14404. Washington, DC: National Transportation Safety Board.

Summary:

"On March 17, 2001, at 0705 eastern standard time, an Airbus Industrie A320-200, N357NW, operated by Northwest Airlines (NWA) as Flight 985, contacted the runway and the terrain during takeoff on runway 3C at the Detroit Metropolitan Wayne County Airport, Detroit, Michigan. The airplane received substantial damage." (National Transportation Safety Board, 2003, October 16)

"The National Transportation Safety Board determines the probable cause(s) of this accident as follows. The pilot induced oscillations and the delay in aborting the takeoff. Factors associated with the accident were the first officer used an improper trim setting and the captain did not identify and correct the setting during the taxi checklist, and the wet runway conditions." (National Transportation Safety Board, 2003, November 25)

National Transportation Safety Board (2001, August 20). *Factual Report of Equipment malfunction in flight incident, Emery Worldwide Airlines flight 102 Boeing (formerly McDonnell Douglas) DC-8-71F, N8084U, Seattle, Washington, January 16, 2001.* Factual Report Aviation NTSB/SEA01IA039. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (2001, September 19). *Probable Cause of Equipment malfunction in flight incident, Emery Worldwide Airlines flight 102 Boeing (formerly McDonnell Douglas) DC-8-71F, N8084U, Seattle, Washington, January 16, 2001.* Probable Cause Aviation NTSB/SEA01IA039. File No. 10520. Washington, DC: National Transportation Safety Board.

Summary:
"On January 16, 2001, approximately 0842 Pacific standard time, a Boeing (formerly McDonnell Douglas) DC-8-71F, N8084U, operating as Emery Worldwide Airlines flight 102 on a 14 CFR 121 non-scheduled domestic cargo flight from Dayton, Ohio, deviated to the east of the published final approach course while on the instrument landing system (ILS) approach to runway 16R at Seattle-Tacoma International Airport (Sea-Tac), Seattle, Washington. The deviation, approximately 0.4 nautical mile to the left of the runway 16R localizer centerline, took the aircraft east of parallel runway 16L and in proximity to a new air traffic control (ATC) tower under construction on the airport, which at the time of the incident was approximately 290 feet high (including a construction crane being used to construct the tower.) The crew subsequently initiated a missed approach and made a second approach and landing attempt, which was without further incident." (National Transportation Safety Board, 2001, August 20).

"The National Transportation Safety Board determines the probable cause(s) of this incident as follows. A malfunctioning relay in the aircraft's flight management system (FMS) switching matrix and associated false 'on course' indication on the captain's course deviation indicator (CDI), resulting in proper localizer course alignment not being obtained or maintained and subsequent flight in close proximity to the new control tower. The reason for the reported false 'on course' indications on the first officer's CDI was not determined. Factors contributing to the incident included low ceiling and obscuration, weak signal received by both localizer receivers due to faulty BNC connectors, and the new control tower." (National Transportation Safety Board, 2001, September 19)

National Transportation Safety Board (2005, June 7). *Factual Report of Loss of control in flight incident, Icelandair flight 662 Boeing B757-200, TF-FII, Baltimore, Maryland, October 19, 2002.* Factual Report Aviation NTSB/ DCA03IA005. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (2005, July 15). *Probable Cause of Loss of control in flight incident, Icelandair flight 662 Boeing B757-200, TF-FII, Baltimore, Maryland, October 19, 2002.* Probable Cause Aviation NTSB/ DCA03IA005. File No. 18151. Washington, DC: National Transportation Safety Board.

Summary:
"On October 19, 2002, about 2000 eastern daylight time (EDT)… a Boeing 757-200, TF-FII, operating as Icelandair flight 662, experienced a stall while climbing from flight level (FL) 330 (i.e., 33,000 feet) to FL 370. The flight lost about 7,000 feet during the recovery and then diverted to Baltimore-Washington International Airport (BWI), Baltimore, Maryland." (National Transportation Safety Board, 2005, June 7).

"The National Transportation Safety Board determines the probable cause(s) of this incident as follows. The captain's improper procedures regarding stall avoidance and recovery. Contributing to the incident were the partial blockage of the pitot static system, and the flightcrew's improper decisions regarding their use of inaccurate airspeed indications. Contributing to the flightcrew's confusion during the flight were the indistinct alerts generated by the airplane's crew alerting system." (National Transportation Safety Board, 2005, July 15).

National Transportation Safety Board (2004, June 22). *Factual Report of Runway overrun on landing, Flight Options, Inc. Beechjet 400A, N498CW, Baltimore, Maryland, May 1, 2002.* Factual Report Aviation NTSB/IAD02FA047. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (2004, September 1). *Probable Cause of Runway overrun on landing, Flight Options, Inc. Beechjet 400A, N498CW, Baltimore, Maryland, May 1, 2002.* Probable Cause Aviation NTSB/IAD02FA047. File No. 16085. Washington, DC: National Transportation Safety Board.

Summary:
"On May 1, 2002, at 1653 eastern daylight time, a Beechjet 400A, N498CW, a fractionally-owned and operated airplane managed by Flight Options, Incorporated, was substantially damaged during a landing overrun at Baltimore-Washington International Airport (BWI), Baltimore, Maryland." (National Transportation Safety Board, 2004, June 22)

"The National Transportation Safety Board determines the probable cause(s) of this accident as follows. The captain's failure to go around. Factors included the captain's preoccupation with the flight management system, the crew's failure to adhere to company standard operating procedures, and the lack of proper crew coordination." (National Transportation Safety Board, 2004, September 1)

National Transportation Safety Board (2004, April 9). *Factual Report of Partial loss of flight instruments incident, Atlantic Coast Airlines Fairchild Dornier DO-328-300, N429FJ, Atlantic City, New Jersey, May 2, 2002.* Factual Report Aviation NTSB/IAD02IA046. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (2004, September 1). *Probable Cause of Partial loss of flight instruments incident, Atlantic Coast Airlines Fairchild Dornier DO-328-300, N429FJ,*

Atlantic City, New Jersey, May 2, 2002. Probable Cause Aviation NTSB/IAD02IA046. File No. 16086. Washington, DC: National Transportation Safety Board.

Summary:
"On May 2, 2002, at 0830 eastern daylight time, a Fairchild Dornier DO-328-300, N429FJ, operated by Atlantic Coast Airlines (ACA) d/b/a Delta Connection flight 6110, was not damaged after the crew reported a strong odor of smoke in the flight deck. The captain declared an emergency and landed without incident at Atlantic City International Airport (ACY), Atlantic City, New Jersey." (National Transportation Safety Board, 2004, April 9)

"The National Transportation Safety Board determines the probable cause(s) of this incident as follows. The partial loss of flight display information for undetermined reasons." (National Transportation Safety Board, 2004, September 1)

National Transportation Safety Board (2007, January 9). *Crash of Pinnacle Airlines Flight 3701, Bombardier CL-600-2B19, N8396A, Jefferson City, Missouri, October 14, 2004.* Accident Report NTSB/AAR-07/01. PB2007-910402. Washington, DC: National Transportation Safety Board.

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

"The National Transportation Safety Board determines that the probable causes of this accident were (1) the pilots' unprofessional behavior, deviation from standard operating procedures, and poor airmanship, which resulted in an in-flight emergency from which they were unable to recover, in part because of the pilots' inadequate training; (2) the pilots' failure to prepare for an emergency landing in a timely manner, including communicating with air traffic controllers immediately after the emergency about the loss of both engines and the availability of landing sites; and (3) the pilots' improper management of the double engine failure checklist, which allowed the engine cores to stop rotating and resulted in the core lock engine condition. Contributing to this accident were (1) the core lock engine condition, which prevented at least one engine from being restarted, and (2) the airplane flight manuals that did not communicate to pilots the importance of maintaining a minimum airspeed to keep the engine cores rotating." (National Transportation Safety Board, 2007, January 9)

National Transportation Safety Board (2005, August 8). *Factual Report of In flight collision with object, Business Jet Services Ltd. Gulfstream Aerospace G-III, N85VT, Houston, Texas, November 22, 2004.* Factual Report Aviation NTSB/DCA05MA011. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (2006, May 30). *Probable Cause of In flight collision with object, Business Jet Services Ltd. Gulfstream Aerospace G-III, N85VT, Houston, Texas, November 22, 2004.* Probable Cause Aviation NTSB/ DCA05MA011. File No. 20896. Washington, DC: National Transportation Safety Board.

> ***Summary:***
> "On November 22, 2004, about 0615 central standard time, a Gulfstream G-1159A, N85VT, operated by Business Jet Services Ltd., struck a light pole and crashed about 3 miles southwest of William P. Hobby Airport, Houston, Texas, while on an instrument landing system approach to runway 4. The two pilots and the flight attendant were killed, an individual in a vehicle near the airport received minor injuries, and the airplane was destroyed by impact forces." (National Transportation Safety Board, 2006, November 14)
>
> "The National Transportation Safety Board determines the probable cause(s) of this accident as follows: the flightcrew's failure to adequately monitor and cross check the flight instruments during the approach. Contributing to the accident was the flightcrew's failure to select the instrument landing system frequency in a timely manner and to adhere to approved company approach procedures, including the stabilized approach criteria." (National Transportation Safety Board, 2006, November 20)

National Transportation Safety Board (2005, August 8). *Factual Report of Loss of control and runway excursion during landing, Gama Aviation Ltd. Gulfstream Aerospace G-IV, G-GMAC, Teterboro, New Jersey, December 1, 2004.* Factual Report Aviation NTSB/NYC05FA026. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (2006, May 30). *Probable Cause of Loss of control and runway excursion during landing, Gama Aviation Ltd. Gulfstream Aerospace G-IV, G-GMAC, Teterboro, New Jersey, December 1, 2004.* Probable Cause Aviation NTSB/ NYC05FA026. File No. 20088. Washington, DC: National Transportation Safety Board.

> ***Summary:***
> "On December 1, 2004, at 1623 eastern standard time, a Gulfstream Aerospace G-IV, G-GMAC, was substantially damaged while landing at Teterboro Airport (TEB), Teterboro, New Jersey." (National Transportation Safety Board, 2005, August 8)
>
> "The National Transportation Safety Board determines the probable cause(s) of this accident as follows. The flightcrew's inadvertent engagement of the autothrottle system, and their failure to recognize the engagement during landing, which resulted in a runway excursion. Factors were the lack of autothrottle switch guards, lack of an autothrottle

engagement audible tone, and gusty winds." (National Transportation Safety Board, 2006, May 30)

National Transportation Safety Board (2006, March 2). *Factual Report of Tail-strike on Go-around, FedEx flight 859, Boeing McDonnell Douglas MD-11F, N601FE, Memphis, Tennessee, September 19, 2004.* Factual Report Aviation NTSB/DCA04MA082. Washington, DC: National Transportation Safety Board.

National Transportation Safety Board (2006, March 28). *Probable Cause of Tail-strike on Go-around, FedEx flight 859, Boeing McDonnell Douglas MD-11F, N601FE, Memphis, Tennessee, September 19, 2004.* Probable Cause Aviation NTSB/DCA04MA082. File No. 19621. Washington, DC: National Transportation Safety Board.

Summary:

"On September 19, 2004, at 1243 central daylight time, a Boeing McDonnell Douglas MD-11F, N601FE, operating as FedEx (FDX) flight 859, experienced a tail strike during a go-around maneuver from runway 09 at Memphis International Airport (MEM)." (National Transportation Safety Board, 2006, March 2)

"The National Transportation Safety Board determines the probable cause(s) of this accident as follows. The pilot's over-rotation during a go-around maneuver initiated because of a bounced landing. The go-around maneuver was initiated at a low speed and high pitch angle, and after reverse thrust was selected, contrary to Boeing and FedEx training guidance." (National Transportation Safety Board, 2006, March 28)

National Transportation Safety Committee (2008). *Aircraft Accident Investigation of AdamAir Flight DHI 574 Boeing B737-4Q8 aircraft, registered PK-KKW over the Makassar Strait, Sulawesi, Republic of Indonesia on 1 January 2007.* Aircraft Accident Investigation Report KNKT/07.01/08.01.36. Republic of Indonesia: National Transportation Safety Committee.

Summary:

"On 1 January 2007, a Boeing Company 737-4Q8 aircraft, registered PK-KKW, operated by Adam SkyConnection Airlines (AdamAir) as flight number DHI 574, was on a scheduled passenger flight from Surabaya (SUB), East Java to Manado (MDC), Sulawesi, at FL 350 (35,000 feet) when it disappeared from radar. … Nine days after the aircraft disappeared, wreckage was found in the water and on the shore along the coast near Pare-Pare, Sulawesi. Locator beacon signals from the flight recorders were heard on 21 January 2007 and their positions logged. … This accident resulted from a combination of factors, including the failure of the pilots to adequately monitor the flight instruments, particularly during the final 2 minutes of the flight. Preoccupation with a malfunction of the Inertial Reference System (IRS) diverted both pilots' attention from the flight instruments and allowed the increasing descent and bank angle to go unnoticed. The pilots did not detect and appropriately arrest the descent soon enough to prevent loss of control." (National Transportation Safety Committee, 2008)

Transport Accident Investigation Commission (2003, November 19). *Aviation Occurrence Report 03-003 of Boeing 747-412 9V-SMT, flight SQ286, tail strike during take-off, Auckland International Airport on 12 March 2003.* Wellington, New Zealand: Transport Accident Investigation Commission.

> ***Summary:***
> "On Wednesday 12 March 2003, at 1547, flight SQ286, a Boeing 747-412 registered 9V-SMT, started its take-off at Auckland International Airport for a direct 9-hour flight to Singapore. … When the captain rotated the aeroplane for lift-off the tail struck the runway and scraped for some 490 metres until the aeroplane became airborne. The tail strike occurred because the rotation speed was 33 knots less than the 163 knots required for the aeroplane weight. The rotation speed had been mistakenly calculated for an aeroplane weighing 100 tonnes less than the actual weight of 9V-SMT. A take-off weight transcription error, which remained undetected, led to the miscalculation of the take-off data, which in turn resulted in a low thrust setting and excessively slow take-off reference speeds. The system defences did not ensure the errors were detected, and the aeroplane flight management system itself did not provide a final defence against mismatched information being programmed into it. During the take-off the aeroplane moved close to the runway edge and the pilots did not respond correctly to a stall warning. Had the aeroplane moved off the runway or stalled a more serious accident could have occurred. The aeroplane take-off performance was degraded by the inappropriately low thrust and reference speed settings, which compromised the ability of the aeroplane to cope with an engine failure and hence compromised the safety of the aeroplane and its occupants. Safety recommendations addressing operating procedures and training were made to the operator, and a recommendation concerning the flight management system was made to the aeroplane manufacturer." (Transport Accident Investigation Commission, 2003, November 19)

Transportation Safety Board of Canada (2003, April 29). *Tail Strike on Take-Off and Aircraft Pitch-Up on Final Approach, Air Canada, Airbus 330-343, C-GHLM, Frankfurt/Main Airport, Germany, 14 June 2002.* Aviation Investigation Report A02F0069. Gatineau, Quebec: Transportation Safety Board of Canada.

> ***Summary:***
> "An Airbus 330-343 aircraft, operating as Air Canada 875, with 253 passengers and 13 crew members on board, was on a scheduled flight from Frankfurt, Germany, to Montreal, Quebec. As the aircraft was taking off at approximately 0830 Coordinated Universal Time on Runway 25R, the underside of the tail struck the runway. The strike was undetected by the flightcrew, but they were notified of the strike during the climb-out by Air Traffic Services (ATS) and by a cabin crew member. …
>
> *Findings as to Causes and Contributing Factors*
>
> 1. The pilot not flying (PNF) inadvertently entered an erroneous V1 speed into the MCDU. The error was not detected by either flightcrew, despite numerous opportunities.

2. The PNF called ‘rotate’ about 25 knots below the calculated and posted rotation speed.
3. The pilot flying (PF) initiated rotation 24 knots below the calculated and posted rotation speed and the tail of the aircraft struck the runway surface.
4. A glide path signal was most probably distorted by a taxiing aircraft and provided erroneous information to the autopilot, resulting in a pitch-up event. The pitch-up could have been minimized if the autopilot had been disconnected earlier by the PF.

Findings as to Risk

1. Other than proper cross-checking, as per SOP, and the speeds displayed on the PFD, the flightcrew had no other means to know that an incorrect speed was inserted in the MCDU. A lack of situational awareness and airmanship contributed to not detecting the incorrectly set speed.
2. No warnings in the flight deck were provided to the flightcrew indicating that the on-board equipment was receiving a false glide path signal. Had the flightcrew noted the information depicted on the approach plate, it is likely that the PF would have been better prepared and reacted accordingly.
3. The flightcrew was not directly informed of the possibility of glide path interference caused by a taxiing aircraft because the aircraft was not within 12 nm from the threshold, in compliance with ATS procedure.
4. The PF allowed the aircraft to climb 1000 feet during the pitch-up, which could have caused a conflict with other aircraft.

Other Findings

1. While the atmosphere in the flight deck was professional, it is possible that the flat authority gradient contributed to a more relaxed attitude toward cross-checking each other’s actions or confirming other information.”

(Transportation Safety Board of Canada, 2003, April 29).

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Appendix E Bibliography

This bibliography lists the references cited in the report, together with other related material, such as regulations, guidance material, and other documents related to the report text but not specifically cited. Note that the related material is not intended to be a comprehensive list of all related documents.

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14 CFR Part 91, Subpart K Fractional Ownership Operations.
14 CFR Part 135 Operating Requirements: Commuter And On-Demand Operations And Rules Governing Persons On Board Such Aircraft.
14 CFR Part 121 Operating Requirements: Domestic, Flag, And Supplemental Operations.
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CS/§ 25.1322 Flightcrew Alerting.
CS/§ 25.1329 Flight Guidance Systems.

AC 120-29A Criteria for Approval of Category I and Category II Weather Minima for Approach.
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Appendix F Categorization Scheme for Reviewing Accident and Incident Data

This appendix includes a listing of the categories used by the Working Group to review and categorize the information from the accident, major incident, and ASRS incident reports.

Systems Used During Event

The systems being used at the time of the event were noted using the following list of categories.

Autoflight Systems

- Autopilot
- Auto-throttles/Auto-thrust
- Mode Control Panel (MCP)
- Flight Management System (FMS)
- Flight director
- ACARS/FANS
- Control display unit (CDU/MCDU))
- Other autoflight system

Flight Instruments

- Flight Mode Annunciator (FMA)
- Primary Flight Display (PFD)
- Navigation Display (ND)
- Attitude Deviation Indicator (ADI) or Electronic Attitude Deviation Indicator (EADI)
- Horizontal Situation Indicator (HSI) or Electronic Horizontal Situation Indicator (EHSI)
- Multi-Function Display (MFD)
- Head's Up Display (HUD) and Head's Up Guidance System (HGS) to include the combiner and cockpit indicators
- Head's Up Display (HUD) control panel
- Electronic Flight Instrument System (EFIS) to include flight displays and EFIS Control Panels (ECP)
- Other flight instruments

Warning Systems

- Altitude alerting system
- Ground Proximity Warning System (GPWS)/Enhanced Ground Proximity Warning System (EGPWS)
- Windshear warning system
- Traffic Collision Avoidance and Alerting System
- High speed limit warning
- Pre-stall stick shaker/pusher
- Other warning system

Navigation

- Area navigation (RNAV)
- Area navigation to include required navigation performance (RNAV RNP)

- Global positioning system (GPS)
- Inertial navigation systems (INS)
- Localizer (LOC)
- VHF omni range aircraft equipment (VOR)
- Distance measuring equipment (DME)
- Lateral navigation mode (LNAV)
- Other lateral navigation source
- Vertical navigation mode (VNAV)
- Level change mode
- Vertical speed mode (V/S)
- Approach or ILS mode (G/S)
- Altitude hold mode
- Other vertical navigation mode

Issues

The set of categories includes issues related to the autoflight/flight path management systems and their design, use, and training.

System Failure

Failure modes were likely unanticipated by designers	Some possible failures were likely not anticipated by designers so there were no contingency procedures provided to pilots, increasing trouble-shooting workload and the opportunity for error.
Failure assessment was difficult	It was difficult for the flight crew to detect, diagnose, and/or evaluate the consequences of system failures and malfunctions (including automated systems) resulting in faulty or prolonged decision making.
Failure recovery was difficult	When systems failed (including automated systems) failed, pilots had difficulty taking over monitoring, decision making, and/or control tasks.

System Complexity

Automation was too complex	An automated system was too complex in that it consisted of many interrelated components and/or operated under many different modes. This made the system difficult for pilots to understand and use safely.
Complex automation had overly simplistic interface	Simplified pilot-automation interfaces hid important complexities, leading to unexpected behaviors and difficulty performing complex operations.

System Functionality

Automation did not work well under unusual conditions	Automation worked well under normal conditions but, due to design limitations, did not have the desired behavior under unusual conditions, such as those close to the margins of its operating envelope. This lead to unsafe conditions.
Automation lacked reasonable functionality	Automation design prevented the device from performing a function that seemed reasonable to the pilot, requiring the use of alternative strategies that increased workload and/or the opportunity for error.
Workarounds were necessary	Pilots used automation in a manner not intended by designers to get desired results or to avoid undesirable consequences, increasing pilot workload and/or opportunity for error. This had unanticipated and undesirable side effects.
Automation performance was limited	The ability of the automation to perform correctly and quickly was limited by design constraints, increasing pilot workload and/or the opportunity for error.
Automation used different control strategies than pilots	Automation used a different strategy of control or control logic than the pilot would have used, leading to the pilot's loss of situation awareness and/or pilot errors.
Automation integration was poor	The lack of integration of automation systems increased pilot workload and/or the opportunity for error.

Levels of Automation

Automation level decisions were difficult	It was difficult for pilots to decide what levels of automation were appropriate in specific circumstances, increasing pilot workload and/or the opportunity for error.
Protections were lost though pilots continued to rely on them	Reversion to lower levels of automation disabled built-in protections, leading to unsafe conditions as pilots continued to rely on them.
Manual operation were difficult after transition from automated control	Manual flight control was difficult for the pilots after transition from automated to manual flight.

System Standardization

Standardization was lacking	There was a lack of function and/or interface standardization between automated systems, leading to increased training requirements, increased pilot workload, and/or poor pilot performance.

Crew Coordination

Crew coordination problems occurred	The use of automation adversely affected crew coordination leading to unsafe conditions.

Cross checking was difficult	It was difficult for one pilot to monitor what the other was doing with automation, reducing awareness of pilot intentions and cross checking for errors.
Pilot control authority was diffused	The traditional distribution of workload between pilots (e.g., between PF and PNF, between C and F/O) was modified under automated flight, allowing safety-critical tasks to be neglected.
Inter-pilot communication was reduced	The presence of automation reduced inter-pilot communication, resulting in less sharing of information.
Task management was difficult	The use of automation made task management more difficult for the flight crew, leading to unsafe conditions.

Other System Issues

Programming was susceptible to error	Programming methods for the FMS/autopilot was susceptible to error.
Automation use was vulnerable to cockpit distractions	Distractions in the cockpit lead to disruptions in control and/or monitoring of automation.
Automation information in manuals was inadequate	Manuals provided to pilots contained incomplete, unclear, or erroneous information about automation, leading to poor pilot performance.

Company Procedures

Automation use philosophy was lacking	There was no comprehensive, coherent philosophy provided to pilots for the use of automation, resulting in inconsistencies and/or uncertainties in its use.
Crew assignment was inappropriate	When two pilots with little automation experience were assigned to an advanced technology aircraft, errors occurred.
Company automation policies and procedures were inappropriate or inadequate	Company policies and procedures for the use of automated systems were inappropriate or inadequate in some circumstances, compelling pilots to use the automated systems when they prefer not to and/or leading to pilot confusion or frustration.
Procedures assumed assume automation	Some procedures were designed under the assumption that automated systems will be used. When it was not, either by necessity or pilot choice, workload increased and/or errors occurred.

Pilot Training

Deficiencies in basic aircraft training existed	Training for automated aircraft did not adequately prepare pilots with basic (i.e., non-automation) knowledge and skills in that aircraft, and pilots lacked the knowledge and skills necessary to operate the aircraft manually.
Training was inadequate	Training philosophy, objectives, methods, materials, and/or equipment were inadequate to properly train pilots for safe and effective aircraft operation.
Transitioning between aircraft increased training requirements	Transitioning back and forth between different types of aircraft increased pilot training requirements.

System Interface

Interface was poorly designed	The pilot-automation interface was poorly designed with respect to human factors considerations, resulting in poor pilot performance.
Information integration was required	Pilots needed to integrate information spread over several parts of the interface, creating additional pilot workload.
Data access was difficult	It was difficult for pilots to access data "hidden" in the architecture of the automated system, increasing pilot workload.
Information overload existed	Large amounts and/or poor formatting of information increased pilot workload.
Data re-entry was required	Data entries did not propagate to related functions in automated systems. The same data had to be entered more than once.
Insufficient information was displayed	Important information that could be displayed by the automated system was not displayed, thereby limiting the ability of pilots to make safe decisions and actions.
Data presentation was too abstract	Data presented in integrated/processed/simplified forms did not fully support effective pilot decision making and pilots lost sight of raw data..
Inadvertent autopilot disengagement was too easy	It was too easy for the pilot to inadvertently disengage the autopilot.
Behavior of automation was not apparent	The behavior of automated system(s) -- what they are doing now and what they will do in the future based upon pilot input or other factors -- was not apparent to pilots, resulting in reduced pilot awareness of system behavior and goals.
Data entry errors on keyboards occurred	Keyboard alphanumeric data entry was prone to errors, adversely affecting safety.
Controls of automation were poorly	Automation controls were designed so they were difficult

designed	to access and/or activate quickly and accurately, or easy to activate inadvertently.
Displays (visual and aural) were poorly designed	Displays (including aural warnings and other auditory displays), display formats, and display elements were not designed for detectability, discriminability, and/or interpretability. This resulted in important information being missed or misinterpreted.

Pilot Attention

Pilots were out of the loop	Pilots were out of the control loop and peripheral to the actual operation of the aircraft and therefore not prepared to assume control when necessary.
Automation demanded attention	The attentional demands of pilot-automation interaction interfered with performance of safety-critical tasks. (e.g., "head-down time", distractions, etc.)
Monitoring requirements were excessive	Pilots were required to monitor automation for long periods of time, a task for which they are perceptually and cognitively ill-suited, and monitoring errors were made.
Both pilots' attention was simultaneously diverted by programming	Both pilots became involved in programming duties simultaneously, diverting the attention of both pilots from safety-critical tasks.

Pilot Automation Awareness

Mode transitions were uncommanded	An automated system changed modes without pilot commands to do so, producing surprising behavior.
Mode awareness was lacking	Pilots were not able to tell what mode or state the automation was in, how it was configured, what it was doing, or how it was going to behave. This lead to reduced situation awareness and/or errors.
Vertical profile visualization was difficult	It was difficult for pilots to visualize vertical profiles based on alphanumeric displays. This difficulty increased pilot workload when flying, or planning to fly, these profiles.

Pilot Confidence

Pilots lacked confidence in automation	Pilots lacked confidence in automation due to their experience (or lack thereof) with it. This result in a failure to use automation when it should have been used.
False alarms were frequent	Frequent false alarms caused pilots to mistrust or ignore automation and therefore not use it or respond to it when they should have.
Pilots were overconfident in automation	Pilots became complacent, overconfident in and/or uncritical of automation, and failed to exercise appropriate vigilance to the extent of abdicating responsibility to it. This lead to unsafe conditions.
Pilots were reluctant to assume control	Pilots were reluctant to assume control from automation. Even when automation malfunctioned or behaved contrary to their expectations they persisted in using it, possibly with time-consuming programming changes. This lead to unsafe conditions.

Pilot Performance

Automation use slowed pilot responses	When using automation, pilot response to unanticipated events and clearances were slower than it would be under manual control, increasing the likelihood of unsafe conditions.
Transitioning between aircraft increased errors	Transitioning back and forth between aircraft lead to problems such as erosion of aircraft-specific skills leading to pilot errors.
Mode selection was incorrect	Pilots inadvertently selected the wrong automated system mode or failed to engage the selected mode, causing the automated system to behave in ways different than the pilots intended or expected.

Role of the Pilot

New tasks and errors were identified	The use of automated systems changed and/or added pilot tasks, making new (often more serious) errors possible.
Pilot's role was changed	The use of automated systems changed the role of the pilot from that of a controller to that of a supervisor resulting in opportunity for errors.

Pilot Situation Awareness

Situation awareness was reduced	Reliance on automation reduced pilots' awareness of the present and projected state of the aircraft and its environment, resulting in incorrect decisions and/or actions.
State prediction was lacking	Automation displays showed only current state and no trend or other information that could help pilots estimate future state or behavior. This prevented pilots from anticipating and preparing for upcoming problems.

