International Civil Aviation Organization

PERSONNEL TRAINING AND LICENSING PANEL

Automation Study Report

November 3, 2023

PAGE LEFT INTENTIONALLY BLANK

Table of Contents

Table of Figures

1 Executive Summary

The Air Navigation Commission (ANC) of the International Civil Aviation Organization (ICAO) tasked the Personnel Training and Licensing Panel (PTLP) to address concerns about automation and its use in flight operations, as well as the importance of developing and maintaining manual flight (MF) and monitoring skills. The PTLP formed the Automation Working Group (also known as WG1) and assigned it Job Card PTLP.005.01 titled Automation Dependency. The scope of the tasking applied to commercial air transport operations under Annex 6 to the Convention on International Civil Aviation, *Operation of Aircraft* Part I – International Commercial Air Transport - Aeroplanes and included pilots in fixed-wing aircraft in air carrier and charter/air taxi operations. It did not include pilots of rotorcraft or remotely piloted aircraft systems.

This job card provided tasking to conduct a study to address the following topics:

(1) Determine the scope of automation dependency issues.
(2) Identify operational procedures and associated policies and practices from a sampling of operators worldwide.
(3) Identify assumptions from aircraft manufacturers.
(4) Identify available guidance for how manual flying is conducted.
    a. Within operator policy
    b. Within regulatory material
(5) Identify how or if automated systems and manual flying are being incorporated into basic licensing, initial and recurrent training and testing.
(6) Identify related research and findings.

To accomplish the tasking, the WG1 organized four subgroups with topics assigned as follows:

- WG1 Subgroup 1 Automation Dependency (Topics 1 and 6)
- WG1 Subgroup 2 Operator Policy (Topics 2 and 4a)
- WG1 Subgroup 3 Manufacturers' Assumptions (Topic 3)
- WG1 Subgroup 4 Regulatory Review (Topics 4b and 5)

The four subgroups collected data from the following sources:

- Seventy-seven transport aeroplane accident reports, worldwide
- Three hundred nine major incident reports, worldwide
- Over 200 research articles and other references
- Forty excerpts from operator policies
- Three manufacturers' responses to survey questions
- Eight State regulators' materials related to pilot licensing and training
- State survey results

For the purposes of this study report, a finding is defined as a conclusion based on the results of analyses of one or more data sources. Seventeen findings were made:

Finding 1: Based on the data and accidents/major incidents analyses, automation dependency continues to be a safety issue worldwide. Contributors to automation dependency can include operator policies, regulatory policies, and lack of confidence in pilot manual flight skills.

Finding 2: Additional automation-related vulnerabilities were identified. These include mode awareness/confusion, data entry errors and other Flight Management System (FMS)-related issues, and unexpected automation behaviour (automation surprises). In addition, lessons were learned that may be useful for other domains.

Finding 3: Automation dependency was under-reported in accidents and major incidents. While dependency is acknowledged within the field, it was not always fully identified in accident and major incident investigation reports as a contributing factor when indicators of dependency were present. This makes it challenging to accurately track the frequency and any trends.

Finding 4: Manual flight errors continue to be cited in accidents and major incidents, and sometimes co-occurred with dependence on automated systems.

Finding 5: Some operators, manufacturers, and regulators approached Automation Management and Manual Flight as separate and distinct tasks or skills, while others approached them more as elements of a continuum.

Finding 6: Monitoring was often addressed in the context of tasks and responsibilities of the Pilot Monitoring (PM), but sometimes was described in relation to the monitoring of automation, monitoring of the flight path, or monitoring of the other pilot.

Finding 7: When monitoring has identified a situation where intervention is appropriate, information on how and when for a pilot to intervene, with automation or another pilot, was addressed in some operator policies and States' regulatory material but not all.

Finding 8: Many of the operator policies identified how and when to conduct automated or manual flight, but did not define the terms in detail or describe them in the context of overall flight path management. Some operator policies provided conflicting guidance on the use of automated versus manual flight, and many did not address pilot monitoring.

Finding 9: While the Original Equipment Manufacturer (OEM) recommendations offered a strong framework, they lacked the specificity and operational context that enable operators to construct a policy reflective of their flight operations.