Pilot Understanding of Automation

Understanding of automation was inadequate	Pilots did not understand the structure and/or function of an automated system or the interaction of automated systems well enough to safely perform their duties.
Automation behavior was unexpected and unexplained	Automation performed in ways that were unintended, unexpected, and/or unexplainable by the pilots, creating confusion, increasing pilot workload to compensate, and/or leading to unsafe conditions.

Pilot Use of Automation

Pilots over-relied on automation	Pilots used automation in situations where it should not have been used.
Pilots under-relied on automation	Pilots did not use automation when they should have, leading to unsafe conditions and/or reduced operating efficiency.
Procedures assumed automation	Some procedures were designed under the assumption that automation will be used. When it was not, either by necessity or pilot choice, workload was excessive and/or errors occurred.

Pilot Workload

Data entry and programming were difficult and time consuming	Procedures for data entry and programming automated systems was unclear, overly difficult, complex, and/or time consuming. This caused errors and/or delays that lead to unsafe conditions.
Automation adversely affected pilot workload	Use of automated systems increased overall pilot workload, or increased pilot workload at high workload times or reduced pilot workload at low workload times, resulting in excess workload and/or boredom.
Information processing load was increased	Information about the mode (state) and behavior of the automated system itself added to the pilot's information processing load, resulting in increased workload and/or opportunities for error.

Planning requirements were increased	Flying an automated aircraft took more planning than flying a manual aircraft. Pilots did not plan far enough ahead to use automated systems, so safety was compromised.

Threats

The threat categories included all threats used in LOSA observations and two additional crew-related threats added by the WG to capture threats that could impact the operation based on inadequate knowledge that the pilots bring to the flight deck or other crew-related threats.

Operator-Related Threats

Operator Operational Pressure	Operational time pressure, missed approach, diversion, other non-normal ops
Cabin Events	Cabin events, flight attendant errors, distraction, interruptions
Aircraft Malfunctions/MEL items	Systems, engines, flight controls, or automation anomalies detected by the flight crew or MEL items with operational implications
Ground Maintenance	Aircraft repairs on ground, maintenance log problems, maintenance errors
Ground/Ramp	Aircraft loading events, fueling errors, agent interruptions, improper ground support, de-icing
Dispatch/Paperwork	Load sheet errors, crew scheduling events, late paperwork changes or errors
Manuals/Charts	Incorrect/unclear Jeppesen pages or operating manuals
Other	Other operator threat

Environmental Threats

Adverse Weather	Thunderstorms, turbulence, poor visibility, wind-shear, icing conditions, IMC
ATC	Tough-to-meet clearances/restrictions, reroutes, language difficulties, controller errors
Airport Conditions	Poor signage, faint markings, runway/taxiway closures, INOP navigational aids, poor braking action, contaminated runways/taxiways
Other	Terrain, traffic, TCAS TA/RA, radio congestion

Crew-Related Threats

Inadequate knowledge	Threat resulting from lack of knowledge by pilots or flight crew
Other	Other threats imposed on the operation due to the flight crew.

Pilot Errors

These categories are the same as those representing the pilot errors included in the LOSA observations.

Communication Errors

Crew-to-External Communication	Crew to ATC - missed calls, misinterpretation of instruction, or incorrect read-backs; wrong clearance, taxiway, gate or runway communicated
Pilot-to-Pilot Communication	Within-crew miscommunication or misinterpretation; sterile cockpit violations

Handling/Input Errors

Manual Handling/Flight Controls	Hand flying vertical, lateral, or speed deviations; approach deviations by choice (e.g., flying below the GS); incorrect flaps, speed brake, autobrake, thrust reverser or power settings
Mode selection error	Selection of inappropriate mode or failure to select a mode when necessary
Ground Navigation	Attempting to turn down wrong taxiway/runway; missed taxiway/runway/gate
Automation	Incorrect altitude, speed, heading, autothrottle settings, mode executed, or entries
Systems/Radio/Instruments	Incorrect packs, altimeter, fuel switch settings, or radio frequency dialed
Ground Navigation	Runway/taxiway incursions; proceeding towards wrong taxiway/runway; wrong taxiway, ramp, gate, or hold spot
Incorrect Aircraft Configurations	Incorrect systems, flight control, automation, engine or weight and balance configuration

Procedural Errors

SOP Cross-verification	Intentional or unintentional failure to cross-verify automation inputs
Checklist	Checklist performed from memory or omitted; wrong challenge and response; checklist performed late or at wrong time; items missed
Callouts	Omitted takeoff, descent, or approach callouts
Briefings	Omitted departure, takeoff, approach, or handover briefing; items missed
Documentation	Wrong weight and balance, fuel information, ATIS, or clearance recorded; misinterpreted items on paperwork; incorrect log book entries
Other	Administrative duties performed after top of descent or before leaving active runway; PF makes own automation change; incorrect application of MEL procedures

Automation Use Errors

Automation MCP/FCU	Automation error related to the Mode Control Panel (MCP), Flight Control Unit (FCU), or equivalent.
FMC/FMGC (Automation)	Automation error related to the Flight Management Computer (FMC), Flight Management Guidance Computer (FMGC), or equivalent.
A/P (Automation)	Automation error related to the Auto Pilot.
A/T and Associated Controls (Automation)	Automation error related to the autothrottles/autothrust system.
Flight Director	Automation error related to the Flight Director system.
Information Management	Automation error related to Information Management.
Other (Automation errors)	Other automation errors.
CDU/MCDU (Automation)	Automation control display unit (CDU) or multifunction control display unit (MCDU).

Undesired Aircraft States (UAS)

The UAS categories were also duplicated from those included in LOSA observations.

Speed Deviation - High	Speed deviation above the selected/commanded speed resulting in an undesired aircraft state.
Speed Deviation - Low	Speed deviation below the selected/commanded speed resulting in an undesired aircraft state.
Lateral Flight Path Deviation	Lateral Flight Path Deviation Undesired Aircraft State.
Vertical Flight Path Deviation - High	Vertical flight path deviation above a desired altitude resulting in an undesired aircraft state.
Vertical Flight Path Deviation - Low	Vertical flight path deviation below a desired altitude resulting in an undesired aircraft state.
Altitude Deviation - High	Altitude deviation above a desired altitude resulting in an undesired aircraft state.
Altitude Deviation - Low	Altitude deviation below a desired altitude resulting in an undesired aircraft state.
Ground Navigation (UAS)	Runway/taxiway incursions; proceeding towards wrong taxiway/runway; wrong taxiway, ramp, gate, or hold spot.
Incorrect Aircraft Configurations	Incorrect systems, flight control, automation, engine or weight and balance configuration.
Other (Undesired aircraft states)	Other undesired aircraft states.

Definitions of Incidents and Accidents

Incident- An occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operation. (ICAO Annex 13)

Accident- An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which (a) a person is fatally or seriously injured as a result of: being in the aircraft; or direct contact with any part of the aircraft, including parts which have become detached from the aircraft; or direct exposure to jet blast (except when the injuries are from natural causes, self-inflicted or inflicted by other persons, or when the injuries are to stowaways hiding outside the areas normally available to the passengers or crew); or (b) the aircraft sustains damage or structural failure which: adversely affects the structural strength, performance or flight characteristics of the aircraft and would normally require major repair or replacement of the affected component (except for engine failure or damage, when the damage is limited to the engine, its cowlings or accessories; or for damage limited to propellers, wing tips, antennas, tires, brakes, fairings, small dents or puncture holes in the aircraft skin); or (c) the aircraft is missing or is completely inaccessible. (ICAO Annex 13)

Appendix G Results of Analyses

This appendix includes detailed descriptions of the Working Group processes, data analyses and results referenced in the main body of the report. The first subsection describes the process used by the WG. The second subsection describes the review of Accidents, Major Incidents, and ASRS Incidents and their comparison with appropriate aggregated data from LOSA. The next two subsections describe factor analyses that were conducted on the ASRS incident data and the combined accident and major incident data. Following that is a subsection describing a co-occurrence analysis that was conducted to understand the relationships between the categories that occurred in the different types of reports (e.g., what threats often occurred with particular errors). The final subsection of this appendix describes a more in depth review of the LOSA data the WG received from the LOSA Collaborative.

It is important to note that the analysis results discussed within this report for accidents, major incidents, and ASRS incidents are based on the subsets of events that fell within the scope of this WG and were reviewed by the WG. These statistics do not represent frequency of occurrence for all accidents, major incidents, ASRS incidents that occurred during the time frame of this study.

Working Group Process

Section 2.3 in the main body of this report described the overall process and tasks[59] accomplished by the Flight Deck Automation Working Group (WG). This subsection expands that discussion with additional information about the process used to accomplish the tasks described in section 2.3 of the report.

The WG process included the following steps in sequence, each of which is discussed below. Each step identifies which tasks from the Terms of Reference it addresses.

1. Select data sources, including accident and incident reports for review. (Task 1, Task 4)
2. Review and categorize individual accident and incident reports. (Task 1)
3. Conduct structured interviews. (Task 2)
4. Review current operations relative to the 1996 FAA report and identify assumptions about future operations. (Task 3, Task 5)
5. Analyze results of data collection, categorization, and interviews. (Task 1)
6. Develop findings. (Task 7)
7. Develop recommendations. (Task 6, Task 7)

[59] Summary of tasks from Terms of Reference (see Appendix A):
Task 1: Gather and review data.
Task 2: Conduct organization interviews.
Task 3: Identify changes since the 1996 HF Team Report.
Task 4: Identify normal operations and positive behaviors.
Task 5: Identify assumptions about future operations.
Task 6: Determine Status of 1996 HF Team Report recommendations.
Task 7: Develop findings and recommendations.

Step 1. Select data sources, including accident and incident reports for review.

Data from several sources were gathered and reviewed including ASRS incident reports, accident reports, major incident reports (reports developed by an investigating board for events that do not meet the definition of an accident), LOSA data, and related reports.

To assure that the reports were within the scope of the WG tasking, the reports had to meet the following criteria:

- The event involved transport category aircraft involving two pilot operations,
- The events occurred (or the investigative reports were published) since the analysis of accidents and incidents in the 1996 FAA report, and
- The accidents/incidents involved flight path and energy-state management as an element of the accident. For example, accidents involving runway incursions were not included.

The WG identified 26 accidents that fell within the scope of the work, occurred (or the report was finalized) since the 1996 FAA report, and for which the final reports were available by July 2009. The WG also identified 20 major incidents that fell within the scope of the work, each of which occurred (or was published) since 1996, and for which the final reports were available by July 2009. See Appendix E for a list of the reports reviewed.

LOSA data allowed insight into normal operations at the observed airlines and includes when things go right as well as when things go wrong. In addition, some of the major incidents represent cases where the pilots' positive behaviors mitigated risk and prevented accidents. Related reports ranged from previous research to descriptions of operational experience from many sources. This information was provided by aviation individuals and organizations, often confidentially, and included individual event reports, aggregated ASAP data, internal operator studies, and others. These were considered and incorporated in the WG analysis and results.

Step 2. Review and categorize individual accident and incident reports.

Each ASRS incident report, accident report, and major incident report was assigned to a subgroup of the WG for review. Each subgroup first reviewed the report to confirm that the report was within the WG scope. If the report was not within the WG scope, it was removed from the WG list of relevant reports.

The subgroup reviewed each of the reports and coded them using an online form. This form represented a categorization scheme for identifying characteristics of each event, and included the following groupings:

- Report descriptive information,
- Systems involved,
- System design, operation, and training issues,
- Threats and errors, and
- Undesired aircraft states.

The categorization scheme was developed based on previous work that developed issues related to autoflight/flight path management systems,[60] and based on the Threat and Error Management (TEM) categories used in LOSA reviews by several airlines. In addition, the WG included categories based on other activities (such as, the JIMDAT SE-30 analysis[61]) and a crosscheck against some current operational data. Appendix F contains a description of the categorization scheme.

The subgroup had to agree on the categorization of each report, so that it was not just the judgment of one individual. It is important to note that, as with all safety reviews based on accident and incident reports, the data can only represent the information written in the reports that were reviewed. The WG did not reanalyze the data associated with the accidents or incidents, but used the findings and conclusions of the reporters or investigating boards as written in the reports to enter them in review categories. This process was very labor intensive.

Step 3. Conduct structured interviews.

The WG interviewed eleven operators, six manufacturers, and one independent training organization about their experiences and challenges. The training groups within each one of the operators and manufacturers were also interviewed. A structured interview method was used that was guided by a set of topics developed for the manufacturers and a set developed for the airlines and training organizations. The interview topics are included in Appendix C.

Step 4. Review current operations relative to the 1996 FAA report and identify assumptions about future operations.

Relevant changes in design, operations, training, and regulatory oversight were identified and defined based on the experience of WG members, formal publications (as referenced in the main body of this report), and information gathered in the interviews of manufacturers and operators. There are many changes being implemented in the next decade or beyond that will have significant effects on the airspace system as a whole and all operations within the airspace system. A complete definition of how these operations will transpire is not yet available, but it is important to make assumptions about these future operations to allow a better understanding of the impact of observations made and data gathered during the project. This was also important as a basis for effective development of findings and recommendations.

Step 5. Analyze results of data collection, categorization, and interviews.

There were several analyses done by the WG. One analysis was to normalize the categorized LOSA, accident and incident data by calculating and comparing the frequency of occurrence of all components of the categorization scheme. While it cannot be assumed that these represent the frequency of occurrence in actual operations, some interesting results were found. For "interesting" results (e.g., accidents occurring in the category higher that 20%), the WG reviewed the associated reports to get more information about what, exactly, the item (e.g., threat

[60] Funk, K., Lyall, B., Wilson, J., Vint, R., Niemczyk, M., Suroteguh, C., and Owen, G. (1999). Flight Deck Automation Issues, International Journal of Aviation Psychology, Volume 9, Issue 2, pp. 109-123.
[61] Commercial Aviation Safety Team (2008), Mode Awareness and Energy State Management Aspects of Flight Deck Automation, Final Report, August 2008.
.

or error) was that occurred as described in the report. This Appendix contains the details of this extended review, below.

A second type of analysis was to conduct factor analyses on the ASRS incident review results and the accident/major incident review results.[62] The factor analyses were conducted to identify which groups of reports tended to account for the variability of the data and what insights or lessons could be learned from reviewing the factors. The resulting groups are described below.

A co-occurrence analysis was conducted and Pathfinder[63] networks were created to try to understand the relationships between categories that consistently co-occurred with other categories to take findings beyond what can be developed with frequency analyses alone.

The data from the structured interviews were summarized for key points. The key points were examined for their relationship to results from other data sources.

Data from LOSA observations on 9155 flights worldwide were shared with the WG by the LOSA Collaborative through aggregate reports that could be compared with other WG data. Also, input was provided from LOSA data that described positive pilot behaviors. Such information cannot easily be understood from the other data sets. A more detailed discussion of the LOSA analysis is included later in this Appendix.

The LOSA Collaborative also supplied a representative sample of over 2200 de-identified narratives where the observer had indicated either a poor/marginal or outstanding assessment for the “use of automation” marker. These narratives provided further insight into threats flightcrew face that operationally impact flight path management systems. The narratives were analyzed to better understand how flightcrew may either err or adapt their use of flight path management systems.

The WG reviewed related reports from research studies or other as mentioned above.

Step 6. Develop findings.

All of the data analyses, the information gathered from interviews and other sources, and the expertise and experiences of the WG members were used to develop findings that addressed the objectives and scope of the WG terms of reference. The WG reviewed the analysis results, looking for both positive results and vulnerabilities.

The data and analysis results were divided into subsets addressing design, operations, training, and regulatory issues. Each of these subsets was broken down and organized into appropriate categories to best understand and describe the conclusions that can be derived from the information. The initial focus was on the data representing operational experience on “the front line.” Relevant results were formulated into findings. Based on the operational experience findings, the WG reviewed the data to determine if the underlying reasons (the “why”) for the operational experience could be determined. Because such information is not often identified in accident and incident reports, much of these results came from interview data and WG expertise.

[62] Child, Dennis 2006. “The Essentials of Factor Analysis”

[63] Schvaneveldt, Durso, Dearholt, “Network Structures in Proximity Data,” The Psychology of Learning and Motivation, Volume 24, 1989.

The WG especially looked for "significant" presence of errors and looked to see whether the 1996 FAA report findings were still valid. If any particular item was strongly present in the data (e.g. manual handling/flight control errors in the accident data), then the WG looked across data sources to see whether there was additional evidence or information to expand on the topic. The WG looked for common (or differing) results across data sources or different analyses.

In addition to the operational data analysis, the WG was asked by the CAST to identify lessons learned from analyzing multiple data sources, as part of a prognostic (versus forensic) approach to safety data analysis. As the analysis progressed and findings were developed, the lessons learned were retained into a set of findings related to the data collection and analysis process.

Step 7. Develop recommendations.

Based on the findings, the WG developed associated recommendations that could be traced back to the findings and the information from which the findings were developed. The WG noted that many of the recommendations require multiple actions to address the finding(s) and that many of the findings and recommendations are interrelated.
As part of this process, it was important to understand the status of implementation of the recommendations from the 1996 HF Team report. The terms of reference for the WG stated that the status of these recommendations was to be assessed along with a judgment about the continued relevance of the recommendations that have not yet been addressed. This task was accomplished using the results of the data analysis, the expertise and industry awareness of the working group members and the information gathered through the interviews.

The process had many of the characteristics of other review and recommendation processes such as that used by CAST, but was driven by the specific tasking from the PARC and CAST that addressed both operational effectiveness and safety, the breadth of data sources reviewed, and the diverse areas of expertise included in the WG.

Accidents, Major Incidents, ASRS Incidents, and LOSA Data

The WG conducted a search of the ASRS database using the keywords identified in Appendix C, then reviewed the resulting set of over 1000 ASRS incident reports that were submitted between January 2002 and December 2007. There were 734 of the incident reports reviewed that were identified as relevant to our scope. Each of these 734 incident reports were reviewed in detail and coded as related to a set of categories chosen by the WG. The coding was accomplished by using an online form and included the following five groups of categories:

- Report descriptive information;
- Systems involved;
- Automated system design, operation, and training issues;
- Threats, errors, and undesired aircraft states; and
- End states (for accidents only).

The WG calculated the frequency of occurrence for all categories. A factor analysis was also conducted on the combined data from the review of the accident and major incident reports. The individual factors were then reviewed to identify lessons learned for each of those groups of

ASRS incidents or accidents/major incidents. The results of these analyses are described later in this section.

Given the normal caveats of ASRS data (e.g., frequencies of reported incident types are not necessarily representative of overall frequency of occurrence in operations and self-reports may be more likely to explicitly describe some types of issues more than others), it was still interesting to note the frequency with which ASRS incidents were classified into the different categories of our classification template.

As described above in the description of the WG processes, LOSA data were obtained from the LOSA Collaborative for the categories that were equivalent among the LOSA data collection and those used by the WG. This allowed a comparison to be made of normal operations as described in the LOSA data, accidents, major incidents, and ASRS incidents all on the same data charts based on the categories. This is a very interesting comparison, and much can be learned by doing it, but it is important to keep in mind the different characteristics of each of the data sets that make a simple comparison inappropriate. These limitations will be discussed in presentations of the data charts that follow.

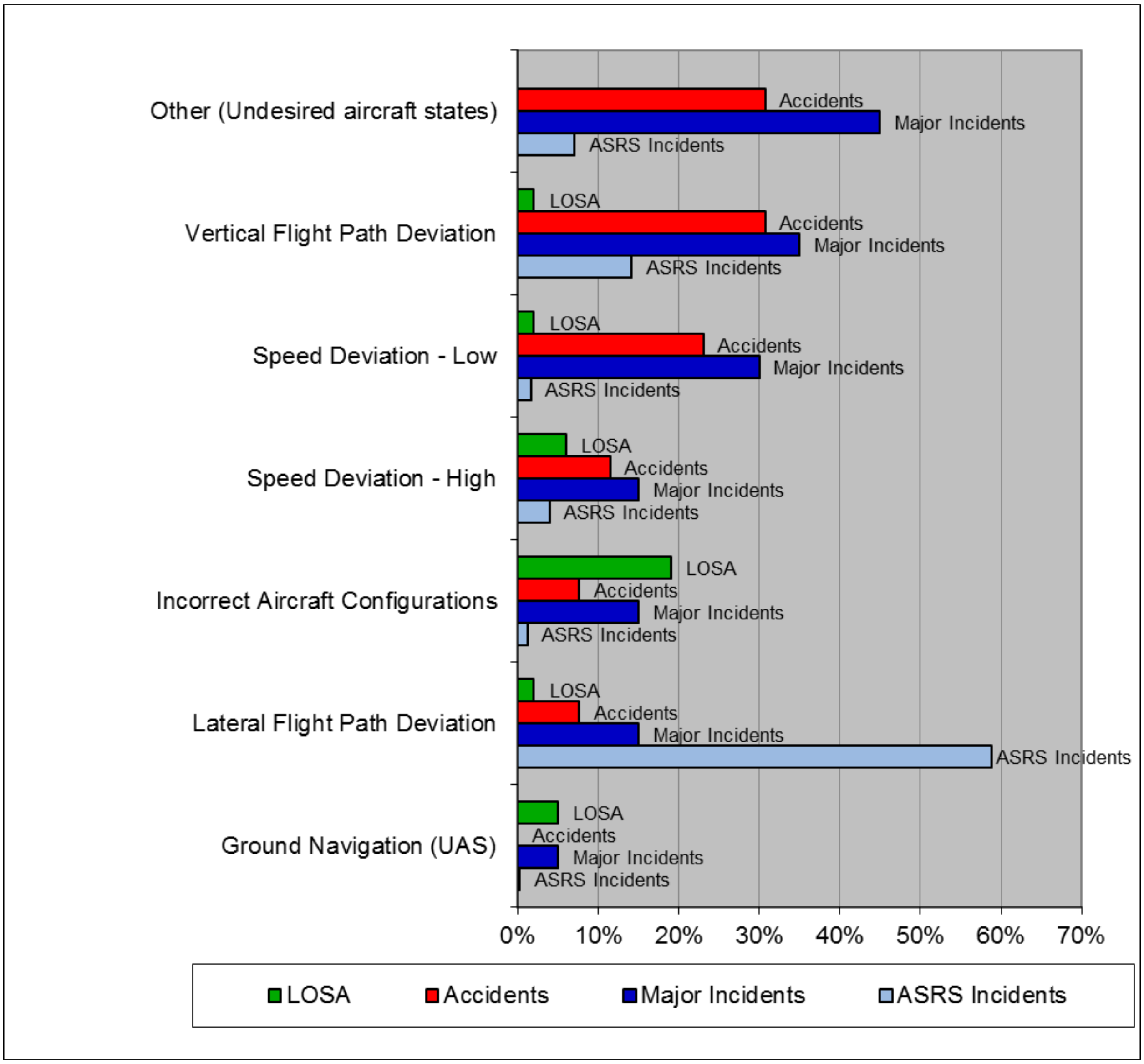
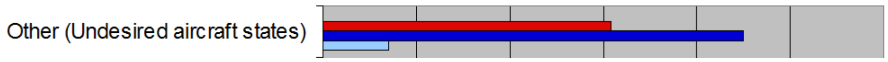


Figure 25. Undesired Aircraft States.

Figure 25 presents the percentage of each of the undesired aircraft states (UASs) represented in the different types of event reports. The figure is ordered from top to bottom by the categories with the highest to lowest percentage in the accidents. This is the same method used to order the categories from top to bottom for all of the figures presenting categories in this appendix.

The WG added the "Other (Undesired Aircraft States)" category to the UAS categories typically used by LOSA, to capture any UAS that was not on the original list of UASs in the WG categorization scheme. The WG broke down the "Other (Undesired Aircraft States)" category in more detail by reviewing each of the event reports in that category again and noting the UAS represented in the report that was not on the original list of UASs. Table 2 presents these additional UASs.

Table 2. Breakdown of "Other UAS" Category



Accidents

- Uncommanded pitch up
- Unintended pitch up and stall
- Lateral and vertical (low) deviations – followed by CFIT
- Tail strike on takeoff
- Runway overrun
- Ground loss of control, high thrust/high speed
- Autopilot disconnect

Major Incidents

- No spoilers (speed brakes), no reverse and manual braking – brake fire and blown main gear tires
- Very low thrust
- Wrong weights – too low speeds for takeoff
- Unreliable airspeed
- Uncommanded roll at 30' during landing
- Diversion with indeterminate fuel state, 2 of 4 engines fuel starvation

ASRS Incidents

- Landed at wrong airport
- Landed on wrong runway
- Landed on closed runway
- Landed without clearance
- Overweight landing
- Shot unauthorized NDB approach
- Aborted takeoff
- Takeoff from wrong runway
- Takeoff with IRSs unaligned
- Multiple system failures
- Dual FMC failure – had to use raw data
- Dual inertial failure
- Loss of all primary NAV/Attitude displays
- Diversion
- Flew with inoperative thrust management computer unnecessarily
- Dual MCDU failures
- Total MCP failure and lost one FMC
- Inoperative glideslope
- Overspeed flaps on approach
- IRS failure or unpowered
- Attitude Heading Reference System #2 failure (Mini IRS system)
- Intermittent dual FMS failure – unable to switch runways
- Displays blank on climbout
- A/I inoperative
- TCAS with parallel traffic
- Loss of separation
- Emergency Fuel declared
- Had to make GAR
- Incorrect software installed
- Loaded and flew wrong departure in FMS
- Flew segment with no NAV
- Flew RVSM despite unable/system failures
- Autopilot hardover and roll
- HUD illumination overshadowed by approach lights at minimums
- Rudder flutter

One UAS category that stands out is lateral deviations for the ASRS incidents at almost 60%. The WG wanted to understand what could have made the lateral deviations so high and chose to plot the ASRS incident lateral deviations by month to determine whether it provided insight into the result. The plot by month is presented in Figure 26. It can be seen that there are peaks between about October 2005 to October through January of 2006. In reflecting on this time period the WG realized that this was the time period in which RNAV departures were implemented in Atlanta and Dallas/Fort Worth. There were many challenges with lateral deviations with the RNAV departures and they were discontinued to address those challenges around the time of the peak coming down on the lateral deviations chart.

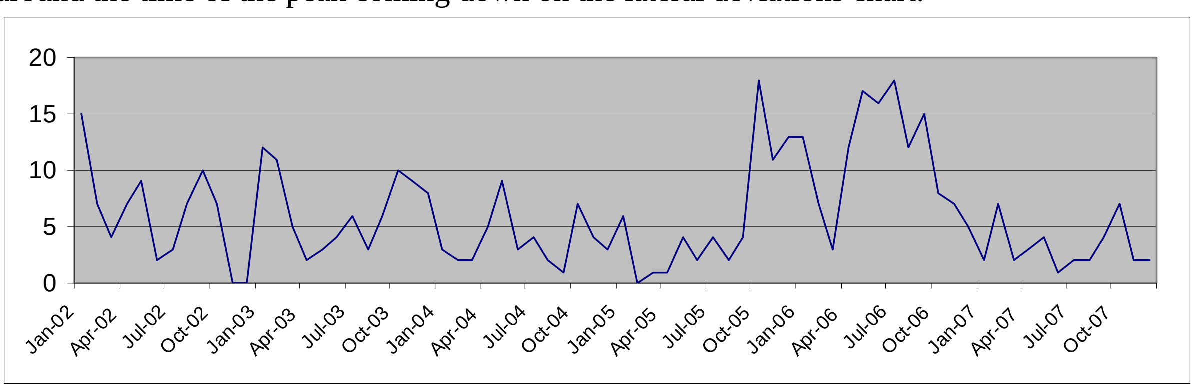


Figure 26. Number of lateral deviations in ASRS incidents plotted by month.

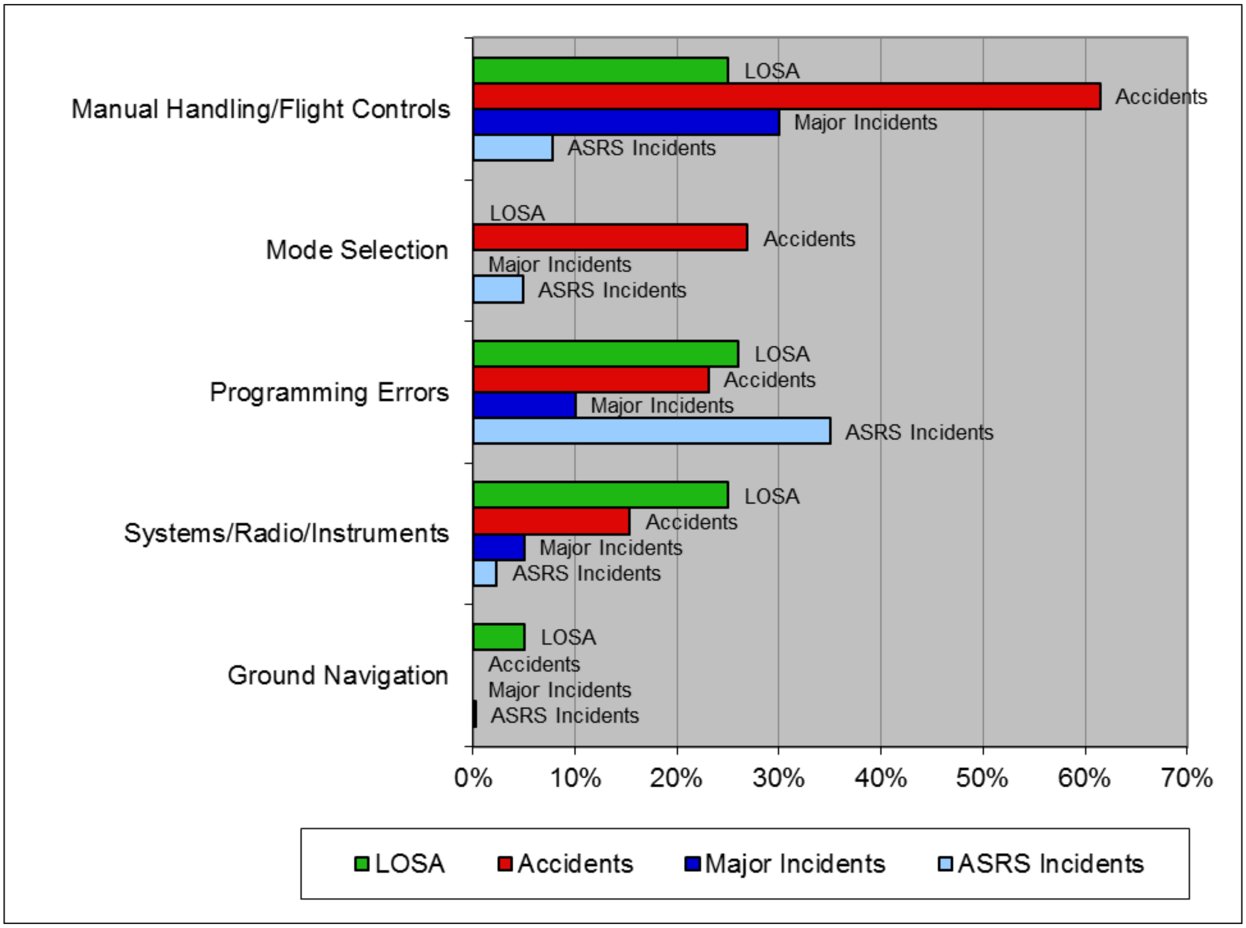


Figure 27. Handling/Input Errors.

One topic that is often raised in a discussion about the use of automated systems is the effects of their use on basic flying skills. The data category that can address this area most directly is that of manual handling/flight control errors, one of the handling/input errors. As shown above in Figure 27, over 60% of the accidents reviewed by the WG had a manual handling/flight control error. In examining the specific types of these errors that occurred in each of the event types, the types of manual handling/flight control errors are presented in Table 3. There are several errors that occurred in accidents, major incidents and ASRS reports. Except for mismanaged throttles/thrust, the manual handling errors that were evident in the ASRS incidents were different from the accidents and major incidents. This could be due to a difference in the types of events or in the elements that were able to be observed by the pilots in their own behavior compared to that by an investigation board.

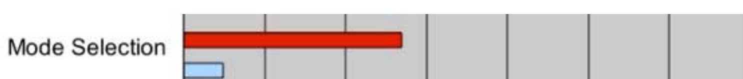
Table 3. Breakdown of "Manual Handling/Flight Control Errors" Category

Accidents	Major Incidents
• Inappropriate stall recovery	• Inappropriate stall recovery
• Dual sidestick inputs	• Dual sidestick inputs
• Mismanaged flight path	• Mismanaged flight path
• Mismanaged throttles/thrust	• Mismanaged throttles/thrust
• Failure to manually handle the airplane after	• Did not recognize uncommanded throttle

autopilot or autothrottle disconnect • Lack of monitoring/maintaining energy/speed • Incorrect upset recovery • Inappropriate control inputs • Inadvertent or inappropriate engagement or disengagement • Failure to retract speed brakes • Overpowered autopilot • Overcontrol after autopilot disengagement • Early rotation • Over rotation	disconnect • Ground handling – asymmetric braking • Ground handling – did not correct for crosswind
ASRS Incidents	
• Mismanaged throttles/thrust • Incorrect configuration of automation • Reliance (mistaken or over-reliance) on flight path management system • Turned wrong way • Incorrect aircraft configuration – flaps • Incorrect control inputs	• Reversion to manual was difficult after automation failure • Inadvertent disengagement of autopilot or autothrottles • Overpowered autopilot • Mental miscalculation • Lack of energy awareness

The WG added the "mode selection error" category to the set of handling/input errors used by LOSA, because it is a topic that occurred in accidents and incidents. The WG reviewed the details of the events that included mode selection errors shown in Figure 27 and the breakdown is presented in Table 4. The investigations of the major incidents did not identify any mode selection errors and only two were identified in the accidents that were reviewed by the WG. The pilots who submitted ASRS reports did report several mode selection errors related to vertical and lateral modes. It is important to remember the nature of the event sources when interpreting these differences because it is possible that investigation boards do not have the data available to them to identify such errors.

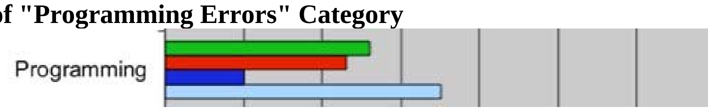
Table 4. Breakdown of "Mode Selection Errors" Category



Accidents	**Major Incidents**
• Misunderstanding of how the aircraft reacts to VNAV in a descent • Lack of knowledge of autopilot control and manual inputs	• None
ASRS Incidents	
VNAV modes • Misuse Of Vertical Speed Mode - Altitude bust • Misuse of Level Change – Altitude Bust • VNAV DESCENT – programming error • Heading Mode – selected instead of airspeed • Tailwind and high speed – could not make crossing restrictions • Open descent – selected on glideslope, left the glide slope • Altitude Hold Mode – could not descend • Selected altimeter rather than altitude select • Speed Mode – programming caused high speed through 10000 feet • Altitude Arm – was not selected, caused altitude bust	Lateral modes • Heading mode – selected airspeed instead and missed the localizer • LNAV mode – programming problem • Selected ½ bank angle and overshot localizer • Selected heading instead of LNAV • CWS Mode – autopilot did not follow the LNAV track

The breakdown for programming errors is presented in Table 5. These details provide a description of the specific types of programming errors that happened in the events. It can be seen that data entry errors and substitution errors occurred in all event types.

Table 5. Breakdown of "Programming Errors" Category



Accidents	Major Incidents
• Incorrect entries • Data substitution errors. I.e., a value was entered into the wrong Control Display Unit (CDU) field and acted upon by the FMC. • An entry was made, or one was thought to have been made, but the resulting information presented to the flightcrew was not what was expected nor was it perceived as being incorrect.	• An error was accepted by the automation but the product was not appropriate for the desired operation. • Data substitution error • Incorrectly selecting a mode for an anticipated downstream operation (anticipated incorrectly).
ASRS Incidents	
The types of programming errors in the ASRS reports were widely varied but could generally be categorized into the following: • Keyboard entry errors (position initialization, waypoint ID, altitudes, holding instructions) • Lateral route errors (loading clearances, ATC late runway/arrival changes, takeoff runway change, complex departure routing changes during a SID/STAR, holding programming errors)	• FMC logic errors: Flightcrews would enter a route but then not notice that a unique FMS operation would delete waypoints or not include route segments. Failure to enter the SID and STAR transitions was a significant number of errors. • Vertical restrictions that were either dropped or not included in the new routing (loading clearances, altitude clearance changes, incorrect modes)

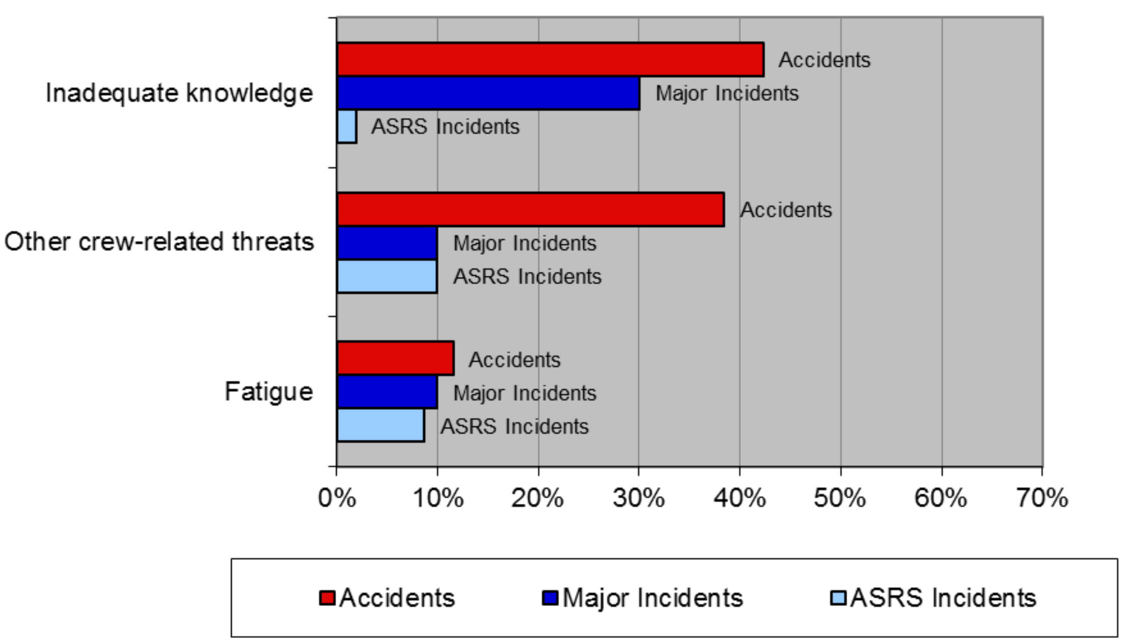


Figure 28. Crew-Related Threats.

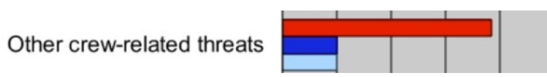
Figure 28 includes the percentage of events that included crew-related threats. These threats were added to the list of threats typically used during the LOSA process because it was important to the WG to capture threats brought into the event by the crewmembers. An inadequate knowledge threat indicates that one or more of the pilots did not have some knowledge important to their performance during the event. Inadequate knowledge does not necessarily imply a training issue. It could also be related to lack of particular experience. Table 6 presents the breakdown of this category describing areas that were identified as inadequate in the reports reviewed.

Table 6. Breakdown of "Inadequate Knowledge Threat" Category

Accidents	Major Incidents
• Autopilot/flight director systems • TCAS procedures • FMS procedures • Upset recovery/high altitude stalls • CRM • Descent procedures • Approach procedures	• Autopilot/flight director procedures • Approach procedures • Descent procedures • CRM
ASRS Incidents	
• FMS Procedures • Approach Procedures • Aircraft systems (INS)	

The area of "Other crew-related threats" was reviewed in more detail to identify any crew-related topics included in the reports other than crew fatigue and inadequate knowledge. Table 7 presents these "Other Crew-Related Threats" for the accidents and major incidents.

Table 7. Breakdown of "Other Crew-Related Threats" Category



Accidents	Major Incidents
• Lack of experience with destination • Self-induced time pressure • Flat authority gradient (neither pilot spoke up) • Lack of familiarity with aircraft type • Negative transfer from previous airplane • Unprofessional attitude • High workload • Poor judgment • "Excessive mental set"- crew determined to land at destination, regardless of bad weather briefed by controller • Irrelevant conversation • Spatial disorientation	• Workload

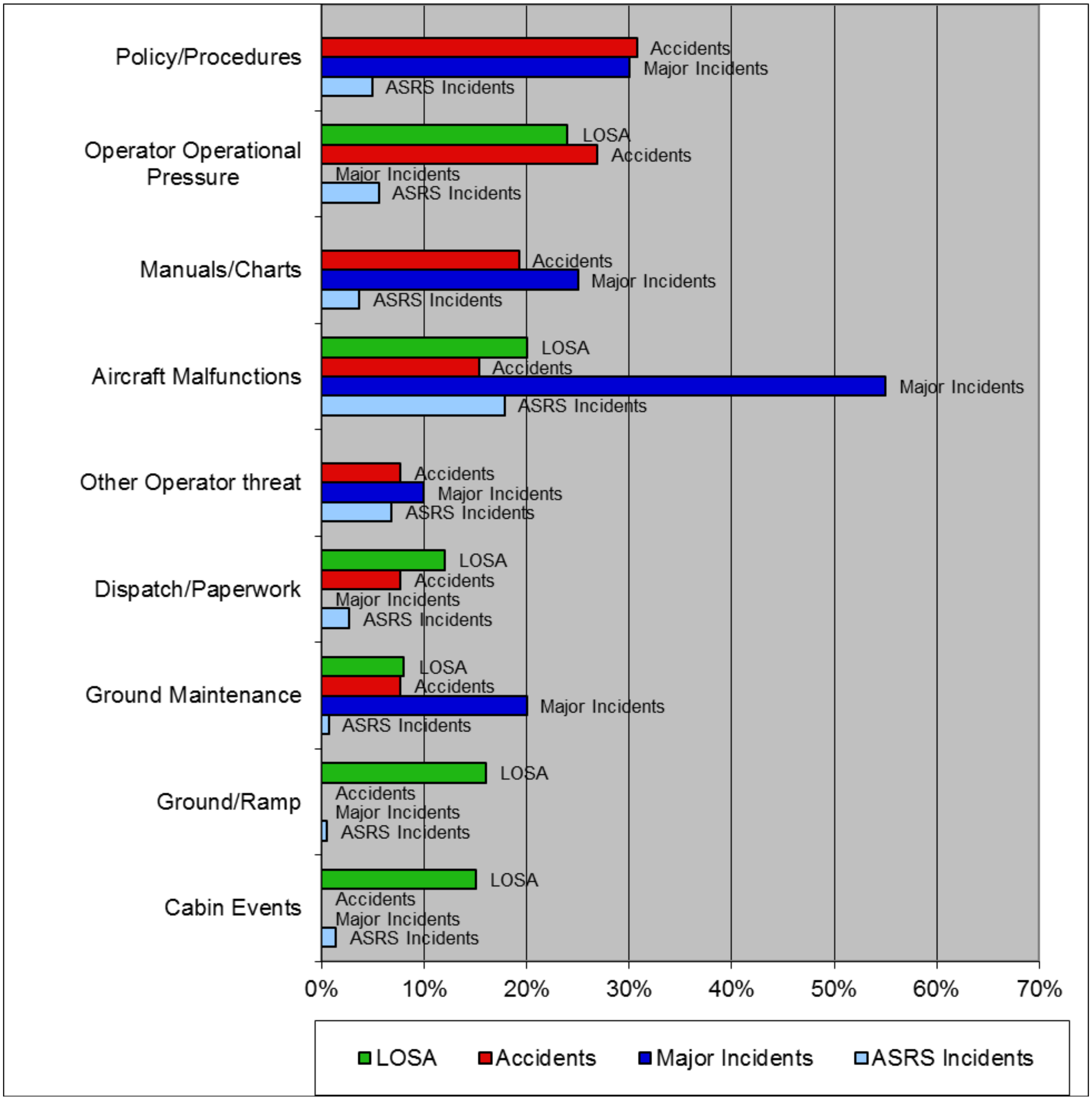


Figure 29. Operator-Related Threats.

The WG included nine operation-related threats in the review categories, as shown in Figure 29. The WG added three operation threat categories to the six typically used by LOSA. The operational threat categories added are Policy/Procedures, Manuals/Charts, and Other Operator-Related Threats. The operator-related threats include some that are considered latent factors that are not consistently considered during investigations. Due to this inconsistency, the data may not thoroughly represent the actual number of these threats that occurred in the events reviewed. It is also difficult for the pilots to know what effects the operator-related factors may have had on the situations they are reporting, therefore, the ASRS incidents likely also under-report the factors associated with these categories. The methods used for LOSA observations tend to be more sensitive to identifying operator-related threats because of their use of trained observers and a set observation form. Also, the LOSA method for sampling from the full set of operations of the company being audited provides an effective opportunity for understanding the prevalence of such threats in the operations observed. One of the data points presented here is that malfunctions occur approximately 20% of the time in LOSA observations, which may be a good representation of normal operations indicating that such malfunctions have not been eliminated from the overall system and this level of reliability needs to be considered when making decisions for operations in the future. Table 8 describes the types of aircraft malfunctions that occurred in the accident, major incident, and ASRS incident reports reviewed.

Table 8. Breakdown of "Aircraft Malfunctions Threat" Category

Accidents	Major Incidents
• autopilot uncommanded disconnect • autopilot uncommanded pitch up • autopilot uncommanded pitch down after "flare" engagement during an autoland • IRU failure	• multiple electrical and electronic failures due to degraded power on the hot battery bus, left dc and right dc buses • FCC software malfunction due to localizer disturbance on takeoff • autopilot and auto-thrust uncommanded disconnect due to intermittent ADIRU #1 and foreign material in #1 Pitot water drain holes • defective K-1 relay, autopilot fore and aft pitch accelerometers, NAV-1 and NAV-2 BNC connectors • left ADC • FAC-2 "theta-trim" flight augmentation computer • electrical failure causing loss of displays • #3 ADIRU on MEL, #1 AIDRU failed causing loss of PIC displays • automatic fuel transfer system failure
ASRS Incidents	
Typically these were FMC problems, such as map shifts, IRU issues, and database problems.	

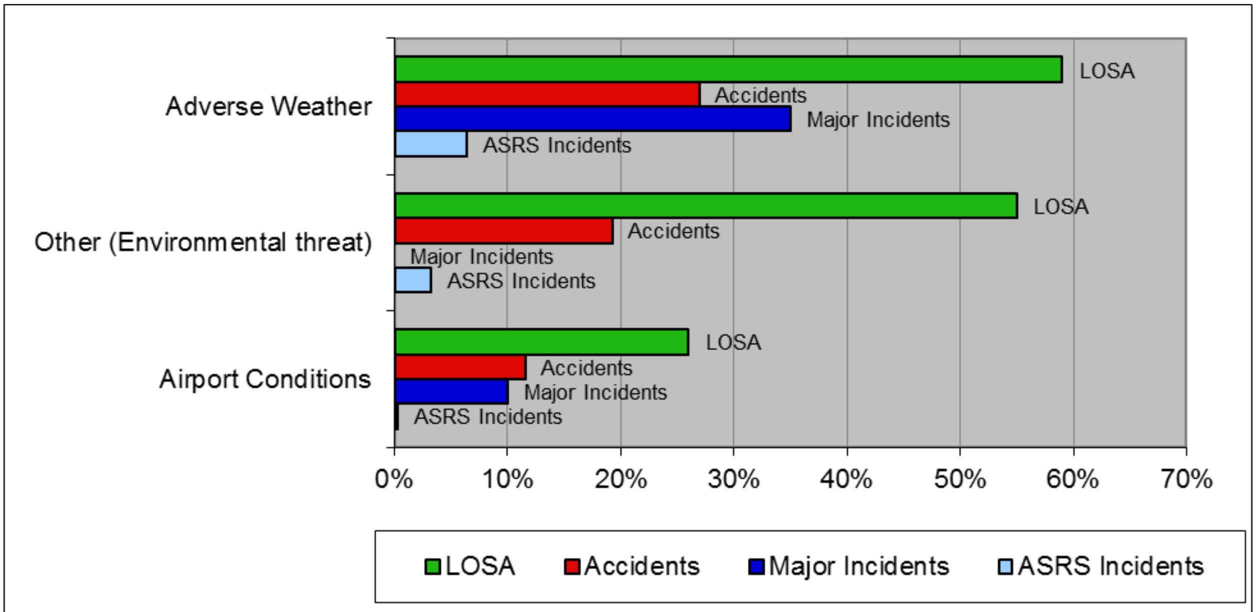
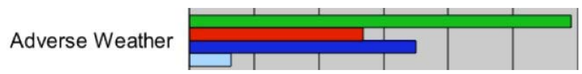


Figure 30. Environmental Threats.

Figure 30 shows the percentages of events that included environmental threats and shows that these types of threats occur regularly in normal operations as represented by the LOSA data. Therefore, these threats should not be treated as isolated indicators of incidents or accidents.

The threats related to adverse whether shown in Figure 30 were detailed for each of the event types and are presented in Table 9. The types of weather threats that were reported in the three types of events are very similar. The WG did not have the breakdown of the LOSA adverse weather threats, but it is likely that the types of weather threats seen in the normal operations recorded in the LOSA observations are similar. This is especially true since some sort of adverse weather threat was recorded in almost 60% of the LOSA flights.

Table 9. Breakdown of "Adverse Weather Threats" Category



■ Accidents	■ Major Incidents
• IMC / Clouds • Low Ceilings • Low Visibility • Turbulence • Crosswind • Rain • Snow • Fog • Windshear • Icing • Strong Headwind on Landing • Downdraft on Landing • Mist	• IMC / Clouds • Low Ceilings • Low Visibility • Turbulence • Crosswind • Rain • Snow • Fog • Clear Air Turbulence
□ ASRS Incidents	
• IMC / Clouds • Low Ceilings • Low Visibility • Turbulence • Crosswind • Rain • Snow • Fog • Windshear • Icing • Clear Air Turbulence	• Thunderstorm • Microburst • Gusty Surface Winds • Tailwind Landing • Strong Tailwind in Descent • Abrupt Wind shift • Sun Glare • Dust Storm

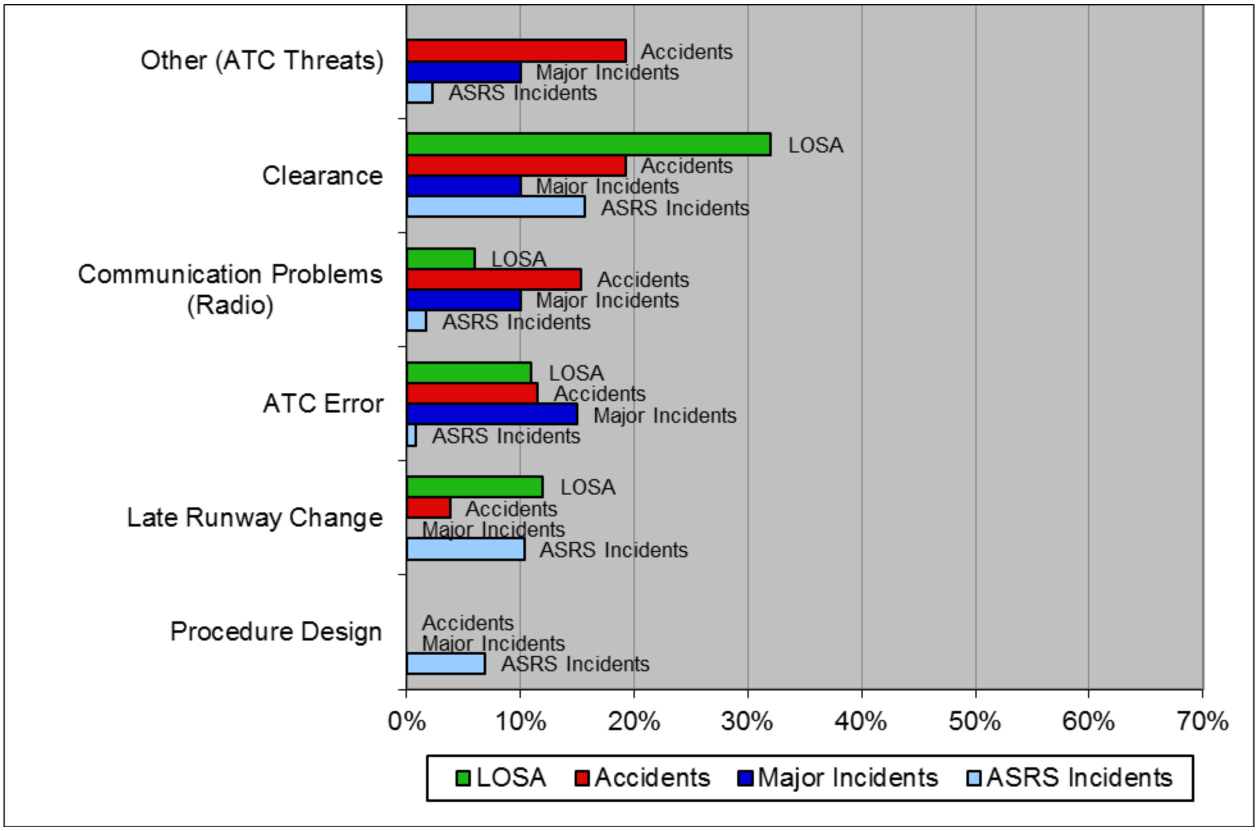


Figure 31. ATC (Airspace System) Threats.

Figure 31 presents the percentages of each event type that included threats related to the airspace system. Challenging or complex clearances often happen in normal operations as can be seen in the LOSA data.

Table 10 shows the breakdown of the "Other ATC Threats" category.

Table 10. Breakdown of "Other ATC Threats" Category

Accidents	Major Incidents
• Foreign ATC threat o Differing levels of surveillance, lack of radar, inadequate training in querying pilots, language barriers o Differing regulations for foreign controller conduct (conflicting and confusing state guidance) • Minimum Safe Altitude Warning algorithms provided insufficient advanced low altitude warning • Inappropriate timing of ATC communications (Company message was transmitted by controller at a critical phase of flight).	• No requirement for ATC "clearance for contingency lateral offset maneuver" - However, pilots are required to inform ATC of offset maneuver - Report questioned value of reporting maneuver - Oceanic communications latency referred to in report. • ATC provided insufficient information (cancellation of 'low visibility procedures' was not communicated); Inadequate controller training (going into/out of low visibility procedures); and transfer of controller duties at an inappropriate time.
ASRS Incidents	
• ATC provided inadequate or inappropriate information o no ATIS	• Inappropriate timing of ATC communications/information o during critical phase of flight

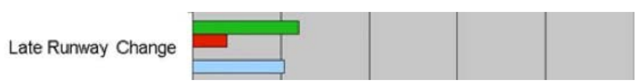
- clearance contained filed SID as well as the actual SID
- neglected to advise of traffic
- runway
- confirmation information
- fix dissimilar to the identifier found on CDU
- did not follow-up regarding routing
- heading [*681068*]
- airport clarification
- transition differed from FMC database
- never advised that flight was off course
- information differed from that found in the FMS

- ATC provided incorrect information
  - issued a GPS approach to an aircraft not equipped with GPS
  - multiple clearances
  - issued incorrect heading
- ATC unavailable/busy
  - ATC terminated services
  - busy with another flight
  - frequency was saturated

  - requested flight contact dispatch regarding an unrelated flight
  - distracted from preflight duties
  - issued vectors and headings when FO was distracted
  - runway change during taxi
  - during taxi out a reroute was issued
  - runway was changed on taxi
  - did not allow enough time for related reprogramming tasks
  - pilot did not have enough time to view the approach chart and program equipment
  - PF did not have time to compare transitions
  - heading should have been issued earlier in flight
- Hand off/transfer of flight at inappropriate time
  - when aircraft was off course
  - following vector request by the pilot
  - trying to correct a heading
  - during descent
- ATC procedures unclear
  - runway routing
- Inadequate controller training
  - concept of turn anticipation

The late runway change threats were broken down for each of the event types and the breakdown is presented in Table 11.

Table 11. Breakdown of "Late Runway Change Threats" Category



Accidents

- Flightcrew accepted runway change offer from ATC without adequate time to prepare for approach.