Finding 10: A small number of policies provided guidance, albeit brief, on the entire concept of flight path management. Such guidance usually consisted of a sentence or two on elements related to flight path management such as cross-checking, monitoring, and intervention. However, most policies only addressed flight path control, omitting guidance on the overall concept of Flight Path Management.

Finding 11: Flight crew briefings have advantages ranging from aiding in the development of a plan of action to a shared mental model. Several policies required briefings to include the intended use of automation systems. Both the content of briefings and their use are important. When reviewing operator policy language that addressed flight crew briefings, several vulnerability areas were identified.

Finding 12: Threat and Error Management (TEM) (or equivalent) principles and the description of the role of the pilot competencies and skills as countermeasures in the TEM framework varied within operator policies, when used. TEM was not always considered as a tool to mitigate operational and environmental threats.

Finding 13: Manufacturers made many assumptions about manual flight, use of automated systems, and pilot training that were integrated into equipment design, manufacturer-recommended training programs, procedures, and documentation.

Finding 14: The terms automation dependency, over-reliance, and complacency overlap, and dependency and over-reliance were used interchangeably in many documents.

Finding 15: There was a lack of standardized definitions of the terms Flight Path Management, Manual Flight Operations, Autoflight and Automated Systems.

Finding 16: The regulatory guidance materials reviewed often used high-level terminology identical or similar to that used in ICAO guidance (e.g. “upset prevention and recovery training (UPRT)”, “flight path management – automation” (FPA), “flight path management – manual flight/control”). However, additional analysis showed that the technical content of the related training was not always the same and often varied across States.

Finding 17: The phrase “levels of automation” was often used to describe a simple hierarchy in a defined and prescribed fashion. While the concept of levels is useful conceptually and for communication, it may be difficult to operationalize.

Subject to the findings of this study, the WG1 will review ICAO documents. If appropriate, the WG1 will develop recommendations to:

- Propose amendments to the licensing provisions of Annex 1 to the ANC.
- Propose amendments to Annex 6 on the qualification or training requirements for pilots on managing automated systems, MF and monitoring.
- Propose relevant guidance on management of automation systems, MF and PM to be incorporated into appropriate ICAO guidance material.
- Identify other ICAO documents that may be impacted by these findings.

2 Introduction

2.1 In ICAO Assembly – 40th Session, Working Paper (WP) A40-WP/296 identified concerns about increasing reliance on automation in commercial aviation. Although increased use of automation has enhanced safety, this trend is believed to contribute to a lack of practice in manual flight (MF) and therefore potentially to a degradation of pilot skills in flight path management during manual flight operations (MFO). In addition, an over-reliance or over-dependence on automation can introduce new hazards and risks.

2.2 When automation systems do not work as intended or do not work well in an operational situation, pilots without sufficient experience and proper training may be reluctant or may not be adequately skilled to take manual control of the aircraft. Other factors distinct from experience and training can contribute to pilot reluctance to take manual control of the aircraft, such as operator policies or regulatory guidance. WP A40-WP/296 highlighted a continuing critical need for pilots to be confident in their MF skills, especially when the operational circumstances call for it, e.g. automation confusion, equipment failure, or systems not operating as intended.

2.3 To address these concerns about automation and its use in flight operations, as well as the importance of developing and maintaining MF and monitoring skills, the Air Navigation Commission (ANC) of ICAO assigned tasking to the Personnel Training and Licensing Panel (PTLP). The PTLP formed the Automation Working Group (also known as WG1) and assigned it Job Card PTLP.005.01 titled Automation Dependency. The scope of the tasking applied to commercial air transport operations under Annex 6 Part I and included pilots in fixed-wing aircraft in air carrier and charter/air taxi operations. It did not include pilots of rotorcraft or remotely piloted aircraft systems.

2.4 This job card provided tasking to conduct a study to address the following topics from Work Programme Element (WPE) 10229:

(1) Determine the scope of automation dependency issues.
(2) Identify operational procedures and associated policies and practices from a sampling of operators worldwide.
(3) Identify assumptions from aircraft manufacturers.
(4) Identify available guidance for how manual flying is conducted.
    a. Within operator policy
    b. Within regulatory material
(5) Identify how or if automated systems and manual flying are being incorporated into basic licensing, initial and recurrent training, and testing.
(6) Identify related research and findings.