Major Incidents

- None

ASRS Incidents

- Crews failed to change runway in FMS after acknowledging change
- Crews input changes, but selected wrong procedure
- Reverted to manual control, but deviated from assigned procedure
- Reprogrammed FMS, but update errors or processing delays resulted in deviations (lateral/vertical)
- Reprogrammed FMS, but did not validate correct path/procedure
- Reprogrammed FMS with resulting discontinuities, dropped waypoints/restrictions, and mode changes
- Reprogrammed FMS with correct information, but crew subsequently erroneously intervened

-

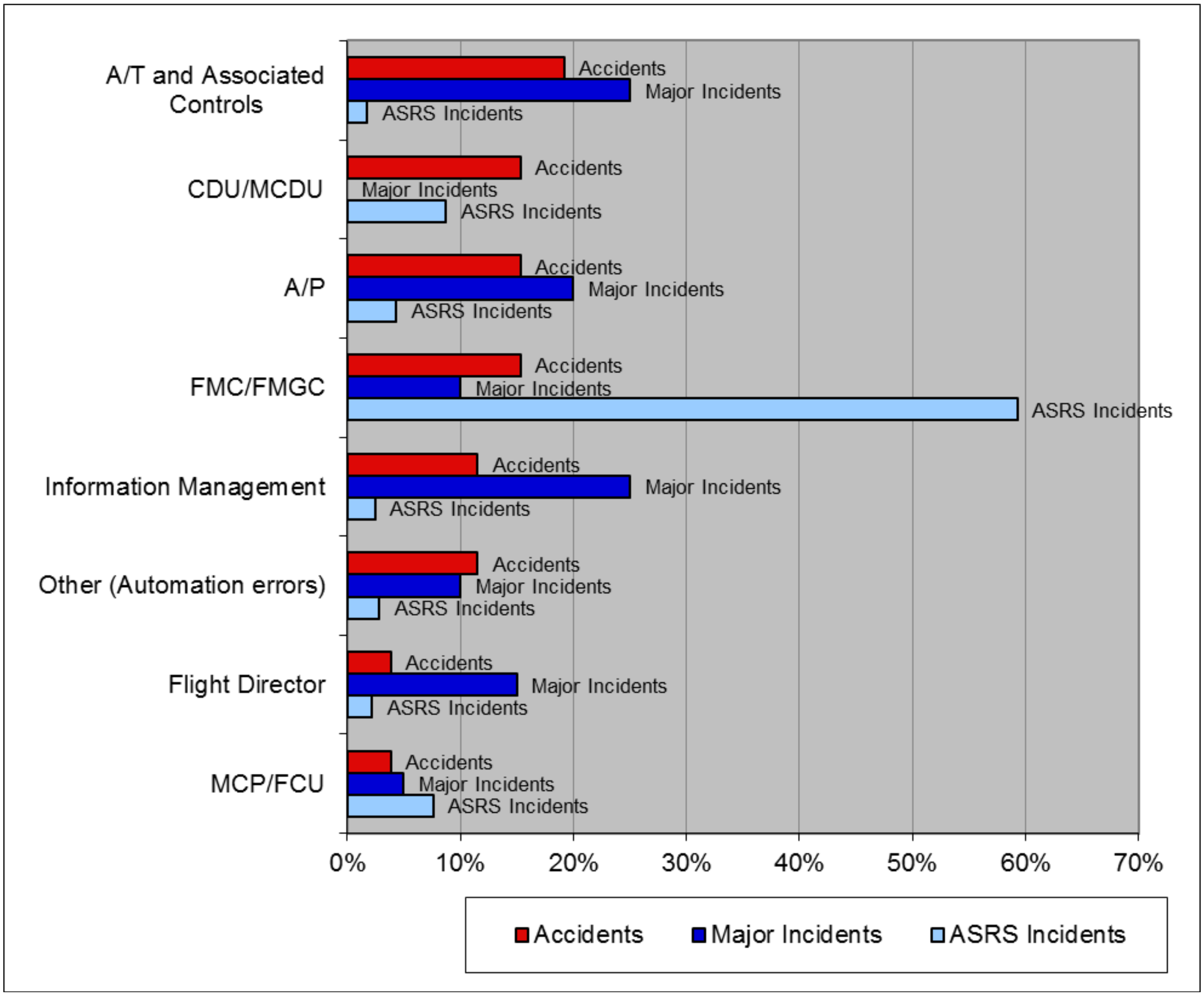


Figure 32. Automation Use Errors.

Figure 32 presents the percentage of pilot errors in using each of the components of the automation systems that are listed. One thing that stands out on the chart is that 60% of the ASRS incident reports in the review set included some type of error in using the flight management computer (FMC/FMGC).

Reports that included FMC/FMGC errors from Figure 32 were reviewed and broken down into more detailed descriptions of the errors made using the automated systems. This breakdown is presented in Table 12. The errors are mostly programming errors and therefore similar to that breakdown, and, with the possible exception of system malfunctions, FMC/FMGC errors are a product of "garbage in and garbage out." Crews misread printed documents, misinterpreted ATC clearances and entered incorrect information into the FMC. There are occasions where the crews had and understood the correct information but entered it incorrectly. This was caused by a lack of knowledge of CDU entry procedures resulting in unresolved discontinuities, and dropped waypoints, speeds and altitudes. In almost all the cases studied, crews did not check their entries into the FMC to verify that the entry satisfied the intent of the clearance received and the crews did not cross verify each other.

Table 12. Breakdown of "FMC/FMGC Errors" Category

Accidents

All of the accidents studied also fell under the category of "Flightcrew Errors in Programming." Within that category were two major standouts.

- programming the FMC incorrectly and NOT verifying the effect on the lateral or vertical path or on aircraft performance.
- programming the FMC at an inappropriate time resulting in preoccupation, errors, missed call outs, and poor judgment in failing to go-around when the aircraft became unstable.

Major Incidents

Major incidents studied also fell under "System Malfunctions" and "Flightcrew Errors in Programming."

System Malfunctions

- failed to analyze a FMC error due to a failed air data system. The crew had an incomplete knowledge of the system.

Flightcrew Errors in Programming

- programmed the FMC incorrectly and did not verify the effect on the lateral or vertical path or on aircraft performance.

ASRS Incidents

ATC Influenced Errors

- After a expedited descent clearance crew confused VNAV and FLCH;
- incorrect VNAV entry after multiple step down clearances;
- "slam dunk" clearance contributed to incorrect lateral path entry;
- late amended clearance caused incorrect lateral and vertical path entry;
- last minute runway change caused line up on wrong runway;
- ATC non-standard phraseology confused crew about the next crossing altitude;
- late holding clearance and incorrect holding;
- wrong spelling of a waypoint in a ATC clearance;
- late runway change and incorrect runway loaded in FMC;
- hold programmed incorrectly after multiple clearance changes;
- late runway change and incorrect departure loaded;
- late runway change and incorrect arrival loaded.

PDC Confusion

- PDC misread and incorrect data loaded into FMC;
- did not read PDC amendment;
- did not read transition in PDC; and clearance change after PDC receipt and no change made in FMC.

Runway Change Prior to Takeoff Errors

- In all cases the runway and associated SID were loaded at the gate using information from ATIS, etc. Upon taxi and initial runway assignment by ATC the FMC was not updated. (Note: pilots called this a "runway change;" however, it was the first time ATC issued them a runway assignment.) The new runway was not entered and/or the new SID was not entered and/or the new SID transition was not entered.

Runway Change on Arrival Errors

- Late runway change by ATC caused lining up on the wrong runway;
- dropped crossing restrictions in the FMC;
- missed turn, discontinuity in route;
- arrival dropped;
- arrival waypoints dropped.

.Departure Change Prior to Takeoff Errors

- Flew incorrect departure after entering departure change in the FMC, but failed to EXECUTE.

Alteration of Arrival Errors

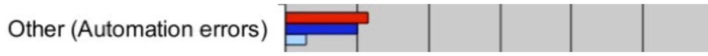
- Late ATC clearance changing arrivals caused missed crossing altitudes and speed restrictions;
- missed turns, deleted waypoints, new arrival dropped when entering new arrival runway in the CDU;
- arrival waypoint misspelled;
- during arrival change aircraft got off course due to no information presented on the navigation display (ND).

Flightcrew Errors in Programming

- filed for one route and entered another;
- incorrectly programmed holding pattern;
- used incorrect VNAV mode;
- failed to program ATC route exception;
- did not notice PDC was different from filed route;
- incorrect approach entry;
- did not enter runway change;
- did not enter new departure after runway change;
- did not enter proper transition on departure or arrival;
- missed crossing altitudes, speed restrictions and turns due to incorrect entries in CDU; and
- entered incorrect performance data.

The category of "Other automation errors" from Figure 32 was reviewed in detail to understand what types of errors were addressed in the events that were not included in the other defined automation errors. The details are presented in Table 13.

Table 13. Breakdown of "Other Automation Errors" Category



Accidents

- Flightcrew errors in verifying entries
  - One of the pilots selected a direct course via the FMS to the incorrect NDB and then did not verify with the other pilot.
  - FO entered incorrect stabilizer trip setting and neither pilot verified the entry.
- Flightcrew errors in operating automation
  - The pilots failed to maintain the required minimum descent altitude (MDA) until the required visual references identifiable with the runway were in sight.
  - The pilots failed to follow company sidestick controller SOP's. Both pilots commanded a descent on their sidestick followed by a climb and then another descent.
- Flightcrew errors in monitoring for automated system malfunctions
  - While in cruise, an IRS malfunction caused #2 EADI failure and the autopilot disconnected without the crew noticing.

Major Incidents

- Failure of multiple automation systems including autopilot, autothrottle, PFD, ND as well as others (result of faulty battery connection).
- Failure of both autopilot and autothrottle systems.
- Failure of the autopilot system.
- Failure of the automatic fuel system computer.

ASRS Incidents

- Flightcrew Errors in Programming Automation – failure to verify entries
  - CDU and ND – Incorrect runway loaded in the CDU and no cross verification was performed.
  - FMS – Correct departure was loaded but not the transition and no crosscheck was performed (comparing the LEGS page with the actual SID Chart).
  - FMS – Error was made when manually entering waypoints and the paper chart was not checked against the LEGS page.
  - ACARS (PDC) and FMS – Incorrect data was loaded for both runway and aircraft type.
  - FMS – Uplinked flight plan was different from the voice clearance and was difficult to correct.
  - FMS/ND – Crew selected incorrect data from navigation database resulting in flight path deviation.
  - The crew incorrectly assumed they were flying a QNH (MSL) approach and the controller was clearing them for a QFE (AGL) approach.
- Flightcrew Errors in Operating Automation – Automation-related procedures
  - INS – Captain demonstrated incorrect procedure to show F/O how to "flush" INS updates.
  - GPWS/FMS – The flightcrew accepted ATC clearance to revised runway without briefing or reprogramming the FMC.
  - GPS – Pilot incorrectly operated a panel
- Flightcrew Errors in Operating Automation – Distractions
  - HUD – Captain was practicing using the HUD and lined up on the wrong runway.
  - CDU – Captain was tired and turned on the wrong taxiway while F/O had his head down programming the FMC.
- Automated System Malfunctions
  - IRS – #2 IRS began to drift and later failed.
  - PFD, ND, IRS – Dual IRS failures producing PFD and ND failures.
  - FMS/GPS – GPS failed.
  - IRS – Both IRSs failed on taxi.
  - FMS – Several waypoints were dropped on an arrival.
  - FMS – FMS computed a vertical profile different from what was in the database and on the chart.
  - HUD – On a low visibility ILS approach using the HUD, approach lights washed out the symbology in the HUD on short final. Flight path vector and flight director became invisible.
- FMS – At near max alt, after abrupt wind shift of 245/49 to 190/20, aircraft lost airspeed and would not accelerate back due to weight.

	mounted GPS which was approved for VFR only.

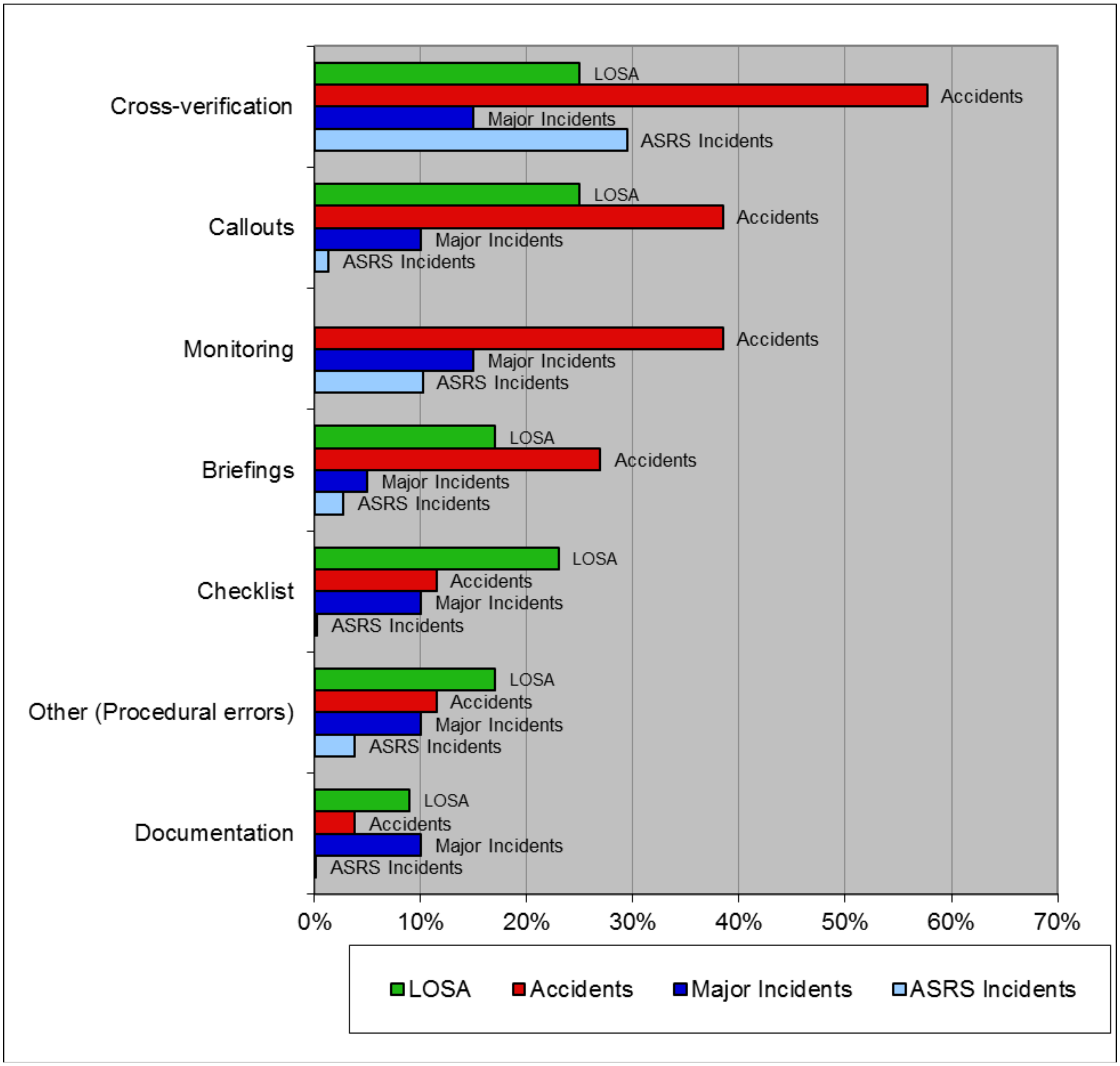


Figure 33. Procedural Errors.

Figure 33 presents the seven subcategories of procedural errors that were evaluated by the WG. Errors associated with cross-verification of the other pilot's inputs and actions were evident in almost 60% of the accidents reviewed by the WG. This is more than twice the percentage observed in the LOSA flights.

The cross-verification errors from Figure 33 were reviewed in more detail. The items that were not verified are described for each of the event types in Table 14.

Table 14. Breakdown of "Cross-Verification Errors" Category

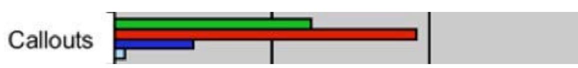
Accidents
- FMC / CDU Input
- MCP Altitude Change
- MCP Mode Change
- Flight Management control change (not on MCP)
- Takeoff Data Entry
- Autothrust – Takeoff
- Autothrust – Airborne
- Autopilot
- Altimeter Setting
- Dual Side stick Input
- Verify proper display

Major Incidents
- Takeoff Data Entry
- Autothrust – Airborne

ASRS Incidents
- FMC / CDU Input
- MCP Altitude Change
- MCP Mode Change
- Flight Management control change (not on MCP)
- Takeoff Data Entry
- IRS/IRU Position Data Entry
- Autopilot
- Altimeter Setting

The callout errors from Figure 33 were reviewed and the callouts that were not made are described in Table 15 for each of the event types.

Table 15. Breakdown of "Callout Errors" Category



Accidents
- standard landing/approach
- descent below MDA,
- declaration of "pilot not flying" [PNF] taking control from "pilot flying" [PF]
- excessive approach speed
- unsafe takeoff configuration
- spoiler position
- throttles not aligned
- ILS status
- LNAV/VNAV performance
- go-around requirement
- aircraft unusual attitude

Major Incidents
- control of side stick
- low altitude warning
- go-around warning

ASRS Incidents
- approaches to altitudes such as 100' above, 1,000' above, 1,000' below, 1,000' to go, etc.
- flap position
- NAV/VNAV engaged

The briefing errors from Figure 33 were broken down for each of the event types. The briefings that were not made or were otherwise in error are presented in Table 16.

Table 16. Breakdown of "Briefing Errors" Category

Accidents	Major Incidents
• approach briefing • takeoff / departure briefing	• visual approach briefing

ASRS Incidents
The majority of the ASRS incident errors involved unsatisfactory coordination and cross verifying following a mix of departure or approach briefings or a change to a previously briefed departure or approach. The quality of the briefing is not known, but the crew coordination following the briefing was specifically identified. Additional errors included: • Poor departure briefings not in compliance with SOPs • Poor approach and departure briefings that were rushed and not thorough, omitting critical departure or approach details • Incorrect approach briefings (wrong data) that were thought to be correct • Incomplete departure briefings that did not cover sufficient detail but were not rushed • Departure briefings not attended to by the other crew member while accomplishing other tasks

Table 17 presents the checklist errors from Figure 33 that occurred in the different events types.

Table 17. Breakdown of "Checklist Errors" Category

Accidents	Major Incidents
• Crew used checklist, but did not use it properly (approach checklist) • Crew did not use the checklist verbatim (skipped items on emergency checklist)+C15	• Crew did not use correct checklist (emergency checklists) • Crew did not use the checklist verbatim (skipped items on emergency checklist)

ASRS Incidents
• Crew did not use checklist (after takeoff checklist) • Crew unable to complete checklist items on time (Approach/Landing checklist)

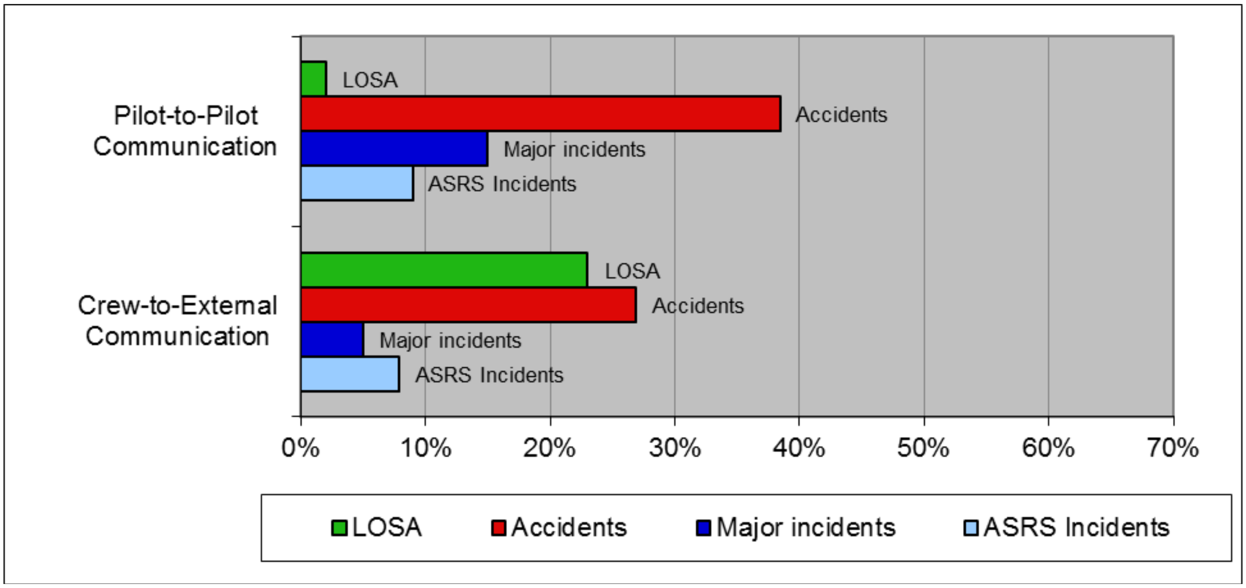
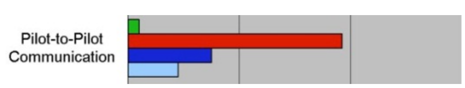


Figure 34. Communication errors.

Figure 34 presents the percentages of communication errors identified in each of the event types. It is interesting to note that pilot-to-pilot communication errors were infrequently observed in the LOSA observations compared to being identified in almost 40% of the accidents that were reviewed by the WG. This is due to the WG including several communication activities in this category that LOSA only included in the Procedural Error category. These include communication for callouts, briefing, and cross-checks between pilots. It is clear from these data that communication errors are present in a significant number of the accidents reviewed by the WG. It is also evident that communication problems alone do not lead to accidents or incidents since they are also present in normal operations as indicated by LOSA for the crew-to-external communication errors. See the section on co-occurrence analyses for the other factors that were also present with communication errors in the accidents and incidents.

The pilot-to-pilot communication errors from Figure 34 were broken down and are described in Table 18 for each of the event types.

Table 18. Breakdown of "Pilot-to-Pilot Communication Errors" Category	
	
Accidents	**Major Incidents**
• Crew coordination/task sharing • Confusion between the flightcrew as to who was in control of the aircraft, procedures for transfer of aircraft control between pilots not followed • Crew callouts not accomplished • Errors made in programming flight guidance system, no cross verification of entries	• Failure of flightcrews to verbally confirm & communicate flight guidance inputs (such as FMS, AP/FD, ATHR/AT, Nav Data, etc.) with the other pilot • Failure to activate inputs, monitor mode annunciations to ensure the autoflight system would perform as required and or intervene if necessary. • Errors made in programming flight guidance system • Failure to monitor basic flight instruments. • Lack of read back or incomplete read back (read back errors) and or failure to either question incorrect or inadequate ATC clearances.
ASRS Incidents	
• Crew coordination/task sharing	• Failure of flightcrews to verbally confirm and

• Irrelevant discussions, distractions and or interruptions by flightcrews that led to procedural errors and or omissions in performance of SOP's. • Rushed arrivals and approaches, no request for delaying vectors	communicate flight guidance inputs (such as FMS, AP/FD, ATHR/AT, Nav Data, etc.) with the other pilot • Failure to activate inputs, monitor mode annunciations to ensure the autoflight system would perform as required and or intervene if necessary. • Both heads down in flight while making FMS data entries • No crosscheck of ground taxi due to FO head down during taxi making FMS entries

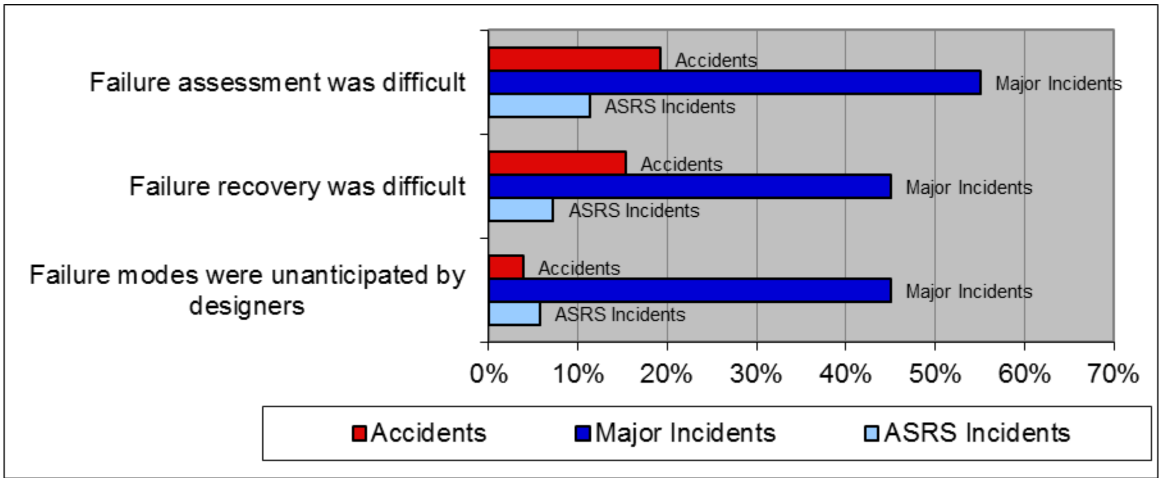


Figure 35. Failure Related Issues.

Figure 35 presents percentages for the three failure-related issue categories included in the review by the WG. The percentages are much higher for the major incidents than for the accidents or ASRS incidents. This may be due to the nature of selection of major incidents to investigate made by the investigating boards. During the timeframe of the major incidents reviewed by the WG many investigations were initiated due to the occurrence of unexpected failures. Failures unanticipated by designers are those that did not include a checklist or procedure.

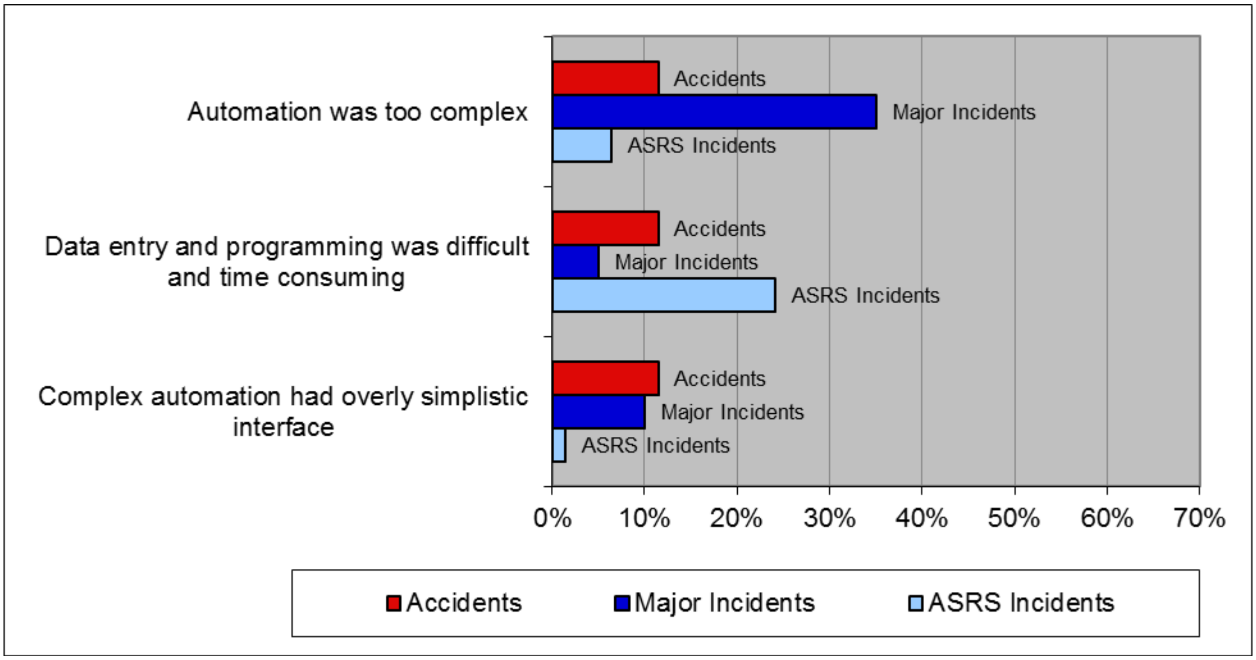


Figure 36. Complexity Issues.

Issues associated with the complexity of the systems are presented in Figure 36. The three complexity issues were equally evident in the accident reports (around 12%), but were differentiated in the major incident reports and the ASRS incidents. For the major incidents the issue "Automation was too complex" was evident in about 35% of the reports, followed by the issue "Complex automation had an overly simplistic interface" (10%) and "Data entry and programming was difficult and time consuming" (5%). For the ASRS incidents reviewed by the WG the most prevalent complexity-related issue was "Data entry and programming was difficult and time consuming" (about 24%) followed by "Automation was too complex" (6%) and "Complex automation had an overly simplistic interface" (2%).

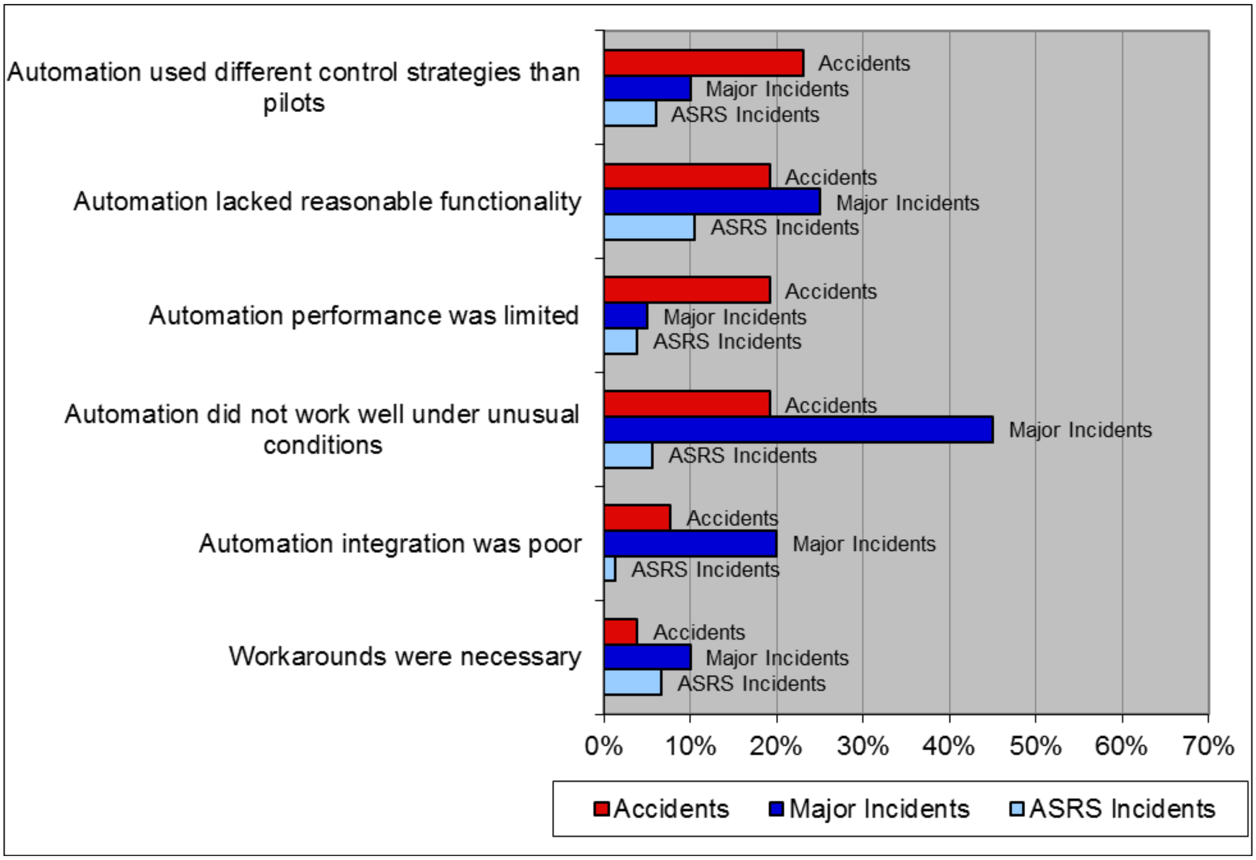


Figure 37. Functionality Issues.

Figure 37 presents data related to several issues associated with the functionality of the automated systems. Of this set of issues the one that was associated with the most accidents in the WG review is "Automation used different control strategies than pilots" which can lead to problems because the pilots do not expect what the automation does. This issue was associated with 23% of the accidents reviewed. The issue that was associated with about 45% of the major incidents reviewed is "Automation did not work well under unusual conditions." As mentioned earlier in the report, major incidents were selected for review by the investigating board and often this choice was due to the occurrence of an unusual event or condition; therefore, it is not surprising that this issue would be prevalent in these data. It is of interest to note that these functionality issues were not frequently reported by the pilots in ASRS incident reports. The most prevalent issue is this set for the ASRS incidents is "Automation lacked reasonable functionality" that occurred in about 10% of the ASRS reports.

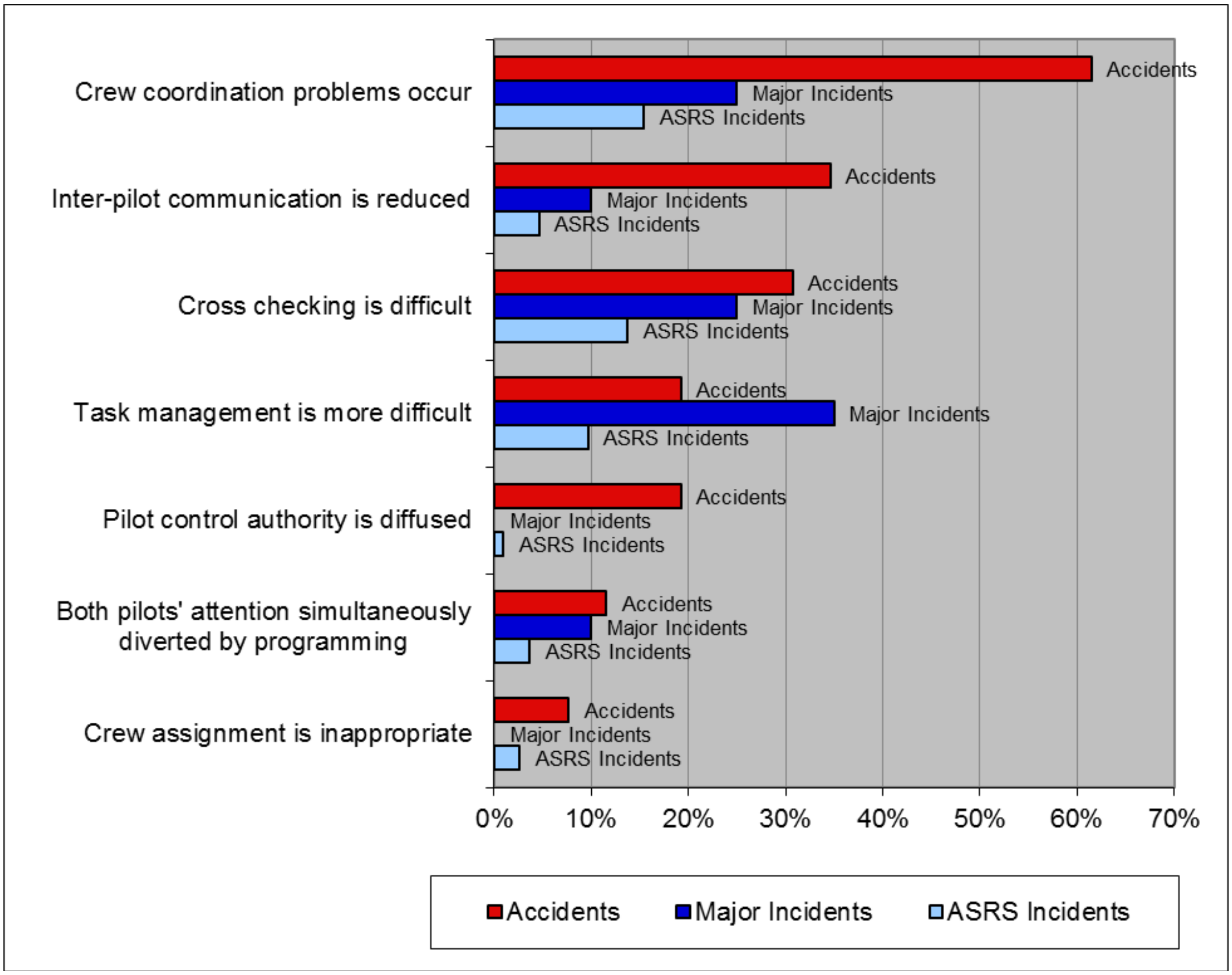


Figure 38. Crew-Centered Issues.

Figure 38 presents a set of issues related to the crew actions and performance with the automated systems. By far the issue that stands out for the accidents is “Crew coordination problems occur” which is associated with over 60% of the accidents. This is consistent with the category of communication errors that was seen in Figure 34 as is the next issue, “Inter-pilot communication is reduced” which is associated with 35% of the accidents.

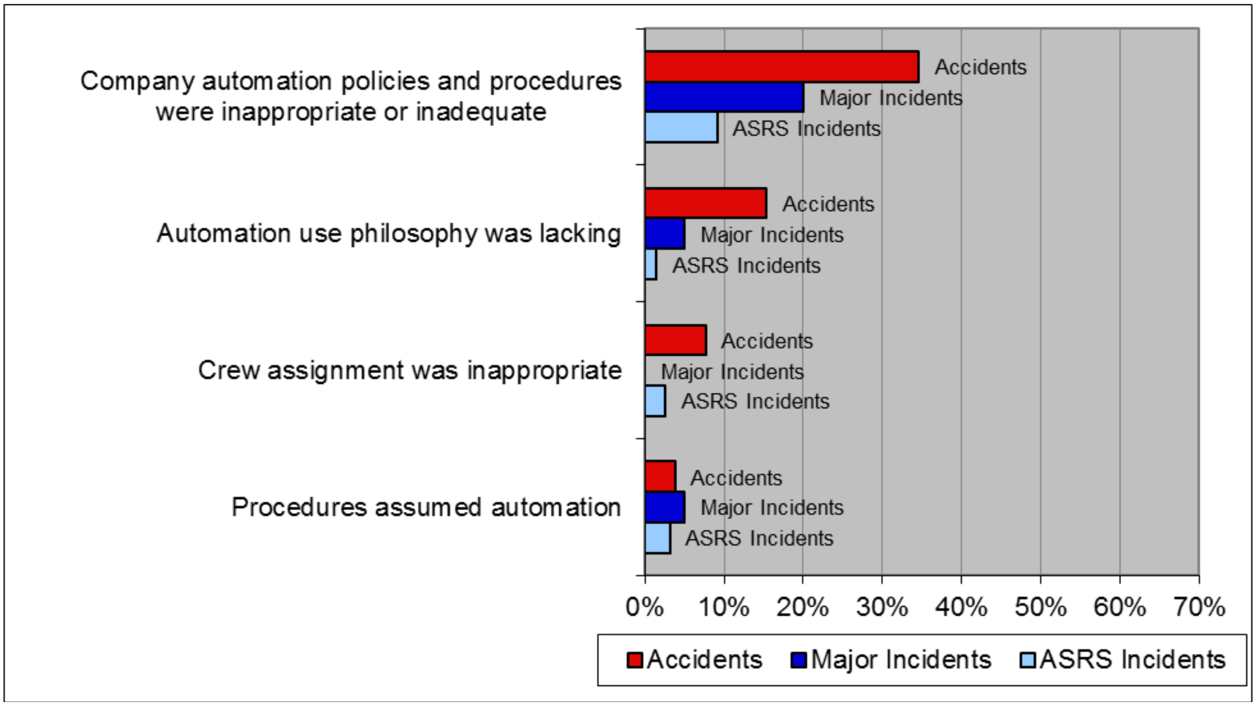


Figure 39. Company Procedures Issues.

Figure 39 presents issues related to company procedures. The issue occurring most frequently for all three data sets was: “Company automation policies and procedures were inappropriate or inadequate.”

The issue related to inadequate company policies and procedures was broken down into more details for each of the event types. The details are provided in Table 19.

Table 19. Breakdown of "Inadequate Policies and Procedures Issue" Category

Accidents	**Major Incidents**
• In one case, the checklist was hard to read, crew co-operation was non-existence and company practices, procedures and training did not support the team work of the flight deck crew. • In one case, company training department did not keep good records on pilot training performance and crew resource management (CRM) principles were not followed • In three cases, the pilots did not received adequate company training nor were there standard operating procedures (SOPs) covering unusual occurrences • In the other four cases, information was available to the pilots in the form of SOPs, training, manuals, etc., but the pilots did not follow those procedures or did not practice good CRM	• In two cases, flight manuals contained the information pilots could use; however, the wording was not absolutely clear • In two cases, company training was not adequate
ASRS Incidents	
• In almost all the “Incident” cases, information was available to the pilots in the form of SOPs, training, manuals, etc., but the pilots did not follow those	o

procedures or did not practice good flight deck resource management (CRM)

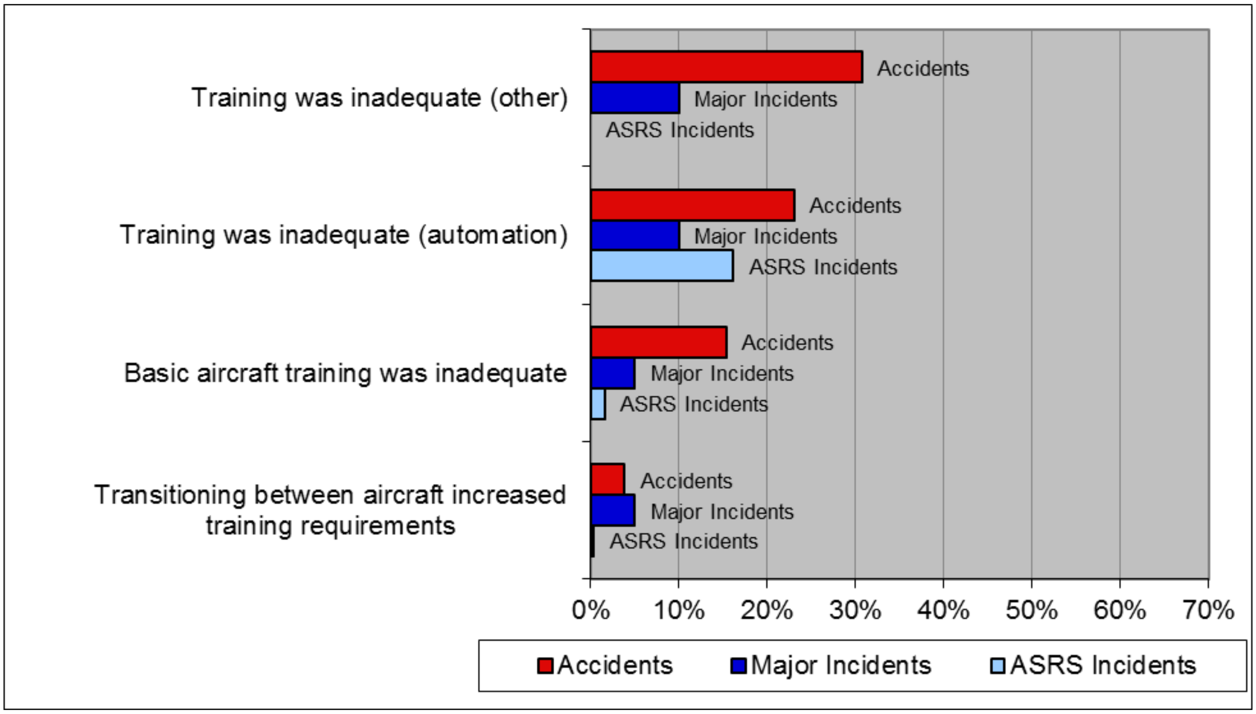


Figure 40. Pilot Training Issues.

Issues related to pilot training are presented in Figure 40. All three data sets showed their highest frequencies for the issue "Training is inadequate" which was associated with 50% of accidents, 30% of major incidents, and about 16% of ASRS incidents. The WG further analyzed those and broke them into two sets describing whether the training inadequacies mentioned were related to training of some automated systems or other types of training. The accidents reflected automation training issues in 23% of the reports and other training issues in 31% of the reports. Major incident reports mentioned automation training issues and other training issues each in 10% of the reports. Also 15% of the accident reports identified deficiencies in basic aircraft training, as did 5% of the major incident reports.

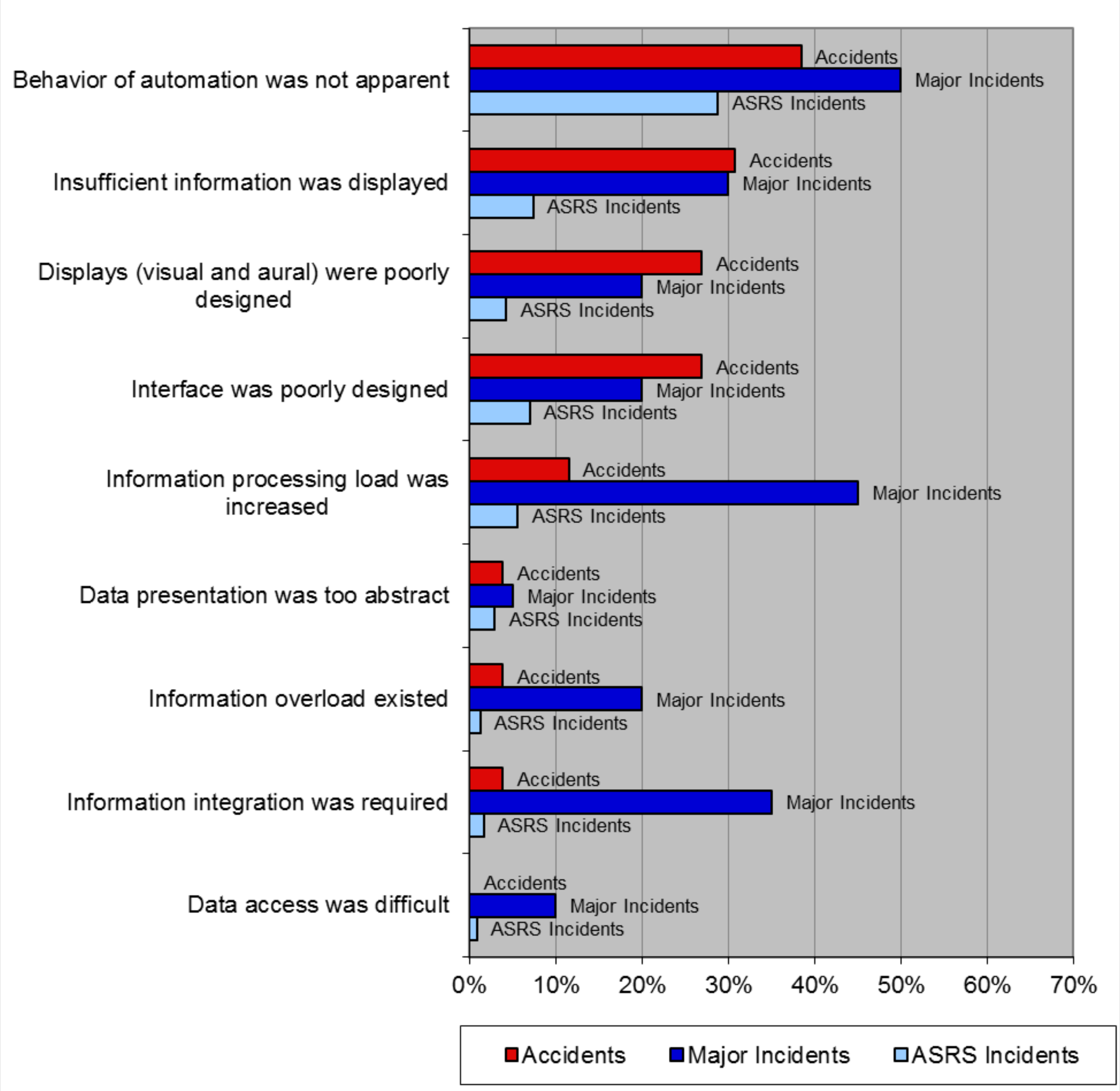


Figure 41. Interface Issues - Information

Figure 41 shows issues related to information and Figure 42 presents those related to controls and other flight deck components. The most prevalent issue in this set is “Behavior of automation was not apparent.” Four of these issues were much more frequent in major incidents than in the other data sets: “Information processing load was increased,” “Information overload existed,” “Information integration was required,” and “Data access was difficult.”

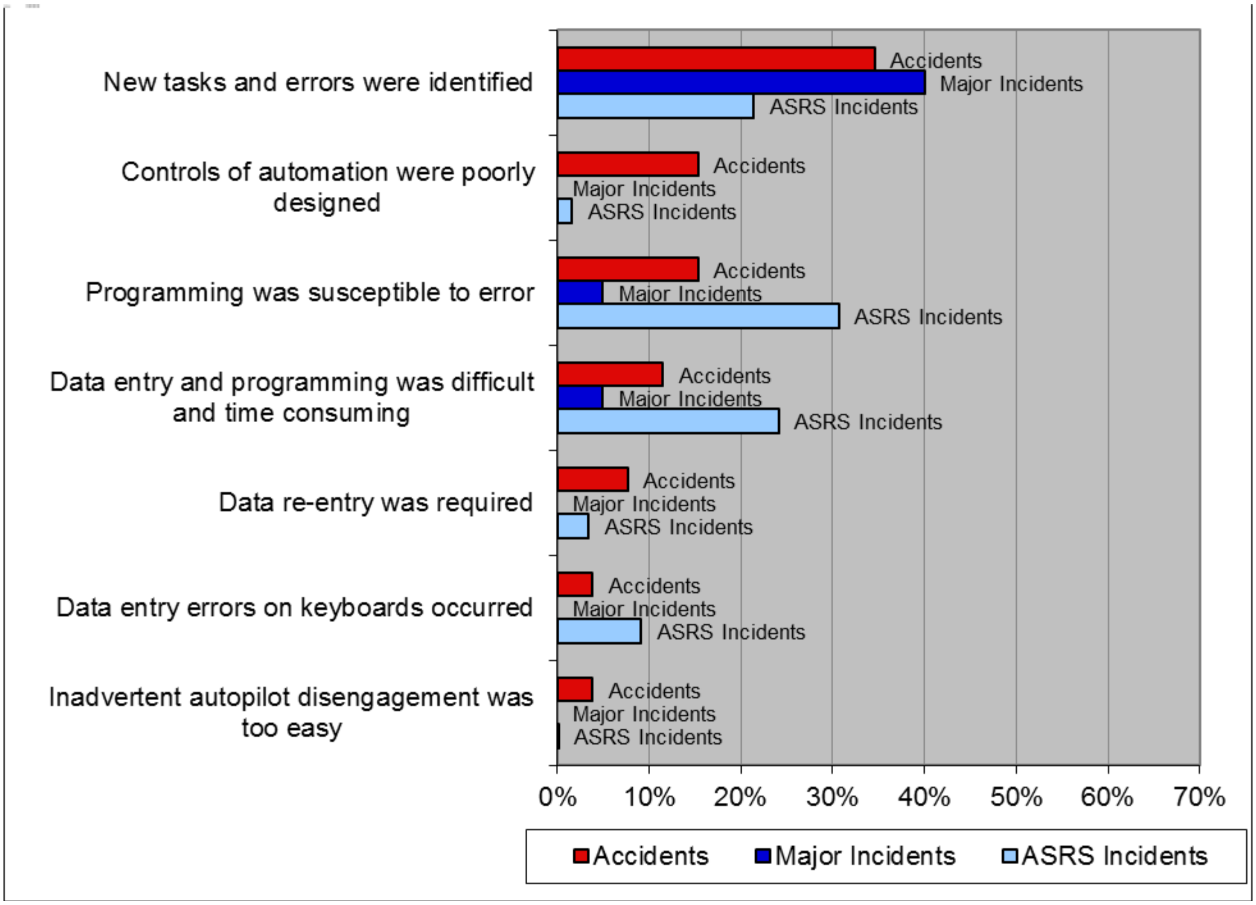


Figure 42. Interface Issues - Controls and Other.

The most frequent issue in Figure 42 is “New tasks and errors exist.” This issue represents that about 35% of accidents we reviewed, 40% of major incidents, and 21% of ASRS incidents had evidence of some sort of new task requirements for the pilots with associated errors that can occur. This is an important issue because it implies that we must take the technology that is on our aircraft into account when understanding the tasks and errors that may occur in operations. We saw a large number of programming errors in the ASRS incidents, shown in Figure 27, and FMC use errors in Figure 32. These are consistent with the issues here related to programming (“Programming is susceptible to error” and “Data entry and programming is difficult and time consuming”) for which we also see as prevalent for the ASRS incidents.

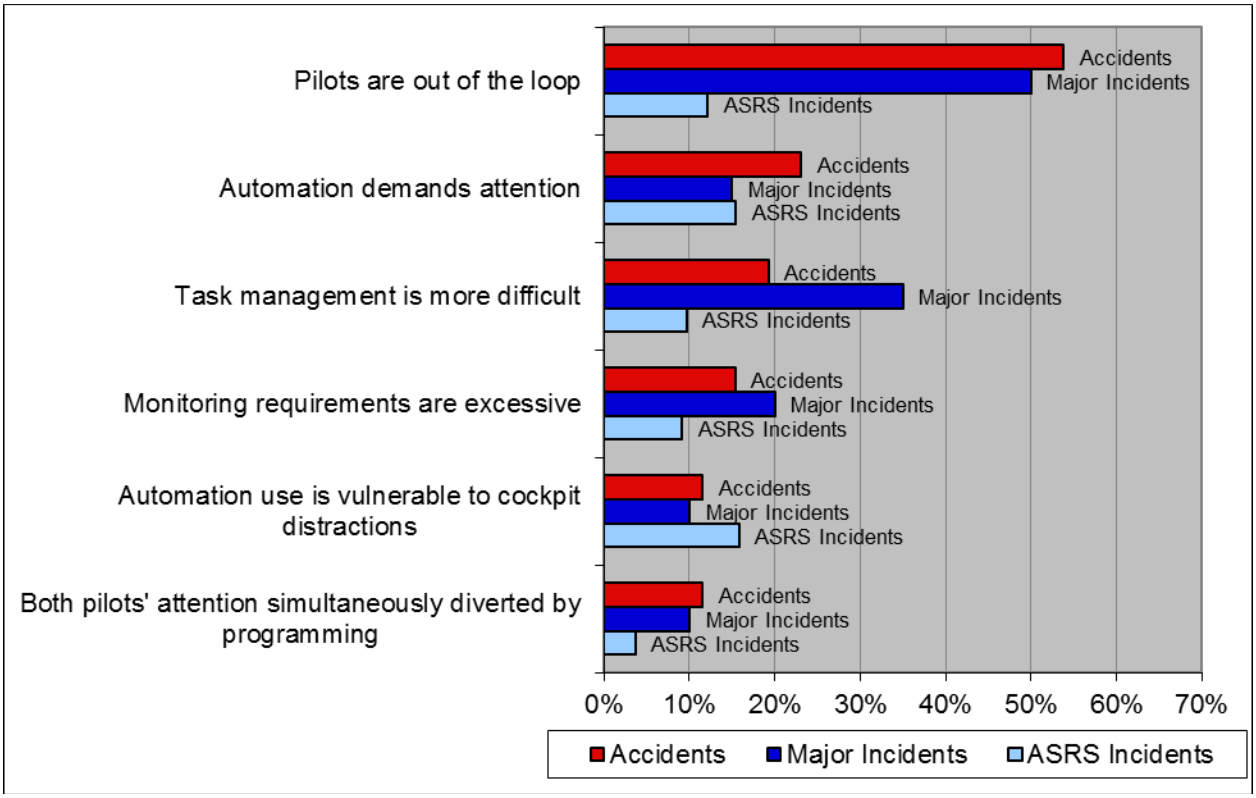


Figure 43. Attention Issues.

Issues related to allocation of pilot attention are presented in Figure 43. The most frequent one of the issues is "Pilots were out of the loop," occurring in over 50% of accidents and major incidents and about 12% of ASRS incidents. This indicates that generally the pilots were not aware of the state of the airplane and/or situation. The other issues address different facets of allocation of attention including some things that can divert pilot attention: programming the automated systems, task management, and general use of the automated systems. The remaining issue here addresses the attention required to monitor the automated systems when they are in use.