2.5 To accomplish the tasking, the WG1 organized four subgroups with topics assigned as follows:

- WG1 Subgroup 1 Automation Dependency (Topics 1 and 6)
- WG1 Subgroup 2 Operator Policy (Topics 2 and 4a))
- WG1 Subgroup 3 Manufacturers' Assumptions (Topic 3)
- WG1 Subgroup 4 Regulatory Review (Topics 4b and 5)

2.6 The remainder of this Study Report describes the working methods and findings of the WG1 and its subgroups.

3 Working Methods and Data Sources

This section describes the working methods and data sources used to produce this study report.

ICAO conducted a survey of the States on automation dependency issues. See Appendix A for a more extensive description of the survey questions and responses received.

Sixty-eight State survey responses were received. Of the 68 responses, 31 (42%) responded affirmatively to the question "Please select any evidence/data analyses and/or reports your State has that can be shared related to pilot over-reliance/dependency on automated systems?" Upon request of additional documentation, supplemental materials were received from two Civil Aviation Authorities (CAA).

In addition to the State survey data, each of the four subgroups collected additional data pertinent to the tasking. The approach to collecting and analysing the data for each subject area is summarized below.

3.1 Subgroup 1: Automation Dependency

Figure 1 shows the process used by the Automation Dependency subgroup.

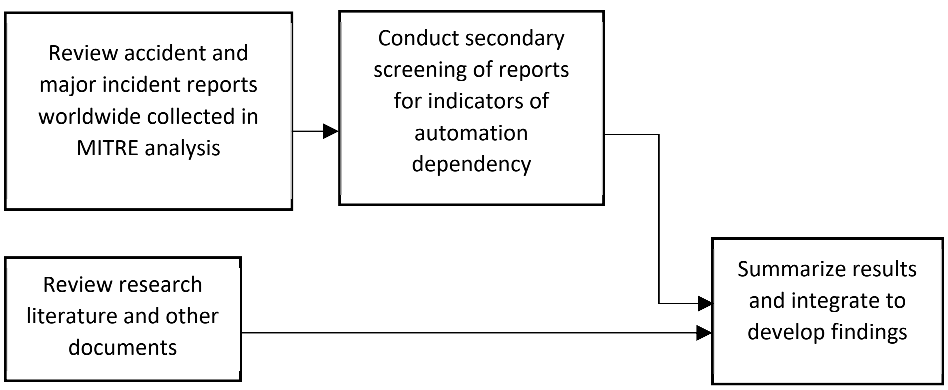


Figure 1. Automation Dependency process

3.1.1 Review of Accident and Major Incident Reports

Reports from a list of accidents[1] and major incidents[2] provided by MITRE[3] were systematically reviewed. These reports did not state automation dependency as a contributing factor and were previously determined not to demonstrate indicators of automation dependency.[4] The purpose of the review was to provide a secondary screening for indicators of automation dependency. The list of accidents and major incidents were global safety events limited to those for which a formal investigation board published final report was publicly available; the events occurred from 1990 to 2021.

[1] Annex 13 *Aircraft Accident and Incident Investigation*, Twelfth Edition, July 2020 defined an accident as "An occurrence associated with the operation of an aircraft which, in the case of a manned aircraft, takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, or in the case of an unmanned aircraft, takes place between the time the aircraft is ready to move with the purpose of flight until such time as it comes to rest at the end of the flight and the primary propulsion system is shut down, 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 and 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 a single engine (including its cowlings or accessories), to propellers, wing tips, antennas, probes, vanes, tires, brakes, wheels, fairings, panels, landing gear doors, windscreens, the aircraft skin (such as small dents or puncture holes), or for minor damages to main rotor blades, tail rotor blades, landing gear, and those resulting from hail or bird strike (including holes in the radome); or
c) the aircraft is missing or is completely inaccessible.
Note 1.— For statistical uniformity only, an injury resulting in death within thirty days of the date of the accident is classified, by ICAO, as a fatal injury.
Note 2.— An aircraft is considered to be missing when the official search has been terminated and the wreckage has not been located.
Note 3.— The type of unmanned aircraft system to be investigated is addressed in 5.1.
Note 4.— Guidance for the determination of aircraft damage can be found in Attachment E.".