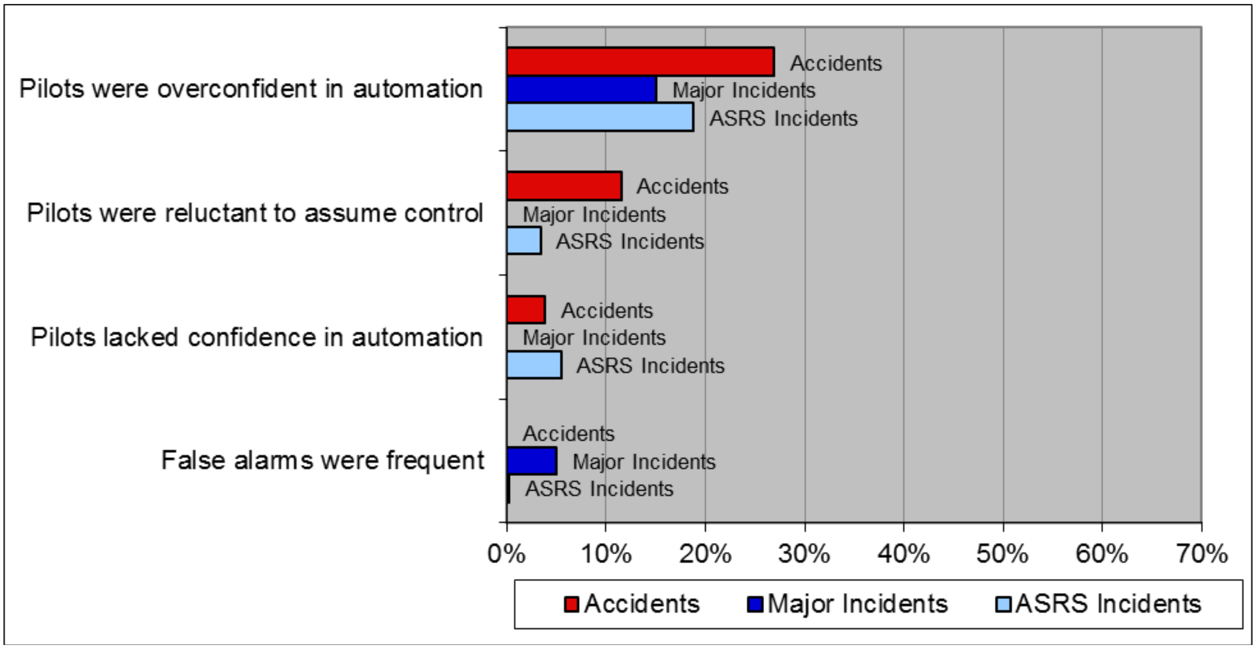


Figure 44. Confidence Issues.

Figure 44 includes issues related to the confidence of the pilots in using the automated systems. It can be seen that pilot overconfidence in the automated systems was more prevalent in all three data sets than the other issues on this chart with it being present in about 27% of the accidents, 15% of the major incidents, and 19% of the ASRS incidents reviewed by the WG. Pilots were also reluctant to assume control from the automation in about 12% of the accidents and 4% of the ASRS incidents. Only about 4% of the accidents and 6% of the ASRS incidents reviewed included information about the pilots lacking confidence in the automated systems.

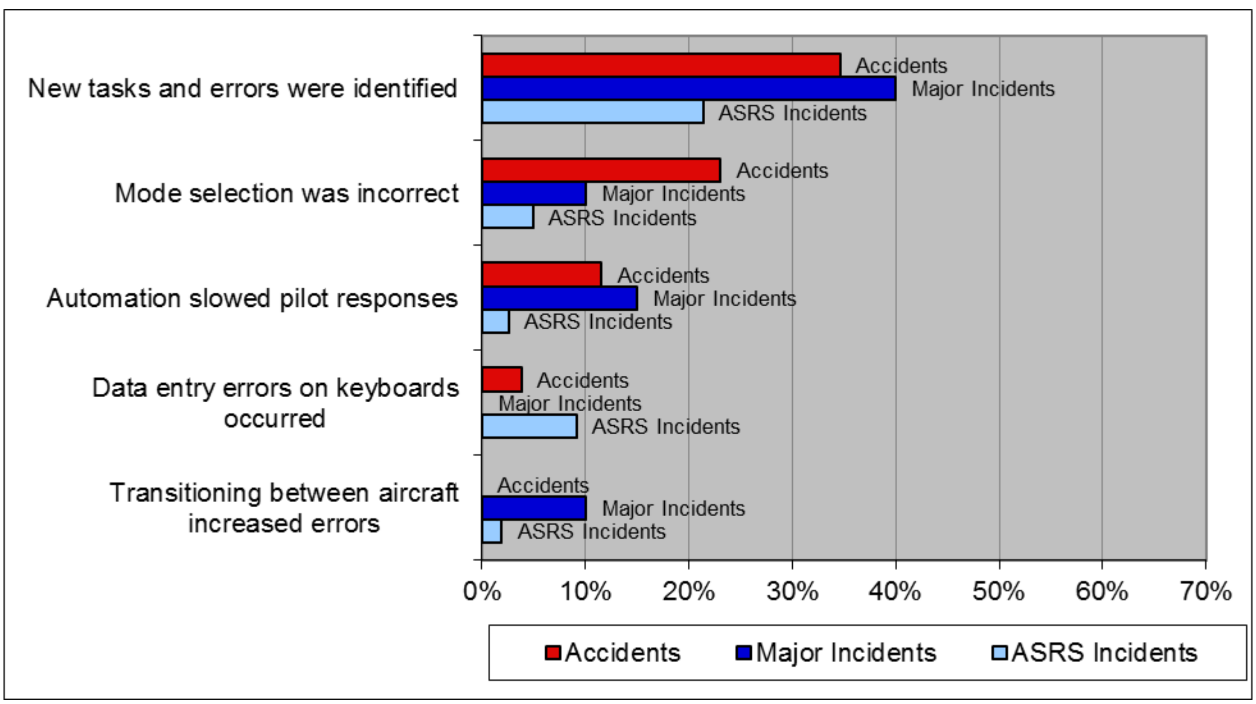


Figure 45. Issues Related to Pilot Performance.

The issues shown in Figure 45 relate in some way to how the pilots perform using the automated systems, with four of the five issues related to types of errors that the pilots make and the fifth related to the slowing of pilot responses when using the automated systems. The most prevalent issue here shows that there are additional tasks that the pilots must accomplish in the airplanes with automated systems and these new tasks are associated with new types of errors. This issue was seen in about 35% of the accidents, 40% of the major incidents, and 21% of the ASRS incidents.

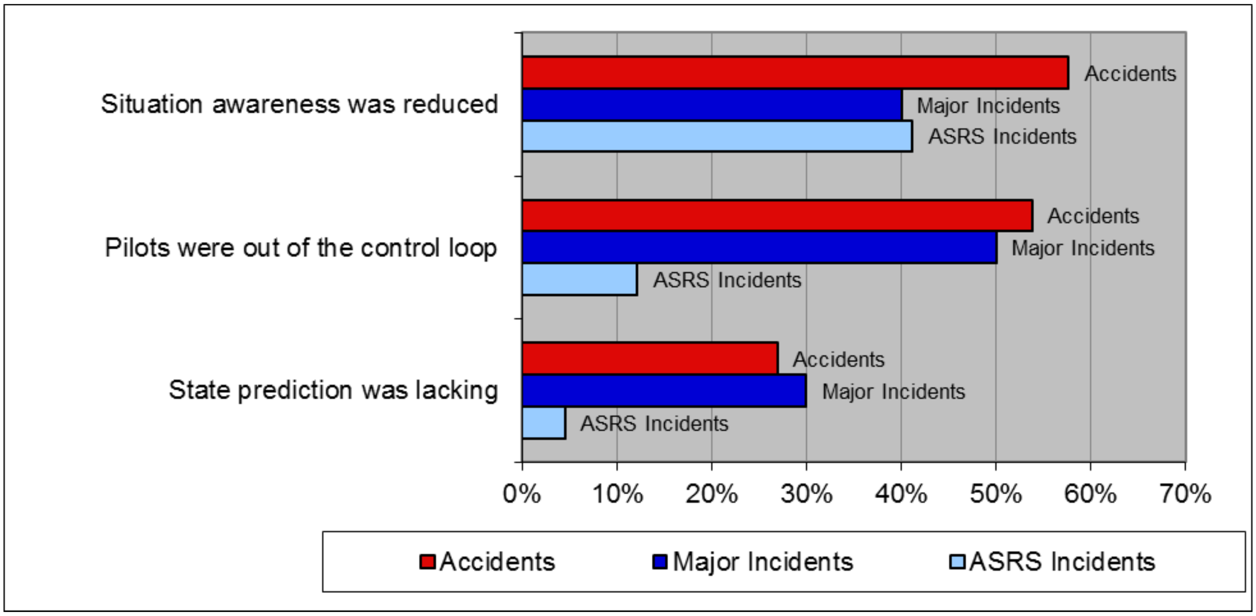


Figure 46. Issues Related to Situation Awareness.

Figure 46 presents the data associated with issues related to pilot situation awareness. The extended description of “Situation awareness was reduced” is “Reliance on automation reduced pilots' awareness of the present and projected state of the aircraft and its environment, resulting in incorrect decisions or actions.” The extended description of “Pilots were out of the loop” is “Pilots were out of the control loop and peripheral to the actual operation of the aircraft and therefore not prepared to assume control when necessary.” The first issue addresses situation awareness as a whole where the second focuses on awareness needed to take control of the airplane. The issue “Situation awareness was reduced” was evident in the highest percentage of accident reports reviewed (58%) followed closely by “Pilots were out of the loop” (54%). For the major incident reports this was opposite with the issue “Pilots were out of the loop” being most observed at 50% followed by “Situation awareness was reduced” at 40%. The third issue in this set, “State prediction was lacking”, focuses on the information needed for maintaining situation awareness and its extended description is “Automation displays showed only current state and no trend or other information that could help pilots estimate future state or behavior. This prevented pilots from anticipating and/or preparing for problems.” This issue was observed in 27% of the accident reports, 30% of the major incident reports, and 4% of the ASRS incident reports.

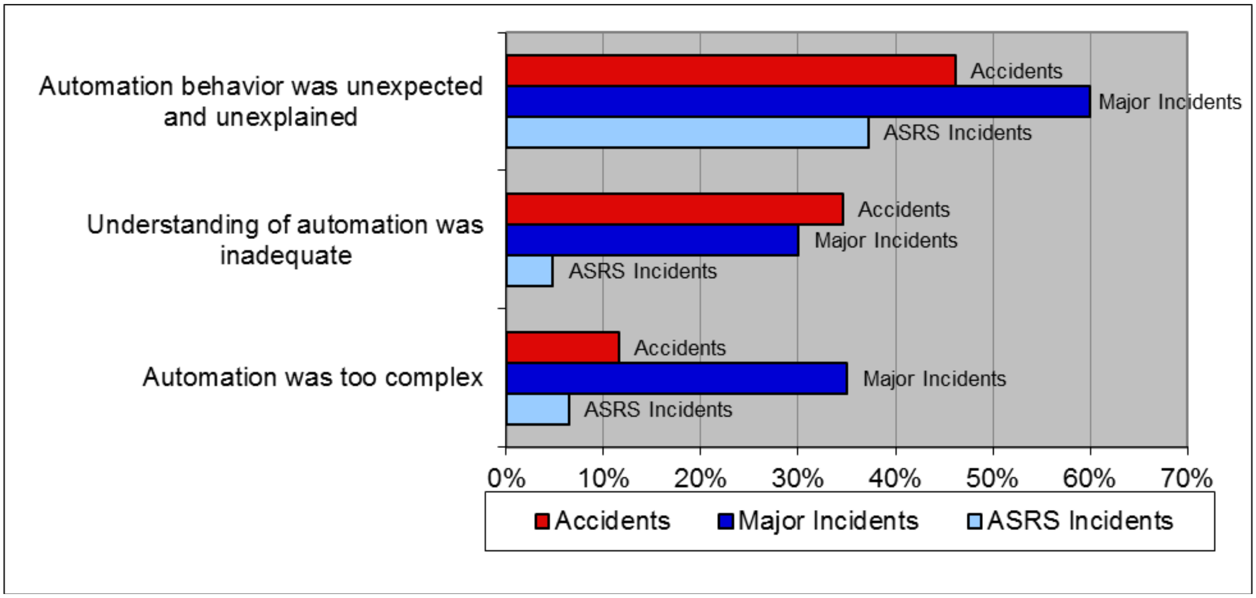
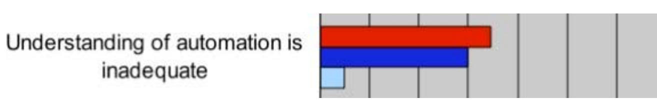


Figure 47. Issues Related to Understanding of Automation.

The issues related to pilot understanding of the automated systems are presented in Figure 47. The most evident of these issues was "Automation behavior is unexpected or unexplained" which was present in about 46% of the accident reports, 60% of major incident reports, and 38% of ASRS incidents. The general issue "Understanding of automation is inadequate" was present in about 34% of the accident reports, 30% of the major incident reports, and 5% of the ASRS incidents. Also included in this set is the issue "Automation is too complex" because complex systems are often difficult to understand. As seen in Figure 36, this issue was present in about 12% of accident reports, 35% of major incident reports, and 6% of ASRS incidents.

The events associated with the issue "understanding is inadequate" were reviewed and the details about what understanding was missing are presented in Table 20.

Table 20. Breakdown of "Understanding is Inadequate Issue" Category



Accidents	Major Incidents
• lack of knowledge of the procedures o crosscheck procedure, o landing procedure, o IRU troubleshoot, o an a/p that disengages on approach needs to be manually flown; o lack of knowledge of ILS procedures, o lack of knowledge of stabilized approach parameters • lack of understanding of FMS design and FMS input • lack of systems knowledge (one was interrelationship of throttle position to spoilers and autobrakes and one was IRU understanding) • misunderstanding of the vertical speed modes (two were unable altitude capture, and one climbed in vertical speed and stalled); • lack of autopilot knowledge (one didn't know that the	• Three involved lack of autopilot knowledge (1 back pressure causes mistrim, 1 ADC/Autopilot integration and 1 didn't know couldn't autoland on snow-covered rwy); • One involved lack of knowledge of high altitude aerodynamics / envelope protection; • One lack of crew knowledge of the fuel display during fuel system malfunction

autopilot trims with pilot back pressure; one didn't understand the autopilot climb/descent/speed modes; one did not have knowledge of how to re-engage a disengaged autopilot while on approach and one did not recognize autopilot had disengaged) • Lack of autothrottle understanding • Lack of knowledge of upset recovery procedures (high alt stall and upset from bad IRU)	
ASRS Incidents	
• Aircraft Malfunctions o lack of understanding of autothrottle control w/ FMS failure o FMS failure not ID'd o Lack of understanding of FMS failure procedures • Vertical Flight Guidance Problems o not understanding VNAV ops o not understanding FLCH ops o not understanding approach mode o not understanding V/S mode o not understanding climb profile o not understanding descent profile o not understanding level off procedures	• FMS Involved o 48 programming o 2 unable intercept to or direct to procedures o 1 not understanding "at/above" o 1 not understanding change from NAV to HDG o 2 not understanding system design(2) o 1 not understanding dropped wypts reverted to CWS o 1 not understanding climb performance o 3 not understanding LNAV ops o 1 not understanding approach procedures o 2 not understanding how to id fixes

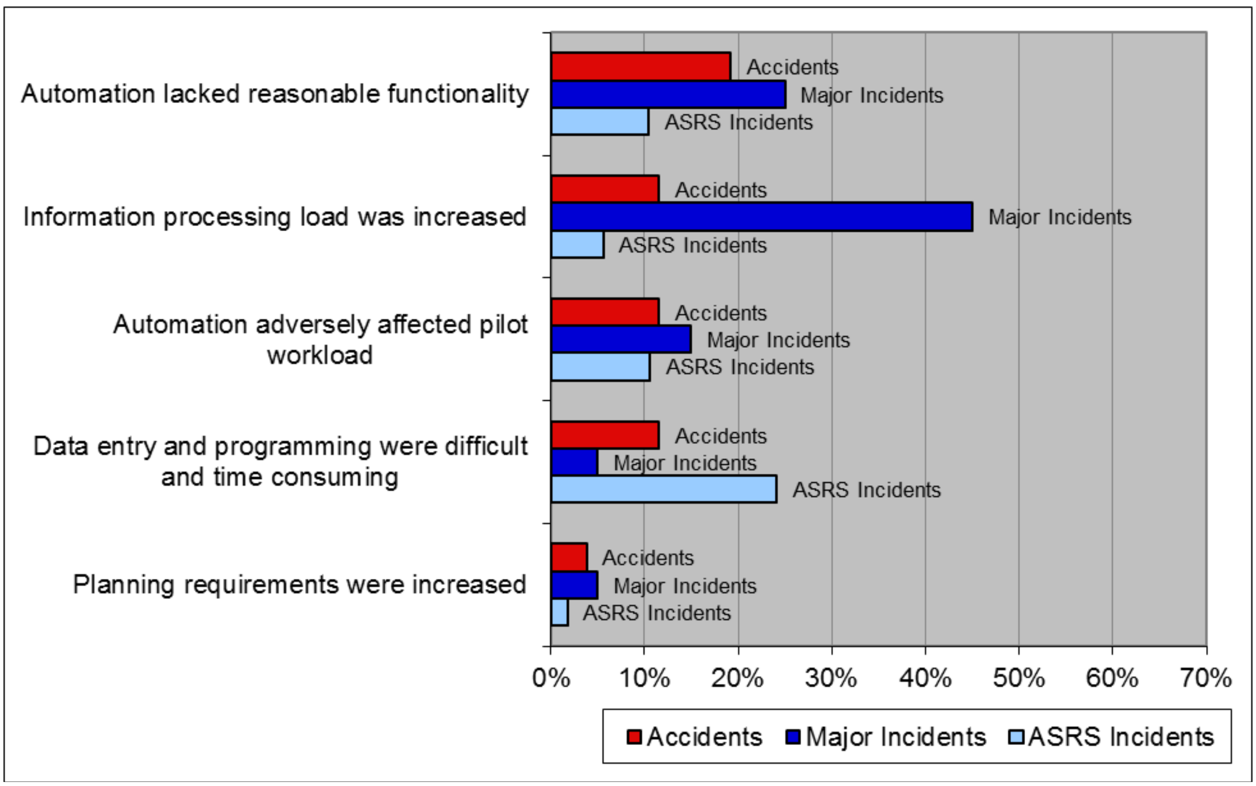


Figure 48. Workload Issues.

Figure 48 includes several issues related to pilot workload. This is another set of issues that shows a qualitative difference between the three data sets with each of them having a different one of the five issues having the highest percentage. The highest percentage of accident reports in this set is for the issue "Automation lacked reasonable functionality" at about 19%, this is followed by "Information processing was increased," "Automation adversely affected pilot workload,” and “Data entry and programming were difficult and time consuming” all evident in about 12%, and “Planning requirements were increased” in about 4%. For the major incident reports “Information processing load was increased” had the highest percentage (45%) followed by “Automation lacked reasonable functionality” ((25%), “Automation adversely affected pilot workload” (15%), and “Data entry and programming were difficult and time consuming” and “Planning requirements were increased” both at about 5%. For the ASRS incidents “Data entry and programming were difficult and time consuming” had the highest percentage of this set with about 24%, followed by “Automation adversely affected pilot workload” and “Automation lacked reasonable functionality” both at about 11%, then “information processing load was increased” at about 6% and “Planning requirements were increased” at about 3%.

ASRS Incident Factor Analyses

A Factor Analysis was conducted on the ASRS incident results to help identify which groupings of ASRS reports accounted for the variability of the data. It was identified that three factors accounted for most of the variability in the data. The specific groups of ASRS reports associated with each factor were then examined to identify the common themes within each group of reports. Based on that review, the following conclusions were drawn:

- Factor 1 generally involves errors in FMS programming of clearances where (1) the clearance or procedure was complex or difficult to understand and/or program, or (2) the clearance was incompatible with the flight deck automation and/or published procedures. These incidents were often accompanied by time pressure or high workload conditions.
- Factor 2 relates primarily to system malfunctions or failures, particularly where they led to difficulty of the crew in understanding or predicting the system’s behavior related to impact on the programmed flight plan or aircraft flight path.
- Factor 3 involves more tactical situations where the autopilot, flight director and mode control panel were involved. Usually the incidents included a lack of mode awareness by the flightcrew. These usually involved vertical navigation, and were often exacerbated by high workload.

Upon review of the ASRS incident summaries comprising each factor, some fairly common self-reported contributing factors and/or exacerbating circumstances, which we’ve called “vulnerabilities,” emerged across incidents for each factor. For Factor 1, the common vulnerabilities included input errors, distractions, and increased workload. For Factor 2, the vulnerabilities included distraction, selection of inappropriate level of automation, confusion and loss of awareness, and role abandonment (e.g., no one flying or monitoring the flight path). For Factor 3, the vulnerabilities included mode confusion, inability to detect errors, lack of crew coordination, and lack of cross verifying.

To explore whether the general commonalties were consistent across ASRS reports, they were divided into those reports that involved lateral deviations and those that involved vertical deviations. Factor analyses were performed on the “lateral deviation” reports and on the “vertical deviation” reports. The analyses showed four “lateral” factors and six “vertical” factors accounting for most of the variability. Based on expert review, the most common elements (with internally consistent themes among the incident reports within each factor) that characterized each of these factors for lateral deviations were:

- Lateral deviation Factor 1 – ATC clearance changes were given during high workload periods;
- Lateral deviation Factor 2 – Critical phases of flight with time pressure – late departure or arrival assignments and/or changes;
- Lateral deviation Factor 3 – Generally involved some type of malfunction or failure; and
- Lateral deviation Factor 4 – Incompatibilities (e.g., between FMS algorithms and ATC expectations, between chart wording and pilot expectations) were fairly common.

Factor	Common situational elements	Common vulnerabilities
Lateral deviation factor 1	ATC clearance changes during high-workload times	Not cross-checking, programming errors, complacency, both pilots head down, distraction
Lateral deviation factor 2	Critical phases of flight with time urgency - often late departure or arrival assignments and/or changes	Role abandonment, lack of cross verifying, distraction (can be exacerbated by fatigue), programming errors
Lateral deviation factor 3	Aircraft malfunction	Lack of crew coordination; programming errors, too much time trying to solve problem
Lateral deviation factor 4	Incompatibilities - between FMS algorithms and ATC expectations, between chart wording and pilot expectations, FMS and charts, etc.	Distractions, confusion, inability to predict behavior of FMS, crew doing troubleshooting too long

Table 21. Lateral Deviation Factors.

The most common elements that characterized each of these factors for vertical deviations were:

- Vertical deviation Factor 1 – FMS programmed while enroute, usually with vertical error without crew awareness; descent and climb scenarios typical;
- Vertical deviation Factor 2 – Commonality is misunderstanding and/or VNAV programming error, typically during arrival, typically with time pressure;
- Vertical deviation Factor 3 – High workload, multiple and late clearance changes, slam dunks;
- Vertical deviation Factor 4 – Crossing restrictions during arrival and departure, combined with high workload due to busy traffic environment, late runway changes, etc.;
- Vertical deviation Factor 5 – Vertical profile where crew misunderstands how the automation works - what the FMS is going to do; and
- Vertical deviation Factor 6 – System failures and/or failure to select appropriate level of automation.

Factor	Common situational elements	Common vulnerabilities
Vertical deviation factor 1	FMS programmed, but vertical was programmed incorrectly without crew awareness, descent or climb scenarios are typical	Programming errors, lack of cross check, distraction, complacency, over-reliance, fatigue

Vertical deviation factor 2	Commonality is misunderstanding and/or VNAV programming errors, typically during arrival, typically with time pressure	Distractions, fatigue, lack of adequate monitoring, lack of mode awareness,
Vertical deviation factor 3	High workload, multiple and late clearance changes, slam dunks	Less than effective Crew Resource Management (CRM), poor crew coordination and communication, losing situation awareness, programming and Mode Control Panel (MCP) errors, ineffective cross verification, role abandonment
Vertical deviation factor 4	Crossing restrictions during arrival and departure, combined with high workload due to busy traffic environment, late runway changes, etc.	Distractions (exacerbated by fatigue, lack of proficiency and/or experience), failure to cross verify, programming errors
Vertical deviation factor 5	Vertical profile where pilots misunderstand how the automation works - what the FMS is going to do.	Role abandonment, distraction, lack of communication with ATC on problems crew is encountering, lack of situation awareness, both pilots heads-down
Vertical deviation factor 6	System failures and/or failure to select appropriate level of automation	Distraction, loss of flight plan situation awareness, intervention that was too late, poor crew coordination

Table 22. Vertical Deviation Factors.

The common vulnerabilities associated with each vertical deviation factor are shown in Table 22. These vulnerabilities were very similar to the vulnerabilities associated with the original factors based on the entire set of ASRS reports.

The remainder of this section is a summary of what this WG learned from manufacturers, airlines, authorities, pilots, and other subject matter experts about changes that have occurred since 1996, and about design, training and operations, and future operational considerations.

This report describes the initial results of the ASRS incident analysis and summarizes what the WG learned from manufacturers, operators, authorities, pilots, and other subject matter experts about changes that have occurred since 1996 related to design, training and operations.

Accident/Major Incident Factor Analysis

A Factor Analysis was also conducted on the data from the combination of the accident and major incident reports. Due to the small number of reports included in the analysis the results identified only one clear factor. There were four accident reports associated with this factor and two prominent categories from our data review: crew-to-external communication errors and cross-verification errors. When these events were reviewed further to better understand this factor it was found that the common underlying theme was lack of crew coordination that resulted in a breakdown in cross-verification of the other pilots' actions and inputs and lack of effective communication with ATC. All accidents had rushed and inadequate briefings. This caused a breakdown in crew coordination on the approach. This lack of crew coordination was displayed in the crew not taking or having the time to do adequate cross-verification.

The problems with effective communication with ATC centered on critical information that should have been anticipated and properly assessed by the pilots (e.g., what is current altimeter, verifying any ATC instructions when English is one's second language). In summary the common ATC communication threads were:

- Not questioning what doesn't make sense (ATC instructions/clearance),
- Not asking/obtaining critical info (new ATIS/altimeter), and
- Ignoring untimely distractions.

Co-Occurrence Analyses

A co-occurrence analysis was conducted in an attempt to understand the relationship between the different issues, errors, and threats that were shown in the data. The measure used for co-occurrence was the intersection or the union of the two categories that were being assessed for similarity of occurrence. Pathfinder networks were used to visualize these co-occurrence relationships and attempt to understand them. There is much work to be continued in this area, but three of the analyses stood out with particular insights that will be shared in this section. These address areas related to manual handling errors, cross-verification errors, and airplane malfunction threats.

Manual Handling Errors

The categories that co-occurred most strongly with manual handling errors are presented in Table 23. It can be seen when comparing across the three types of reports that they are showing different patterns of categories. This suggests that the characteristics of the accidents, major incidents, and ASRS incidents that included manual handling errors did not develop from similar situations.

Table 23. Categories that strongly co-occurred with manual-handling errors.

Accidents	Major Incidents	ASRS Incidents
• Issue: manual operation is difficult after transition from automated control • Issue: Crew coordination problems occur • Issue: Training is inadequate • Issue: Behavior of automation is not apparent • Issue: Understanding of automation is inadequate • Threat: Inadequate knowledge • Error: Cross-verification	• Issue: Situation awareness may be reduced • Issue: Interface may be poorly designed • UAS: Altitude Deviation • Threat: Fatigue • Threat: Inadequate knowledge • Error: Pilot-to-Pilot Communication	• Issue: Task management is more difficult • Threat: Crew factors - other • Threat: Environmental - other • Threat: Adverse Weather

Cross-Verification Errors

The other categories that co-occurred most strongly with cross-verification errors are presented in Table 24. As with the review of manual handling errors, the three event types show different sets of categories that most strongly co-occur. However, these sets have more of a common theme, which is related to crew communication and coordination, diverted attention, and distraction.

Table 24. Categories that strongly co-occurred with cross-verification errors.

Accidents	Major Incidents	ASRS Incidents
• Error: Pilot-to-pilot communications • Error: Callouts • Error: Briefings • Error: Manual handling/flight controls	• Issue: Crew coordination problems occur • Issue: Cross-checking is difficult • Issue: Both pilots' attention is diverted by programming	• Issue: Crew coordination problems occur • Issue: Training is inadequate • Issue: Cross verifying is difficult • Issue: Automation use is vulnerable to flight deck distraction • Issue: Pilots are out of the loop • Threat: Other (Threats associated with flightcrews) • Error: Use of CDU/MCDU • UAS: Lateral Flight Path Deviation

Malfunctions

The categories that co-occurred most strongly with aircraft malfunction threats are presented in Table 25. In all event types there is a relationship between the difficulty in assessing a failure and the malfunction threat. The additional categories most strongly co-occurring with the different event types are a bit different from each other, describing differing characteristics that were focused on in the reports. For ASRS incidents the pilots often focused on the unexpected nature of the behavior of the automation when the malfunction occurred. The nature of the major incident events frequently being chosen for investigation because of an unusual malfunction or failure is consistent with the issue of failures being unanticipated by designers. As described earlier in the report, the WG categorized a failure as unanticipated by designers if it did not have a procedure or checklist associated with it. The situations described by the set of categories that co-occur with malfunctions in the accidents focus more on the situation in which the pilots find themselves, such as previous ground maintenance or flying with autopilot and something going wrong, or the consequences that result (protections are lost). There is a common thread across the event types, but they each have a unique character.