[2] As defined in the PARC/CAST FltDAWG (FAA 2013) report, a major incident is defined as an aviation safety event that was investigated by a formal investigative agency but does not meet the definition of an accident.
[3] The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) was contracted by the FAA to conduct a study of worldwide air carrier operations accident and incident reports that were related to flight path management to search for indicators of automation dependency. The results of their analysis (MITRE Technical Report MTR230091) provided a starting point for the results documented in this Study Report.
[4] Indicator: A cue that may demonstrate that automation dependency is occurring, such as insufficient system parameter monitoring by the pilot (airspeed, altitude, ground track, fuel calculations, etc.) due to reliance on automated systems management/intervention.

A total of 386 reports were reviewed, including 77 accidents and 309 major incidents. Each case was reviewed by at least two members of the subgroup or affiliates to examine the cases for indicators of automation dependency, that is, markers or signals that automation dependency might be present. Indicators of automation dependency included, but were not limited to:

- Insufficient monitoring (e.g. of modes, hazards, or system performance);
- Inadequate response to automated system performance issues (e.g. decaying airspeed);
- Insufficient performance during various flight procedures (e.g. setting up a stabilized approach); and
- Use of systems when not appropriate (e.g. continuing to reprogram or change automated system inputs in time critical situations).

A more extensive list of indicators of automation dependency is provided in Appendix B. The accident and major incident reports found to have indicators of automation dependency are also provided in Appendix B.

3.1.2 Secondary Screening of Accidents, Major Incidents and Research Material

Of the 77 accident reports and 309 major incident reports, the subgroup reviewed the 53 accidents and 272 major incidents for secondary screening that were not initially categorized by MITRE as having indicators of automation dependency. (Twenty-four accidents and 37 major incidents were already determined to demonstrate indicators of automation dependency by MITRE in their initial review, and did not receive secondary screening.) Each report reviewed for secondary screening was assigned into one of the following three categories:

- Unrelated to automation dependency – the subgroup reviewers did **not** find indicators of automation dependency.
- Potentially related to automation dependency – the subgroup reviewers **did** find potential indicators of automation dependency that led them to request further review from MITRE. However, the published report did not provide sufficient detail to conclusively label the case as automation dependency.
- Likely related to automation dependency – the subgroup reviewers found indicators of automation dependency. There was sufficient detail to label the case as automation dependency.

This dispositioned list was submitted to MITRE for their team to conduct their own analysis of all reports classified as potentially related to or likely related to automation dependency. The analysis used the final results from the MITRE study, as documented in this Study Report.

3.1.3 Document and Literature Review

Policy, guidance, research articles, and other documents that were relevant to the topic of automation dependency were reviewed, along with having extensive discussions regarding the concept of automation dependency. Articles from an extensive annotated bibliography of over 200 cited references that focused on automation and flight operations were prioritized for review. The bibliography review process consisted of prioritizing research articles by relevance of topic, specifically aviation automation dependency and applicability to training and licensing. Through this process, 20 research articles were selected for review. In addition, more than 27 policy- and guidance-related documents were reviewed along with other relevant sources, such as professional publications. The full list of references can be found in Appendix C.

3.2 Subgroup 2: Operator Policy

The Operator Policy subgroup was tasked with identifying operational procedures and associated policies and practices related to automation, MFO and pilot monitoring (PM) from a sampling of operators worldwide. Figure 2 shows the process used by the Operator Policy subgroup.