Table 25. Categories that strongly co-occurred with aircraft malfunction threats.

Accidents	Major Incidents	ASRS Incidents
• Issue: Failure assessment is difficult • Issue: Protections are lost though pilots continue to rely on them • Issue: Pilots have responsibility but lack authority • Threat: Ground maintenance • Error: Use of autopilot • End State: Inflight	• Issue: Failure assessment is difficult • Issue: Failure modes were unanticipated by designers	• Issue: Failure assessment is difficult • Issue: Automation behavior is unexpected and unexplained • UAS: Other

damage/injuries		

LOSA Analysis

A sub-team of the WG worked with the LOSA Collaborative to conduct an analysis of a broad set of LOSA data to better understand the issues identified during observations of normal operations. For this purpose a representative sample of recent LOSA narratives was extracted for analysis.

The selection LOSA data included recent observations of US and international carriers. The following aircraft types were included in the sample:

Embraer E190
Airbus A310, A320, A330, A340
McDonnell Douglas MD80,
MD88/90
Boeing B737-200 through 900
Boeing B747-200/300/400
Boeing B757, B767, B777

The LOSA classification system was used to select events of interest. Narrative records of flights that had been coded by the observer as either poor/marginal or outstanding crew ratings in the category of automation management were extracted. Part of this process meant that narratives were collated into three flight phases – Predeparture/Taxi, Take-off/Climb, and Descent/Approach/Landing – used in LOSA. The data extracted were de-identified before review by the WG.

Over two thousand two hundred flights were selected in the initial sample. This sample was compared with another independent sample of 1757 from the LOSA archive to determine how representative the original sample might be of the full set. The following table presents the percentage of either poor/marginal or outstanding automation management ratings by phase of flight category, with the comparative LOSA sample in parentheses for each of them. The percentages are very similar and suggest that the sample used for analysis in not considerably different from the data in the full LOSA archive.

Percentage of flights with Poor/Marginal and Outstanding Automation Management ratings by LOSA Phase			
	Predeparture	Take-Off/Climb	D-A -L
Poor / Marginal	2.92 (3.41)	9.65 (9.79)	11.53 (11.84)
Outstanding	1.79 (2.22)	5.38 (5.92)	7.76 (7.57)

Issues –

Because these reports reflect observer ratings and the observers in differing LOSAs are drawn from the client carrier, it is likely that differing perspectives were brought to bear across the various LOSAs. These differences would naturally affect the observer rating of crew performance in regard to automation use.

The sample strategy and de-identification requirements meant that a single flight could not be examined in its entirety and the relationship of crew behaviors in one phase could not be linked to crew behaviors in another.

The sampling strategy meant that the narratives were not linked to the LOSA observed threats, errors and their subsequent management. Threats, outcomes and crew behaviors were extracted from the selected narratives following review by other industry experts. In this process at least two experts agreed on a short synopsis of the event of interest. This synopsis was then coded into a matrix by another expert.

Coding Scheme

The coding process reviewed narratives and determined if a factor related to the following categories was relevant to the determination of the poor/marginal or outstanding automation rating based on the issues, circumstances and crew behaviors described. It is important to note that these factors are not necessarily errors. Firstly, they may reflect an outstanding use of flight path management systems or anticipatory briefings or decision that avoided the potential adverse outcome. Secondly, they may reflect non-optimal rather than deficient behaviors. These factors may also describe the circumstances (e.g., ATC clearance) that lead to the poor/marginal or outstanding rating.

The coding process captured whether or not the narrative described issues or errors associated with the following Flight Path Management systems and controls: programming, entry of figures/data and use of the FMC/S, the selection and use of modes, the selection of other related automated flight path controls such as FCP/MCU Alt, APPR arming, Auto-thrust/throttle, Auto-pilot engagement and Flight Director. The use of information displays such as the ND was included in this section.

The coding process then examined the narratives for the presence of relevant SOP related factors including; mode and altitude callouts, other confirmations, confirm cross-check, briefings, or whether the PF made their own flight path management system selections.

The coding process critically examined the narratives to determine if a knowledge, understanding or ability to use the flight path management system was documented as relevant to the issue described.

The coding process then determined if any ATC related factors described were relevant to the issue. Specific issues such as a runway change, or re-clearance/clearance were identified.

The last factors that were captured involved information automation relating to the uplinking of data and the use of electronic checklists.

The narratives were examined for evidence of any adverse consequences or outcomes either avoided or associated with the issues and factors already coded. These adverse consequences included; unexpected mode reversion, Lateral Mode Confusion, Vertical Mode confusion, A/T mode confusion, Speed/Energy issues, Lateral or Vertical path deviation, both heads down, altitude excursion or bust, weather penetration, or workload

The narratives were finally examined for evidence of relevant threat and/or error management behaviors and coded to reflect the following: nothing specific, error management, anticipation, threat managed – terrain, weather, mechanical, traffic, Flight Planning, Turbulence, other system related, and late notice change

Analysis and Results

Automation Errors

The LOSA database was queried to explore the coding of Automation Errors.
This review of Automation Errors found:

1. 63% of the Automation Errors were inconsequential; the rest (37%) were associated with an additional error or undesired aircraft state (UAS).
2. 52% of Automation Errors were detected and acted upon by the flightcrew before they were associated with an additional error or UAS.
3. 24% of the Automation errors occurred during Predeparture/Taxi-Out, 21% during TO/Climb, 8% during Cruise, and 47% during Descent/Arrival/Landing.
4. For flights in which Automation Errors were not recorded, 36% were rated poor/marginal for Monitor/Cross verify and 22% were rated Poor/Marginal for Automation Management.
5. For flights in which Automation Errors were recorded, 49% were rated poor/marginal for Monitor/Cross verify and 43% were rated Poor/Marginal for Automation Management.
6. For flights in which Automation Errors were recorded as mismanaged and were associated with an additional error or UAS, 62% were rated poor/marginal for Monitor/Cross verify and 55% were rated Poor/Marginal Automation Management.

These results indicate that not all errors coded as an Automation Error were also recorded with a rating of poor or marginal for Automation Management indicating that all errors were not considered related to management of the automation. The narrative analysis was undertaken to further investigate and to better understand these relationships and differences.

Analysis of Outstanding vs. Poor Ratings

A descriptive analysis of the coded information was conducted. Although data has been extracted that reflect the combination of categories or how an element of one category is reflected when another is considered – no inferential analysis was undertaken.

Predeparture/Taxi Narratives with Poor /Marginal Ratings

5. The majority of poor/marginal ratings in the predeparture/taxi phase related to an SOP error, typically a failure to cross verify a FMC entry properly.
6. The potential for mode confusion dominated the adverse consequences. This is to be expected as the aircraft was not yet in a position for potential issues to become real ones.
7. 36.9% of the narratives with poor/marginal ratings referred to some type of adverse consequence. These consequences were largely associated with confusion related to either a lateral (58.3%) or vertical (37.5%) mode.
8. ATC re-clearances and departure, routing or runway changes were identified in about 30% of the narratives.
9. The only other factor identified was some indication by the observer that the crew was unable to perform a function associated with the use of automation that they should have been able to do. A theme indicating a lack of knowledge appeared in just under one in seven ratings. Not surprisingly, FMC factors dominated this “lack of knowledge” theme.

10. It appears that an ATC factor was more likely to lead to a failure to cross-verify or perform a briefing appropriately becoming consequential. This should be an expected result as, without a change, the failure to cross-verify would not normally result in an unresolved discrepancy.

Predeparture/Taxi Narratives with Outstanding Automation Management Ratings

1. Nearly 40% of outstanding ratings did not provide enough information to ascertain why they were given that rating.
2. Few adverse consequences avoided could be drawn from the narratives.
3. A strong theme of good performance of SOPs and sound briefings along with consistent monitoring and cross-verifying was evident. However, few if any of these indicated more than sound compliance with required procedures. (Related to #2 above.)
4. Less than one quarter of the narratives provided any specific circumstances justifying the outstanding rating. Comments such as "Good VVM" were typical and although the narrative described specific SOPs, nothing more specific was included.
5. Again, as expected, use of the FMC rather than the mode selector panel dominated the automation management descriptions in the narratives in the pre-departure phase.
6. When the rating was supported by specific circumstances, the crew's response to ATC changes and/or a display of good knowledge of the equipment, procedures, or local environment accounted for the majority of these outstanding ratings.

One concerning consequential finding flows from these results. The professional observers rated mere SOP compliance as outstanding automation management suggesting that less than SOP compliance related to callouts, cross-checking and verification may be broadly accepted as the norm.

Takeoff/Climb Narratives with Poor /Marginal Automation Management Ratings

1. SOP errors accounted for more than half of the ratings with deficient callouts, monitoring or cross-checking the primary factors. However a significant amount, nearly one quarter, of SOP errors were related to a crewmember making their own selections of controls when specified otherwise.
2. Identified SOP errors were rarely associated with an adverse consequential outcome.
3. Consequential adverse outcomes were rarely linked with poor callouts, monitoring, cross-checking, briefings, or making selections inappropriately.
4. A Poor / Marginal rating for automation management during the take-off /climb phase was associated with an adverse consequence 41% of the time.
5. While FMC factors accounted for about the same number (43.7%) of poor/marginal ratings as mode selection factors (41.4%), an adverse consequence related to a mode selection factor was twice as likely (21.4% versus 10.2%). Mode issues accounted for more than 50% of adverse consequences. Note: In accordance with 2 and 3 above, consequential outcomes associated with FMC or Mode issues were rarely linked with poor SOPs.
6. Vertical Path issues (16.7%) were highly consequential. More than 3 out of 4 vertical path issues were associated with an adverse outcome and accounted for 31.5% of consequential issues. Mode, rather than FMC, related factors contributed the majority here. The use of VS and VNAV modes inappropriately accounted for about 2/3 of vertical path factors or 20% of all adverse consequences.

7. Lateral Path Factors –While accounting for more than ¼ of all ratings (26%), Lateral path factors were related to fewer adverse consequences (24.7%) than vertical path factors. More lateral path factors were related to SOP violations that had fewer negative outcomes. Again mode selection factors contributed nearly three times as many adverse consequences than FMC factors. FMC factors were again to be more likely related to inconsequential SOP violations. Heading versus LNAV or Managed lateral modes accounted for the vast majority of these consequences.
8. Speed factors –While speed factors accounted for only half the number of poor marginal ratings (13%), they were extremely consequential and were a factor in nearly ¼ of all adverse consequences. FMC and Mode factors contributed fairly equally to speed factors. Not surprisingly, selection of an inappropriate vertical mode contributed all of the mode selection factors here. FMC related factors tended to either reflect an issue with the programming of 250 below 10 000 or a mode reversion that took the crew by surprise or an inability for the crew to reprogram or set the FMC up properly following such a reversion.
9. ATC was no longer the primary associated external factor at this stage of flight.
10. While lack of knowledge was associated with just over 10% of poor/marginal ratings, about 90% of these were consequential.
11. When the PF elected to hand-fly at an inappropriate time (14.9%), consequential outcomes leading to increased workload and a smattering of lateral and vertical mode confusions, speed excursions or altitude busts occurred about 1/3 (5.6%) of the time. Hand flying inappropriately, was not normally identified as an SOP error by the observers.

Take-off/Climb Narratives with Outstanding Automation Management Ratings

1. Very Good SOPs accounted for nearly 1/3 of the ratings (29.2%), however, very good SOP compliance was only occasionally related (less than 1 in 10) to a consequence avoided. Similarly, very good SOPs were rarely linked to error management, anticipation or threat management behaviors. This followed a similar pattern to the lack of compliance with SOPs leading to adverse outcomes described in the discussion of poor/marginal ratings for this phase in the last section. When the use of a mode was associated with a consequence avoided or threat and error management, SOPS were never a factor.
2. Fewer outstanding ratings (10.8%) than in the predeparture phase (37.5%) could not be linked to a specific crew behavior. This suggests that the observer was relating more observations to specific crew actions.
3. An outstanding rating was associated with a potential adverse consequence avoided 34.5% of the time. A lateral or vertical deviation from desired parameters was avoided in nearly 40% and workload reduced in more than 1/3 of these instances.
4. This rating could be linked to action taken because of threats (other than ATC) in 27.5% of narratives. As mentioned above few of these example referenced very good SOPs. Knowledge, use of modes and then FMC were the top related factors associated with these behaviors.
5. This rating could be linked to action taken because of ATC interventions in 28.3% of narratives. One in eight flights reflects action taken by the crew to meet clearances imposed by ATC.

6. While ATC is related to more than one-third of all consequences avoided and action taken to meet a clearance relates to just under 20 percent of consequence avoided, many of the narratives described the use of the automation in such cases to reflect a high degree of anticipation of changes or optimizing its use in light of ATC factors rather than the avoidance of a consequence that would have occurred if action had not been taken. ATC was related to a mode factor twice as often as to an FMC factor.
7. While many of the adverse outcomes associated with poor use of automation in the take-off/climb phase reflected mode confusion, avoiding mode confusion was rarely something mentioned in the narratives for higher performing crews. While this is to be expected, it is worthwhile noting that the avoidance of a mode confusion was normally associated with anticipation, knowledge and/or briefing above and beyond what was normally SOP.
8. Knowledge was identified as an important factor in over 20% of outstanding ratings. Approximately ½ of these were related to the avoidance of consequences. This accounted for just under 1/3 of all consequences avoided. Knowledge was related to the use of modes twice as often to the use of the FMC. However, knowledge was linked to majority of cases when the FMC was linked to the avoidance of consequences. Whereas, knowledge was only linked to the use of modes in 45% of similar cases. The cases where knowledge could be explicitly linked with mode usage to avoid a consequence is typified by the following example – crew selected heading to overfly rather than fly-by a way point. Other cases, may also imply the application of knowledge i.e., use of selected speed to expedite climb, however, in these cases knowledge was not coded unless it was explicitly stated in the narrative.
9. Modes were identified as contributing to the rating nearly twice as often as the FMC (37.5 versus 20.0%). This ratio was maintained with just more than half of each being related to the avoidance of consequences. Their respective contributions to all consequences avoided being 24.5% for FMC and 43.9% for modes.
10. As opposed to poor performing crews, observers identified crews that elected to engage the autopilot early, in response to a threat or to reduce workload as outstanding in 16.7% of the events. Nearly 2/3 of these were events linked with an adverse outcome avoided and were a factor in more than 30% of all adverse consequences avoided.

Descent/Approach/Landing Narratives with Poor/Marginal Automation Management Ratings

1. SOP errors accounted for 28% of the poor/marginal ratings in this phase. The contribution related to crewmembers making their own selections of controls when specified otherwise was much reduced from the Take-off/Climb phase.
2. Identified SOP errors were consequential in just under 1/3 of the time and were related to 17.6% of all consequential outcomes. This is a more significant contribution than other phases examined.
3. Poor / Marginal ratings were associated with an adverse consequence 46.3% of the time. More than one adverse outcome can be coded against a single event. Vertical Mode confusion, speed/energy issues and/or lateral or vertical deviations were all coded against about 40% of consequential outcomes. Compared with the Take-off/Climb phase, a poor/marginal automation rating was twice as likely to result in a lateral or vertical deviation away from desired parameters. Lateral deviations remained about the same and the increase came from the increased numbers of vertical deviations. The majority of vertical deviations were high and related to ATC intervention with speed control, direct

routing, track shortening or other clearance change. A lack of knowledge rather than poor SOPs appears to be linked to these deviations. A failure to react with appropriate mode selections when the FMC programmed path is varied through ATC request is typical of the narratives.

4. While ATC was only identified as a factor in 16.3% of narratives, it was extremely consequential (about 9 out of ten cases) and was related to more than 30% of adverse outcomes. Of those factors coded, runway changes, speed control, track shortening, radar vectors, and/or direct routing accounted for majority of consequential outcomes.
5. Lack of knowledge was associated with nearly 40 percent of poor/marginal ratings; about 3 in 5 became consequential and were related to more than half of all adverse outcomes.
6. The FMC (37.4%) and mode issues (45.1%) retained about the same relative proportional contribution to the poor marginal rating as in the Take-off/Climb phase. 70% of mode issues became consequential versus 60% of FMC issues that were related to an adverse outcome. Once again mode issues (68.1%) contributed more to adverse outcomes than FMC issues (47.9%). Just as in the Take-off/Climb phase the FMC was more likely to be coded because of inconsequential SOP violations. Of note is the finding that in this phase more coding of both FMC and mode issues together (15.6%) occurred. This combination was extremely consequential with nearly 90% related to an adverse consequence.
7. Vertical Path issues (14.8%) were highly consequential with more than 2 in 3 times and accounted for 24.4% of consequential issues. While FMC and mode issues contributed about equally to these consequences, mode issues were much more likely to be consequential. Where FMC and mode issues where coded together, they were extremely consequential.
8. Lateral path issues (15.2%) were related to about the same number of adverse consequences (10.5%) as vertical path issues. While just more than 2 in 3 lateral path FMS issues were related to an adverse consequence, all lateral path mode issues were tied to an adverse outcome. However, in this specific lateral path case, no mode issue was coded in isolation from a FMC issue. Again those lateral path issues associated with SOP violations tended to have fewer negative outcomes. Mode selection issues contributed nearly three times as many adverse consequences than FMC issues. FMC issues were more often related to inconsequential SOP violations. A lack of knowledge was strongly linked to the FMC and lateral issues in particular.
9. This phase saw the majority of mode issues, when also specifically identified with lateral, vertical, speed or some constraint issue to be subsumed within an issue also identified with the FMC. This is to be expected as the lateral, vertical and speed paths are intertwined together on arrival and an issue in one normally requires adjustment in the others. Where a planned path is changed, it is normally initiated or adjusted on the FMC and modes may be adjusted to cater for the changes. In this case, changes to the FMC programmed path required some change to the modes to achieve flight path goals. If these changes had not been required then there would not have been an adverse outcome. So this result is a natural outcome of the coding process and should not be seen as a special relationship.
10. As in other phases, nearly all FMC events that were related to an adverse outcome also represented lateral, vertical, speed or other constraint issues.
11. Unlike the Take-off /Climb phase, the PF electing to hand-fly at an inappropriate time (3.9%) was not a major factor in adverse outcomes. Again, hand flying inappropriately, was not normally identified as an SOP error.

Descent/Approach/Landing Narratives with Outstanding Automation Management Ratings

1. The proportion of events citing Very Good SOPs (14%) was less than half, that of the Take-off/Climb phase. However just as the SOP compliance was related to more adverse events for poor/marginal crews, high performing crews contributed to 8.9 % of all consequences avoided with good SOPs. However, very good SOPs were still rarely linked to error management, anticipation or threat management behaviors.
2. About the same number of outstanding ratings (9.9%) as in the Take-off/Climb phase (10.8%) could not be linked to a specific crew behavior. This suggests that the underlying "they did a good job" over-grading rate seems to be at about 10% when in flight.
3. This rating was associated with a potential adverse consequence avoided 58.7% of the time, nearly double that of the Take-off/Climb phase. A lateral or vertical deviation from desired parameters was avoided in more than 60%, a speed/energy factor overcome in 50.5%, and workload reduced in 34.7%, of these instances.
4. This rating could be linked to action taken because of threats (other than ATC) in 34.9% or anticipation in 31.4% of narratives. As mentioned above few of these example referenced very good SOPs. Just as with the Take-off/Climb phase, knowledge, use of modes and then FMC were the top related factors associated with these behaviors. However, in this phase, knowledge was not as strongly linked to the use of modes or the FMC as in the Take-off/Climb phase.
5. ATC factors were a strong theme throughout the narratives, appearing in 58.1% of all. ATC factors were extremely consequential and were linked to some crew action in 74.3% of the instances when an adverse outcome was avoided. This figure is nearly triple that recorded for ATC factors in the take-off/climb phase.
6. Many of the narratives described use of the automation in such cases to reflect a high degree of anticipation/threat awareness (2/3 of all anticipation and more than ½ of threat-related factors). Once again ATC was related to a mode factor about twice as often as to an FMC factor. Mode factors were related to either Error management, anticipation, threat management or an adverse consequence avoided about twice as often as an FMC related factor.
7. Once again higher performing crews did not need to avoid mode confusion; rather they employed the appropriate mode to avoid more serious consequences. When indicated, the avoidance of mode confusion was normally associated with anticipation, knowledge, and/or briefing above and beyond what was normally SOP.
8. Knowledge was identified as an important factor in over 1/4 of ratings. The use of knowledge was strongly linked with the avoidance of adverse outcomes. More than 9 in 10 cases where knowledge was a factor were identified with the avoidance of consequences. This accounted for just under 41.6% of all consequences avoided. Knowledge was also related to just under half of the events where crew behavior related to threat avoidance was identified. The distinction between the role of knowledge in either mode or FMC factors was not as clear-cut as in the take-off/climb phase.
11. Where mode usage or FMC were identified as factor linked to either the avoidance of consequences or crew behaviors related to threat and error management, SOP compliance was rarely a co-factor.
12. Modes were identified as contributing to the rating nearly twice as often as the FMC (62.2 versus 31.4%). This ratio was maintained with more than 2/3 of each being related to the avoidance of consequences. Their respective contributions to all consequences

avoided being 38.6% for FMC and 76.2% for Modes. These figures are nearly double those recorded in the Take-Off/Climb phase.

9. The engagement status of the autopilot was not a key factor in this phase.
10. The briefing, and in particular, a briefing going further than what was expected in SOPs, emerged as a key factor. Unlike other phases, briefing was coded more often than the SOP general marker. Briefings were a highly consequential factor and were identified in more than ¼ of adverse consequences avoided. When coded separately to the SOP marker, briefings were linked with 23% of avoided consequences and figured significantly in threat and error management behaviors.

Appendix H Status of Recommendations in 1996 FAA report on the Interfaces between Flightcrews and Modern Flight Deck Systems

This Appendix summarizes the recommendations from the 1996 FAA report and the status of their implementation in the table below. For each recommendation, the table identifies efforts related to implementation of the recommendation. For each recommendation, the table identifies (in italics) any findings from the Flight Deck Automation Working Group that update or address the 1996 recommendation.

Following the table is a summary of the 1996 FAA report recommendations in text form for easy reference.

Recommendation	Recommendation text	Status
Measurement of and Incentives for Safety Measures-1	The FAA should: • Lead the aviation community to use accident precursors increasingly and consistently as an additional measure of aviation safety; • Work with industry to establish systems/processes for collecting precursor data and for tracking the influence of system changes (e.g., design changes, training changes) on safety; and • Work with industry to investigate other means of assessing or communicating safety (e.g., ways of measuring errors intercepted, incidents or accidents prevented, etc.).	FOQA, ASAP, LOSA are significant steps in this direction. *This has been updated in Recommendation 18 – Methods and Recommended Practices for Data Collection, Analysis, and Event Investigation that Address Human Performance and Underlying Factors.*

Measurement of and Incentives for Safety Measures-2	In accident/incident investigations where human error is considered a potential factor, the FAA and the National Transportation Safety Board should thoroughly investigate the factors that contributed to the error, including design, training, operational procedures, the airspace system, or other factors. The FAA should encourage other organizations (both domestic and foreign) conducting accident/incident investigations to do the same. This recommendation should apply to all accident/incident investigations involving human error, regardless of whether the error is associated with a pilot, mechanic, air traffic controller, dispatcher, or other participant in the aviation system.	Done on an ad hoc basis. *This has been updated in Recommendation 18 – Methods and Recommended Practices for Data Collection, Analysis, and Event Investigation that Address Human Performance and Underlying Factors.*
Measurement of and Incentives for Safety Measures-3	The FAA should explore means to create additional incentives to improve safety through appropriate design, training or operational improvements.	Limited implementation.
Flightcrew Management and Direction of Automation AutomationMgt-1	The FAA should ensure that a uniform set of information regarding the manufacturers' and operators' automation philosophies is explicitly conveyed to flightcrews.	Current practice often does this but not always. *This has been updated in Recommendation 9 - Operational Policy for Flight Path Management.*

Flightcrew Management and Direction of Automation AutomationMgt-2	The FAA should require operators' manuals and initial/recurrent qualification programs to provide clear and concise guidance on: • 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).	The Air Transport Association Automation Subcommittee wrote a paper containing a model training program for automation management, in response to the HF Team report. *Updated in Recommendation 9 -Operational Policy for Flight Path Management.*
Flightcrew Management and Direction of Automation AutomationMgt-3	The FAA should initiate a review of the autopilots on all transport category airplanes to identify the potential for producing hazardous energy states, excessive pitch or bank angles, subtle departures from the intended flight path, slow-overs, hard-overs, or other undesirable maneuvers. Results of this review should be the basis for initiating appropriate actions, such as design improvements, flight manual revisions, additional operating limitations, or changes in training programs or operational procedures.	Completed. Results incorporated into updated 14 CFR 25.1329 Flight Guidance Systems. Final FAA regulation and Advisory material published 2006.
Flightcrew Management and Direction of Automation AutomationMgt-4	The FAA should assure that analyses are conducted to why flightcrews deviate from procedures, especially when the procedural deviation contributes to causing or preventing an accident or incident.	Extensive research done on procedural non-compliance but still an issue. *Updated in Recommendation 8 – Design of Flightcrew Procedures.*

Flightcrew Management and Direction of Automation AutomationMgt-5	The FAA should request industry to take the lead in developing design guidelines for the next generation of flight management systems	PARC, CNS (formerly RNAV) Task Force, RTCA. *Updated in Recommendation 16 – Flight Deck Equipment Standardization.*
Flightcrew Situation Awareness SA-1	The FAA should take action to increase flightcrews' understanding of and sensitivity to maintaining situation awareness, particularly: • Mode and airplane energy awareness issues associated with autoflight systems (i.e., autopilot, autothrottle, flight management system, and fly-by-wire flight control systems); • Position awareness with respect to the intended flight path and proximity to terrain, obstacles, or traffic; and • Potential causes, flightcrew detection, and recovery from hazardous pitch or bank angle upsets while under autopilot control (e.g., wake vortex, subtle autopilot failures, engine failure in cruise, atmospheric turbulence).	Some has been done through advisory material (automation management in AC 120-51D, CFIT training aid, advanced maneuver training) but improvements need to be made. Extensive activities in upset prevention and recovery (AC 120-109 Stall and Stick Pusher Training) and others. Implementation of mandate for TAWS in 14 CFR 121.354 Terrain Awareness and Warning System. *Updated in Recommendation 13 - Pilot Training and Qualification.*
Flightcrew Situation Awareness SA-2	The FAA should require operators' initial and recurrent training programs as well as appropriate operating manuals to: • Explicitly address autoflight mode and airplane energy awareness hazards; • Provide information on the characteristics and principles of the autoflight system's design that have operational safety consequences; and • Provide training to proficiency of each flight management system capability to be used in operations.	Some information about automation management has been included in the AC 120-51E Crew Resource Management. ATA Automation Subcommittee has written a paper describing a model training program for automation. It is a first step but not a complete solution. *Updated in Recommendation 13 - Pilot Training and Qualification.*

Flightcrew Situation Awareness SA-3	The FAA should encourage the development and implementation of new concepts to provide better terrain awareness.	Completed. Requirement for TAWS in Parts 121 and 135, and associated advisory material is completed.
Flightcrew Situation Awareness SA-4	The FAA and the aviation industry should develop and implement a plan to transition to standardized instrument approaches using lateral navigation (LNAV) and vertical navigation (VNAV) path guidance for three-dimensional approaches. Minimize the use of approaches that lack vertical path guidance.	CAST, AWOHWG are working on this. AC 120-29A was published and provides an important foundation. Other standards/criteria were being done through the TAOARC (Terminal Area Operations Aviation Rulemaking Committee) and now through PARC (Performance-Based Operations Aviation Rulemaking Committee). *Updated in Recommendation 11 – Airspace Procedure Design.*
Flightcrew Situation Awareness SA-5	The FAA should sponsor research and develop guidance on means of providing effective feedback to support error detection and improved situation awareness.	Regulation and advisory materials (CS/14 CFR 25.1302 Installed Systems and Equipment for Use by the Flight Crew) have been published by EASA and the FAA. *Updated in Recommendation 6 – Flight Deck System Design and Recommendation 12 – Flight Deck Design Process and Resources.*

Flightcrew Situation Awareness SA-6	The FAA should encourage standardization, as appropriate, of automation interface features, such as: • The location, shape, and direction of movement for takeoff/go-around and autothrottle quick disconnect switches; • Autoflight system mode selectors and selector panel layout; • Autoflight system modes, display symbology, and nomenclature; and • Flight management system interfaces and nomenclature.	Support of groups like SAE S-7 and G-10 and other industry standard groups is ongoing but this isn't really being addressed for transport airplanes. GAMA Publication 12 is an attempt to do this for GA. *Updated in in Recommendation 16 – Flight Deck Equipment Standardization.*
Flightcrew Situation Awareness SA-7	The FAA and the aviation industry should update or develop new standards and evaluation criteria for information presented to the flightcrew by flight deck displays and audio advisories (e.g., primary flight displays, navigation/communication displays, synoptics showing system states).	Numerous activities have been done that address this recommendation, including FAA AC 25-11 Electronic Displays, RTCA MOPS on Moving Map Displays, and others. Regulation and advisory materials (CS/14 CFR 25.1302 Installed Systems and Equipment for Use by the Flight Crew) have been published by EASA and the FAA.
Flightcrew Situation Awareness SA-8	The FAA should ensure that operators and flightcrews are educated about hazardous states of awareness and the need for countermeasures to maintain vigilance. The FAA should encourage operators to: • Develop operational procedures and strategies to foster attention management skills with the objective of avoiding hazardous states of awareness; and • Develop techniques to apply during training to identify and minimize hazardous states of awareness.	*Updated in Recommendation 13 - Pilot Training and Qualification.*

Flightcrew Situation Awareness SA-9	The FAA should sponsor research, or assure that research is accomplished, to develop improved methods for: • Evaluating designs for susceptibility to hazardous states of awareness (e.g., underload, complacency, absorption); and • Training to minimize hazardous states of awareness.	Some research has been completed by both FAA and NASA.
Communication and Coordination Comm/Coord-1	The FAA should identify existing air traffic procedures that are incompatible with highly automated airplanes. These incompatible procedures should be discontinued or modified as soon as feasible.	ATPAC attempts to do this but is not completely successful. *Updated in Recommendation 10 - Pilot-Air Traffic Communication and Coordination and Recommendation 11 - Airspace Procedure Design.*
Communication and Coordination Comm/Coord-2	The FAA should task an existing advisory group or, if necessary, establish a new forum to ensure coordination between the design of air traffic procedures and the design and operation of highly automated airplanes.	Communications, Navigation and Surveillance Task Force does this somewhat but not in a general sense. The FAA's process for RNAV procedure development covers this to some degree. *Updated in Recommendation 10 - Pilot-Air Traffic Communication and Coordination and Recommendation 11 - Airspace Procedure Design.*

Communication and Coordination Comm/Coord-3	The FAA should lead an industry-wide effort to share safety information obtained from in-service data and from difficulties encountered in training. This effort should be capable of assisting in the identification and resolution of problems attributed to flightcrew error.	The FOQA and ASAP work is addressing this but needs to be taken further. Infoshare is intended to address this. *This has been updated in Recommendation 18 – Methods and Recommended Practices for Data Collection, Analysis, and Event Investigation that Address Human Performance and Underlying Factors.*
Communication and Coordination Comm/Coord-4	The FAA should require operators to have an appropriate process, with demonstrated effectiveness, for informing flightcrews about relevant accidents, incidents, in-service problems, and problems encountered in training that could affect flight safety.	FAA is moving towards a systems safety approach that will increasingly address the underlying issue. Some operators have more effective implementation than others. *This has been updated in Recommendation 18 – Methods and Recommended Practices for Data Collection, Analysis, and Event Investigation that Address Human Performance and Underlying Factors.*
Communication and Coordination Comm/Coord-5	The FAA should encourage the redesign and modernization of the information provided to the flightcrew in notices to airmen (NOTAMs), charts, approach plates, instrument procedures, meteorological data, etc. The information should be prioritized and highlighted in terms of urgency and importance, and presented in a clear, well organized, easy-to-understand format suitable for use with current and future airplanes.	SAE G10 has a subgroup addressing a portion of this topic. *This has been updated in Recommendation 3 – Information Automation.*
Communication and Coordination Comm/Coord-6	The FAA should improve and increase interaction between the Flight Standards and Aircraft Certification Services.	AVS integration office has been established.