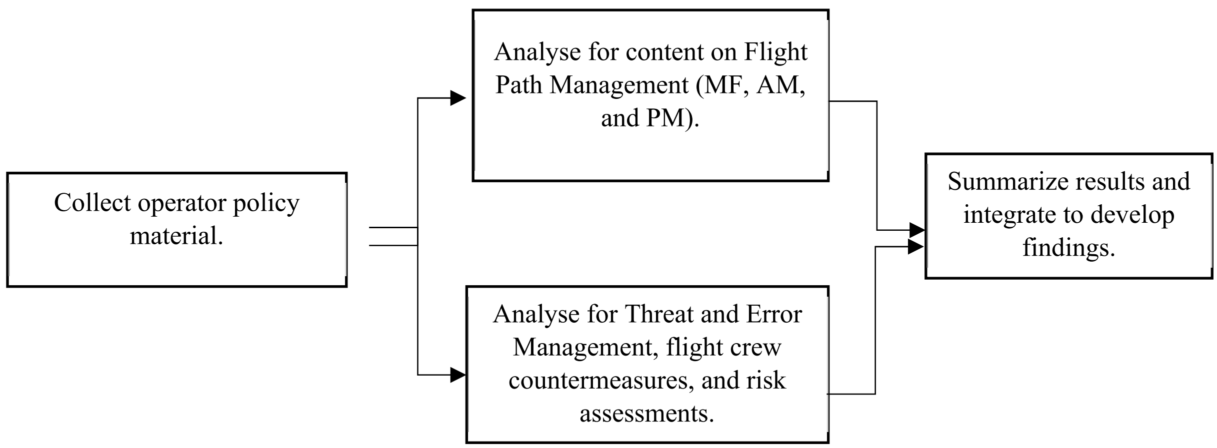


Figure 2. Operator Policy process

The subgroup collected and reviewed 40 operator policies from States affiliated with the following ICAO regional offices[5]:

Regional Office	Excerpts from Operator Policies Received
EUR/NAT = European and North Atlantic	13
APAC = Asia and Pacific	6
NACC = North American, Central American and Caribbean	9
SAM = South American	4
ESAF = Eastern and Southern African	2
MID = Middle East	5
WACAF = Western and Central African	1

Figure 3. Operator Policies and Associated Regional Offices

The Operator Policy subgroup conducted two analyses:

1. The first analysis focused on reviewing operators' policies and assessing the extent to which flight path management components (automation management (AM), MFO and manual control, and PM) are addressed in the policies.

2. The second analysis focused on reviewing operators' policies and assessing the extent to which certain human performance components (Threat and Error Management (TEM), flight crew countermeasures, risk assessments, etc.) were addressed in the policies with respect to flight path management.

The above-mentioned analyses were consolidated, and the findings designed to support the desired outcome of the WPE 10229.

3.3 Subgroup 3: Manufacturers' Assumptions

The process used by the Manufacturers' Assumptions subgroup is depicted below in Figure 4.

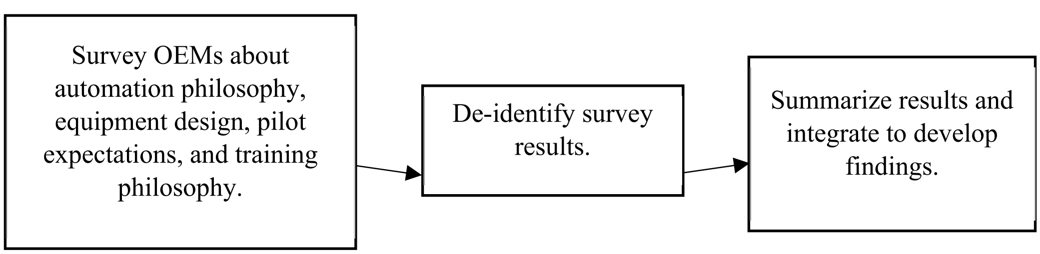


Figure 4. Manufacturers' Assumptions Process

[5] Each regional office is responsible for serving the States to which it is accredited. The list is available at https://www.icao.int/secretariat/RegionalOffice/Pages/default.aspx

The Manufacturers' Assumptions subgroup developed survey questions as described in Appendix A. The survey was provided to seven Original Equipment Manufacturers (OEMs) to inquire about several aspects of automation philosophy, equipment design, pilot expectations, and training philosophy. The survey was made available for the OEMs, all part of the International Coordinating Council of Aerospace Industries Associations (ICCAIA) from June 2022 to October 2022. Survey results were received from three manufacturers. These results were summarized, and de-identified to ensure that OEM proprietary information remains protected.