Communication and Coordination Comm/Coord-7	The FAA and industry should improve the coordination and distribution of tasks undertaken by federal advisory committees and industry technical committees to reduce overlap and avoid duplication of effort.	RTCA Task Force on Certification made a similar recommendation; the Certification Select Committee recognized the recommendation but did not acted on it
Communication and Coordination Comm/Coord-8	The FAA should improve communication about research programs, research results, and advances in technology to appropriate FAA personnel.	The AVS research process addresses this recommendation.
Communication and Coordination-9	The FAA should hold research funding sponsors and researchers accountable for supporting the transfer of research results.	The AVS research process addresses this recommendation.
Communication and Coordination Comm/Coord-10	The FAA should assure strategic leadership and support establishment of a coordinated research portfolio in aviation human factors on the national and international levels.	There is some coordination between the FAA, NASA and Department of Defense.
Processes for Design, Regulatory, and Training Activities Processes-1	The FAA should task an aviation industry-working group to produce a set of guiding principles for designers to use as a recommended practice in designing and integrating human-centered flight deck automation.	SAE G10 developed a recommended practice document (ARP) for the flight deck design process. Regulation and advisory materials (CS/14 CFR 25.1302 Installed Systems and Equipment for Use by the Flight Crew) have been published by EASA and the FAA.

Processes for Design, Regulatory, and Training Activities Processes-2	The FAA should establish regulatory and associated advisory material to require the use of a flight deck certification review process that addresses human performance considerations.	Regulation and advisory materials (CS/14 CFR 25.1302 Installed Systems and Equipment for Use by the Flight Crew) have been published by EASA and the FAA. *Updated in Recommendation 6 - Flight Deck System Design and Recommendation 12 – Flight Deck Design Process and Resources.*
Processes for Design, Regulatory, and Training Activities Processes-3	The FAA and the aviation industry should investigate the use of innovative training tools and methods to expand pertinent safety related knowledge of flightcrews on a continuing basis. The FAA and the aviation industry should explore incentives to encourage continued training and education beyond the minimum required by the current regulations.	The implementation of InfoShare has provided a forum for sharing safety information across operators. This information can be provided to pilots through each operator's processes. *This has been updated in Recommendation 18 – Methods and Recommended Practices for Data Collection, Analysis, and Event Investigation that Address Human Performance and Underlying Factors.*
Criteria, Regulatory Standards, Methods and Tools for Design and Certification Criteria-1	The FAA should require evaluation of flight deck designs for susceptibility to design-induced flightcrew errors and the consequences of those errors as part of the type certification process.	14 CFR 25.1302 Installed Systems and Equipment for Use by Flightcrews and associated AC 25.1302 have been published. *Updated as part of Recommendation 15 - Regulatory Process and Guidance for Aircraft Certification and Operational Approvals.*

Criteria, Regulatory Standards, Methods and Tools for Design and Certification Criteria -2	The FAA should prepare and distribute interim guidance material that updates current autopilot certification policy.	Completed.
Criteria, Regulatory Standards, Methods and Tools for Design and Certification Criteria-3	The FAA should task an appropriate Aviation Rulemaking Advisory Committee Harmonization Working Group (HWG) with updating the autopilot regulatory standards (14 CFR 25.1329). This HWG should include specialists knowledgeable in human factors methods and skills from both industry and the regulatory authorities.	Completed.
Criteria, Regulatory Standards, Methods and Tools for Design and Certification Criteria-4	The FAA should revise/update the following specific FARs and associated advisory material: § 25.1322 Warning, caution, and advisory lights: Revise to reflect the current and anticipated design practice for modern transport category airplanes. § 25.1335 Flight Director: Revise to reflect the current and anticipated design practice for modern transport category airplanes. § 121.703 Mechanical reliability reports: Revise the requirements to also include reporting of significant flight deck automation failures and/or anomalies that adversely affect safe flight path management. Reinforce the Aviation Rulemaking Advisory Committee (ARAC) activity in this area.	14 CFR 25.1322 and associated AC have been completed. § 25.1335 was included into the update to 25.1329.

Knowledge and Skills of Designers, Pilots, Operators, Regulators, and Researchers Knowledge-1	The FAA should encourage flight deck design organizations to: (1) Make human factors engineering a core discipline of the flight deck system design activity; and (2) Ensure that the design team has sufficient human factors and operational knowledge and expertise by: • Distributing guiding principles for flightcrew-centered design (as described in Recommendation Processes-1) to all design team members; • Including human factors expertise as part of the design team; • Assuring that each relevant member of the team has at least a basic knowledge of human factors in order to understand and communicate human performance issues and human-centered design considerations; and • Assuring that flight deck design team members have relevant operational knowledge.	Regulation and advisory materials (CS/14 CFR 25.1302 Installed Systems and Equipment for Use by the Flight Crew) have been published by EASA and the FAA. *Updated in Recommendation 6 - Flight Deck System Design and Recommendation 12 – Flight Deck Design Process and Resources.*

Knowledge and Skills of Designers, Pilots, Operators, Regulators, and Researchers Knowledge-2	The FAA should reassess the requirements that determine the content, length, and type of initial and recurrent flightcrew training. Ensure that the content appropriately includes: • Management and use of automation, including mental models of the automation, and moving between levels of automation; • Flightcrew situation awareness, including mode and automation awareness; • Basic airmanship; • Crew Resource Management; • Decision making, including unanticipated event training; • Examples of specific difficulties encountered either in service or in training; and • Workload management (task management). The FAA should work with industry to develop guiding principles and associated advisory material for training, operational procedures, and flightcrew qualification for the areas listed above.	The rewrite of Part 121 Subparts N and O is underway. Various advisory circulars have been updated on several of these topics. *Updated in Recommendation 13 - Pilot Training and Qualification.*
Knowledge and Skills of Designers, Pilots, Operators, Regulators, and Researchers Knowledge-3	The FAA should strongly encourage or provide incentives to make advanced maneuvers training an integral part of the training curriculum, especially in recurrent training.	Several activities have been done in this area, including AC 120-109 Stall and Stick Pusher Training. *Updated in Recommendation 13 - Pilot Training and Qualification.*

Knowledge and Skills of Designers, Pilots, Operators, Regulators, and Researchers Knowledge-4	The FAA should reassess recency requirements for flightcrews involved in long haul operations. Consider providing incentives and alternative methods for flightcrews to practice takeoffs and landings, and perhaps arrival and departure procedures that are infrequently used.	Various activities have addressed this. *Updated in Recommendation 13 - Pilot Training and Qualification.*
Knowledge and Skills of Designers, Pilots, Operators, Regulators, and Researchers Knowledge-5	The FAA should reassess the airman certification criteria to ensure that pilots are released with a satisfactory level of skills for managing and using automation. Since current training is often oriented toward preparing pilots for checkrides, the airman certification criteria should be reassessed to ensure appropriate coverage of the topics listed in Recommendation Knowledge-2.	AC for CRM has some related material about this subject. *Updated in Recommendation 13 - Pilot Training and Qualification.*
Knowledge and Skills of Designers, Pilots, Operators, Regulators, and Researchers Knowledge-6	Operators should ensure that flight safety and training managers are appropriately educated about human factors considerations, particularly with regard to automation.	Unknown.
Knowledge and Skills of Designers, Pilots, Operators, Regulators, and Researchers Knowledge-7	The FAA should improve the education of Air Traffic Service personnel about the capabilities and limitations of highly automated airplanes.	This is done on an ad hoc basis. *Updated in Recommendation 10 - Pilot-Air Traffic Communication and Coordination and Recommendation 11 - Airspace Procedure Design.*

Knowledge and Skills of Designers, Pilots, Operators, Regulators, and Researchers Knowledge-8	The FAA should provide appropriate regulatory personnel with a guide or roadmap to current Federal Aviation Regulations, advisory material, policy memoranda, and other guidance material dealing with human performance related to the flightcrew-vehicle interface. The FAA should ensure that this material is used in aircraft certification projects, airline qualification program assessments, and airman qualification.	HF Certification Job Aid is being distributed. Training in various internal workshops has been provided.
Knowledge and Skills of Designers, Pilots, Operators, Regulators, and Researchers Knowledge-9	The FAA should develop a systematic training program for appropriate Aircraft Certification and Flight Standards Services personnel to provide initial and recurrent training in the area of human factors as it relates to certifying new products and evaluating flightcrew performance. The training should include instruction on: • Insight into the relationship among the flightcrew, the flight deck design, and the operational environment; • Flightcrew information processing; • Workload, human error, and situation awareness; • Other flightcrew performance issues, including fatigue, CRM, and attention management; • Design and evaluation of flight deck displays; • Aircraft control laws and feedback systems; • Human-automation interaction; • Human-centered design principles and guidelines; and • Ergonomics - fitting the design to the user.	Several training workshops and an Interactive Video Training program on evaluating displays have been completed. Other tools include the HF Certification Job Aid and General Guidance document developed for AIR personnel. AFS is not yet involved.

Knowledge and Skills of Designers, Pilots, Operators, Regulators, and Researchers Knowledge-10	The FAA should appropriately staff the standards organizations and aircraft certification offices with human factors expertise and integrate personnel with such expertise into certification teams, participating and applying their expertise in the same manner as other certification team members (e.g. airframe, flight test, systems and equipment, propulsion).	AIR has hired several HF specialists, although there has been difficulty in backfilling positions when attrition occurs. AVS has one Chief Scientific and Technical Advisor for Flight Deck Human Factors and one CSTA for maintenance HF.
Knowledge and Skills of Designers, Pilots, Operators, Regulators, and Researchers Knowledge-11	The FAA should increase Aircraft Certification and Flight Standards Services personnel's knowledge about each other's roles and responsibilities. In particular, increase certification pilots' and engineers' knowledge of line operations considerations, and Aircraft Evaluation Group personnel's knowledge about airworthiness certification considerations.	This will require education about the relationship between the airworthiness and operating rules, among other topics.
Knowledge and Skills of Designers, Pilots, Operators, Regulators, and Researchers Knowldege-12	The FAA should improve the knowledge of personnel in Aircraft Certification and Flight Standards Services about processes for identifying and communicating requirements for research (either specific studies required or identification of areas of concern).	The AVR R&D requirements process document has been updated,
Knowledge and Skills of Designers, Pilots, Operators, Regulators, and Researchers Knowlege-13	The FAA should encourage researchers to learn more about industry and FAA's research needs and about operational considerations in aviation.	Ad hoc basis.

Cultural and Language Differences Culture-1	The FAA should ensure that research is conducted to characterize cultural effects and provide better methods to adapt design, training, publications, and operational procedures to different cultures. The results of the research should also be used to identify significant vulnerabilities, if any, in existing flight deck designs, training, or operations, and how those vulnerabilities should be addressed.	NASA is doing some work in this area under their Aviation Safety Program
Cultural and Language Differences Culture-2	The FAA should encourage simplified flight deck messages, training, manuals, and procedures with clearer meaning to non-native English speakers. The FAA should encourage the use of internationally understood visual symbols and pictures where appropriate, rather than verbal descriptions or directions.	Regulation and advisory materials (CS/14 CFR 25.1302 Installed Systems and Equipment for Use by the Flight Crew) have been published by EASA and the FAA. *Updated in Recommendation 6 - Flight Deck System Design and Recommendation 12 – Flight Deck Design Process and Resources.*
Cultural and Language Differences Culture-3	The FAA should provide leadership to update ICAO phraseology standards and to encourage their use.	Example: TIPH vs line up and wait. This is an ongoing need. *Updated in Recommendation 10 - Pilot-Air Traffic Communication and Coordination.*

Cultural and Language Differences Culture-4	The FAA should promote timely and clear communications between flightcrews and Air Traffic Services through: • Accelerated efforts for transmission of information via datalink, as appropriate (e.g., Automatic Terminal Information Service (ATIS), weather, pre-departure clearances (PDC)); • Assuring clear and intelligible transmission of ATIS and clearance information where datalink is unavailable or unsuitable; and • Standard procedures and taxi routes	Data link communication is being pursued. Standard procedures and taxi routes are being done in some locations.

Measurement of and Incentives for Safety

Recommendation Measures-1: The FAA should:

- Lead the aviation community to use accident precursors increasingly and consistently as an additional measure of aviation safety;
- Work with industry to establish systems/processes for collecting precursor data and for tracking the influence of system changes (e.g., design changes, training changes) on safety; and
- Work with industry to investigate other means of assessing or communicating safety (e.g., ways of measuring errors intercepted, incidents or accidents prevented).

Recommendation Measures-2: In accident/incident investigations where human error is considered a potential factor, the FAA and the National Transportation Safety Board should thoroughly investigate the factors that contributed to the error, including design, training, operational procedures, the airspace system, or other factors. The FAA should encourage other organizations (both domestic and foreign) conducting accident/incident investigations to do the same. This recommendation should apply to all accident/incident investigations involving human error, regardless of whether the error is associated with a pilot, mechanic, air traffic controller, dispatcher, or other participant in the aviation system.

Recommendation Measures-3: The FAA should explore means to create additional incentives to improve safety through appropriate design, training, or operational improvements.

Management of Automation

Recommendation AutomationMgt-1: The FAA should ensure that a uniform set of information regarding the manufacturers' and operators' automation philosophies is explicitly conveyed to flightcrews.

Recommendation AutomationMgt-2: The FAA should require operators' manuals and initial/recurrent qualification programs to provide clear and concise guidance on:

- Examples of circumstances in which the autopilot should be engaged, disengaged, or used in a mode with greater or lesser authority;
- 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).

Recommendation AutomationMgt-3: The FAA should initiate a review of the autopilots on all transport category airplanes to identify the potential for producing hazardous energy states, excessive pitch or bank angles, subtle departures from the intended flight path, slow-overs, hard-overs, or other undesirable maneuvers. Results of this review should be the basis for initiating appropriate actions, such as design improvements, flight manual revisions, additional operating limitations, or changes in training programs or operational procedures.

Recommendation AutomationMgt-4: The FAA should assure that analyses are conducted to better understand why flightcrews deviate from procedures, especially when the procedural deviation contributes to causing or preventing an accident or incident.

Recommendation AutomationMgt-5: The FAA should request industry to take the lead in developing design guidelines for the next generation of flight management systems.

Flightcrew Situation Awareness

Recommendation SA-1: The FAA should require operators to increase flightcrews' understanding of and sensitivity to maintaining situation awareness, particularly:

- Mode and airplane energy awareness issues associated with autoflight systems (i.e., autopilot, autothrottle, flight management system, and fly-by-wire flight control systems);
- Position awareness with respect to the intended flight path and proximity to terrain, obstacles, or traffic; and
- Potential causes, flightcrew detection, and recovery from hazardous pitch or bank angle upsets while under autopilot control (e.g., wake vortex, subtle autopilot failures, engine failure in cruise, atmospheric turbulence).

Recommendation SA-2: The FAA should require operators' initial and recurrent training programs as well as appropriate operating manuals to:

- Explicitly address autoflight mode and airplane energy awareness hazards;
- Provide information on the characteristics and principles of the autoflight system's design that have operational safety consequences; and
- Provide training to proficiency of the flight management system capabilities to be used in operations.

Recommendation SA-3: The FAA should encourage the aviation industry to develop and implement new concepts to provide better terrain awareness.

Recommendation SA-4: The FAA and the aviation industry should develop and implement a plan to transition to standardized instrument approaches using lateral navigation (LNAV) and vertical navigation (VNAV) path guidance for three-dimensional approaches. The use of approaches that lack vertical path guidance should be minimized and eventually eliminated.

Recommendation SA-5: The FAA should encourage the exploration, development, and testing of new ideas and approaches for providing effective feedback to the flightcrew to support error detection and improved situation awareness.

Recommendation SA-6: The FAA should encourage standardization, as appropriate, of automation interface features, such as:

- The location, shape, and direction of movement for takeoff/go-around and autothrottle quick disconnect switches;
- Autoflight system mode selectors and selector panel layout,
- Autoflight system modes, display symbology, and nomenclature; and
- Flight management system interfaces, data entry conventions, and nomenclature.

Recommendation SA-7: The FAA and the aviation industry should update or develop new standards and evaluation criteria for information presented to the flightcrew by flight deck displays and aural advisories (e.g., primary flight displays, navigation/communication displays, synoptics showing system states).

Recommendation SA-8: The FAA should ensure that flightcrews are educated about hazardous states of awareness and the need for countermeasures to maintain vigilance. The FAA should encourage operators to:

- Develop operational procedures and strategies to foster attention management skills with the objective of avoiding hazardous states of awareness; and
- Develop techniques to apply during training to identify and minimize hazardous states of awareness.

Recommendation SA-9: The FAA should sponsor research, or assure that research is accomplished, to develop improved methods for:

- Evaluating designs for susceptibility to hazardous states of awareness (e.g., underload, complacency, absorption); and
- Training to minimize hazardous states of awareness.

Communication and Coordination

Recommendation Comm/Coord-1: The FAA should identify existing air traffic procedures that are incompatible with highly automated airplanes. These incompatible procedures should be discontinued or modified as soon as feasible.

Recommendation Comm/ Coord-2: The FAA should task an existing advisory group or, if necessary, establish a new forum to ensure coordination between the design of air traffic procedures and the design and operation of highly automated airplanes.

Recommendation Comm/ Coord-3: The FAA should lead an industry-wide effort to share safety information obtained from in-service data and from difficulties encountered in training. This effort should be capable of assisting in the identification and resolution of problems attributed to flightcrew error.

Recommendation Comm/ Coord-4: The FAA should require operators to have an appropriate process, with demonstrated effectiveness, for informing flightcrews about relevant accidents, incidents, in-service problems, and problems encountered in training that could affect flight safety.

Recommendation Comm/ Coord-5: The FAA should encourage the redesign and modernization of the information provided to the flightcrew in notices to airmen (NOTAMs), charts, approach plates, instrument procedures, meteorological data, etc. The information should be prioritized and highlighted in terms of urgency and importance, and presented in a clear, well-organized, easy-to-understand format suitable for use with current and future airplanes.

Recommendation Comm/ Coord-6: The FAA should improve and increase interaction between the Flight Standards and Aircraft Certification Services.

Recommendation Comm/ Coord-7: The FAA and industry should improve the coordination and distribution of tasks undertaken by federal advisory committees and industry technical committees to reduce overlap and avoid duplication of effort.

Recommendation Comm/ Coord-8: The FAA should improve communication about research programs, research results, and advances in technology to appropriate FAA personnel.

Recommendation Comm/ Coord-9: The FAA should hold research funding sponsors and researchers accountable for supporting the transfer of research results.

Recommendation Comm/ Coord-10: The FAA should assure strategic leadership and support establishment of a coordinated research portfolio in aviation human factors on the national and international levels.

Processes for Design, Regulatory, and Training Activities

Recommendation Processes-1: The FAA should task an aviation industry working group to produce a set of guiding principles for designers to use as a recommended practice in designing and integrating human-centered flight deck automation.

Recommendation Processes-2: The FAA should establish regulatory and associated advisory material to require the use of a flight deck certification review process that addresses human performance considerations.

Recommendation Processes-3: The FAA and the aviation industry should investigate the use of innovative training tools and methods to expand pertinent safety related knowledge of flightcrews on a continuing basis. The FAA and the aviation industry should explore incentives to encourage continued training and education beyond the minimum required by the current regulations.

Criteria, Regulatory Standards, Methods and Tools for Design and Certification

Recommendation Criteria-1: The FAA should require evaluation of flight deck designs for susceptibility to design-induced flightcrew errors and the consequences of those errors as part of the type certification process.

Recommendation Criteria-2: The FAA should prepare and distribute interim guidance material that updates current autopilot certification policy.

Recommendation Criteria-3: The FAA should task an appropriate Aviation Rulemaking Advisory Committee Harmonization Working Group (HWG) with updating the autopilot regulatory standards (14 CFR 25.1329). This HWG should include specialists knowledgeable in human factors methods and skills from both industry and the regulatory authorities.

Recommendation Criteria-4: The FAA should revise/update the following specific FARs and associated advisory material:

- § 25.1322 Warning, caution, and advisory lights: Revise to reflect the current and anticipated design practice for modern transport category airplanes.
- § 25.1335 Flight Director: Revise to reflect the current and anticipated design practice for modern transport category airplanes.
- § 121.703 Mechanical reliability reports: Revise the requirements to also include reporting of significant flight deck automation failures and/or anomalies that adversely affect safe flight path management. Reinforce the Aviation Rulemaking Advisory Committee (ARAC) activity in this area.

Knowledge and Skills of Designers, Pilots, Operators, Regulators and Researchers

Recommendation Knowledge-1: The FAA should encourage flight deck design organizations to:

(1) Make human factors engineering a core discipline of the flight deck system design activity; and

(2) Ensure that the design team has sufficient human factors and operational knowledge and expertise by:

- Distributing guiding principles for flightcrew-centered design (as described in Recommendation Processes-1) to all design team members;
- Including human factors expertise as part of the design team;
- Assuring that each member of the team has at least a basic knowledge of human factors in order to understand and communicate human performance issues and human-centered design considerations at some appropriate level; and
- Assuring that flight deck design team members have relevant operational knowledge.

Recommendation Knowledge-2: The FAA should reassess the requirements that determine the content, length, and type of initial and recurrent flightcrew training. Ensure that the content appropriately includes:

- Management and use of automation, including mental models of the automation and moving between levels of automation;
- Flightcrew situation awareness, including mode and automation awareness;
- Basic airmanship;
- Crew Resource Management;
- Decision making, including unanticipated event training;
- Examples of specific difficulties encountered either in service or in training; and
- Workload management (task management).

The FAA should work with industry to develop guiding principles and associated advisory material for training, operational procedures, and flightcrew qualification for the areas listed above.

Recommendation Knowledge-3: The FAA should strongly encourage or provide incentives to make advanced maneuvers training an integral part of the training curriculum, especially in recurrent training.

Recommendation Knowledge-4: The FAA should reassess recency requirements for flightcrews involved in long haul operations. Consider providing incentives and alternative methods for flightcrews to practice takeoffs and landings, and perhaps arrival and departure procedures that are infrequently used.

Recommendation Knowledge-5: The FAA should reassess the airman certification criteria to ensure that pilots are released with a satisfactory level of skills for managing and using automation. Since current training is often oriented toward preparing pilots for checkrides, the airman certification criteria should be reassessed to ensure appropriate coverage of the topics listed in Recommendation Knowledge-2.

Recommendation Knowledge-6: Operators should ensure that flight safety and training managers are appropriately educated about human factors considerations, particularly with regard to automation.

Recommendation Knowledge-7: The FAA should improve the education of Air Traffic Service personnel about the capabilities and limitations of highly automated airplanes.

Recommendation Knowledge-8: The FAA should provide appropriate regulatory personnel with a guide or roadmap to current Federal Aviation Regulations, advisory material, policy memoranda, and other guidance material dealing with human performance related to the flightcrew-system interface. The FAA should ensure that this material is used in aircraft certification projects, airline qualification program assessments, and airman qualification.

Recommendation Knowledge-9: The FAA should develop a systematic training program for appropriate Aircraft Certification and Flight Standards Services personnel to provide initial and recurrent training in the area of human factors as it relates to certifying new products and evaluating flightcrew performance. The training should include instruction on:

- Insight into the relationship among the flightcrew, the flight deck design, and the operation environment;
- Flightcrew information processing;
- Workload, human error, and situation awareness;
- Other flightcrew performance issues, including fatigue, CRM, and attention management;
- Design and evaluation of flight deck displays;
- Aircraft control laws and feedback systems;
- Human-automation interaction;
- Human-centered design principles and guidelines; and

- Ergonomics -- fitting the design to the user.

Recommendation Knowledge-10: The FAA should appropriately staff the standards organizations and aircraft certification offices with human factors expertise and integrate personnel with such expertise into certification teams, participating and applying their expertise in the same manner as other certification team members (e.g., airframe, flight test, systems and equipment, propulsion).

Recommendation Knowledge-11: The FAA should increase Aircraft Certification and Flight Standards Services personnel's knowledge about each other's roles and responsibilities. In particular, increase certification pilots' and engineers' knowledge of line operations considerations, and Aircraft Evaluation Group personnel's knowledge about airworthiness certification considerations.

Recommendation Knowledge-12: The FAA should improve the knowledge of personnel in Aircraft Certification and Flight Standards Services about processes for identifying and communicating requirements for research (either specific studies required or identification of areas of concern).

Recommendation Knowledge-13: The FAA should encourage researchers to learn more about industry and FAA's research needs and about operational considerations in aviation.

Cultural and Language Differences

Recommendation Culture-1: The FAA should ensure that research is conducted to characterize cultural effects and provide better methods to adapt design, training, publications, and operational procedures to different cultures. The results of the research should also be used to identify significant vulnerabilities, if any, in existing flight deck designs, training, or operations, and how those vulnerabilities should be addressed.

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