3.4 Subgroup 4: Regulatory Review

The Regulatory Review subgroup collected information on how the areas of AM, MF and PM are addressed in regulatory frameworks and associated regulators' guidance material related to all the following:

- Initial licensing training;
- Type rating training;
- Type rating – operator recurrent training;
- Regulator's guidance material on AM, MF, and PM.

The subgroup collected information from eight States and reviewed the ICAO framework as well. The following table summarizes the regulatory input sources and the ICAO regional offices from which the States are affiliated.

Regional Office	Number of regulators responded
EUR/NAT	2
APAC	3
NACC	2
SAM	1

Figure 5. Regional Offices and Regulators Responses

The survey to States did not result in additional regulatory material to analyse.

Figure 6 shows the process used, and the process is further described below.

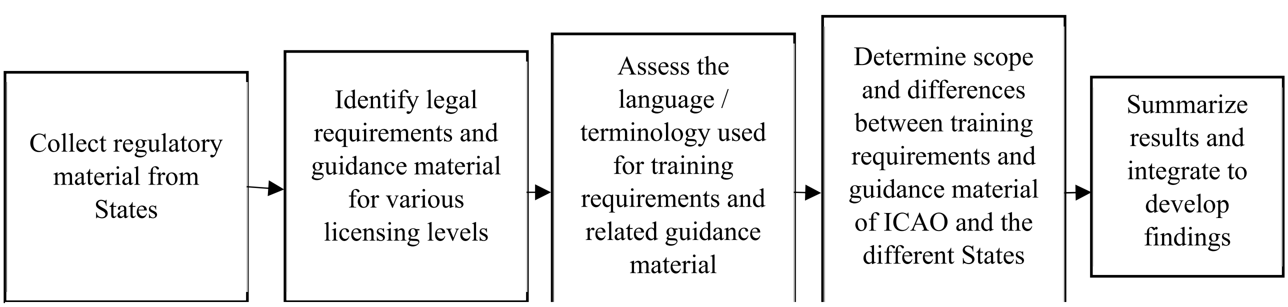


Figure 6. Regulatory Review Process

The collected material contained high-level descriptions of training requirements and regulator's guidance material as well as links to the relevant source documents (regulations, published guidance material). The subgroup reviewed these descriptions and consulted the relevant source documents, to do the following analyses:

- The first analysis within this subgroup identified the legal requirements and guidance material in the various licensing levels for that State.
- From the material identified in the first analysis, the subgroup conducted a second analysis in which the language/terminology used for training requirements and related guidance material was reviewed to make a high-level determination of their scope and focus and any differences between training requirements and guidance material of ICAO and the different States.

Appendix D contains tables of the regulatory material reviewed.

3.5 Integrating Material from the Subgroups

The data collection and analyses from the four subgroups were compiled and reviewed by WG1, and the findings below are organized by the topics in the WG1 tasking.

4 Findings

4.1 General

This section describes the findings[6] from the analyses done with the data provided to WG1. Each of the findings below includes a discussion and rationale.

Before describing the findings, some explanatory material is provided below to help with use of terminology, with general information about automation (or automated systems), MF, and monitoring (PM and flight path monitoring). This section then provides a summary of the topic areas in which the findings are grouped.

Manual flying, manual handling, manual flight, and MFO are phrases that are used in different ways to describe operation of the aircraft where the pilot is physically controlling pitch, roll, yaw, and/or thrust. Although many uses of the phrases are focused on the motor skills required to control the aircraft, there are also cognitive skills that are an important part of MFO. For the purposes of this report, the phrase "manual flight" (MF) is used and refers to both the motor skills and cognitive skills.

The distinction between MF and automated flight is not binary, though it is often referred to as though it were such. In a modern flight deck, varying systems and modes can be engaged or disengaged during normal flight. Heading hold, altitude hold, lateral navigation, vertical navigation and others are some simple examples of the control automation that can be utilized by the flight crew, depending on the systems on the aeroplane. This report will refer to manual and automated flight, while acknowledging that the terms do not fully describe the non-binary nature of the topics.

In this report, the wording "autoflight systems" refers to the autopilot (AP), the flight director (FD), and the autothrust/autothrottle (AT). "Automated System" refers to any equipment or system supporting the flight path management including the autoflight systems.

The term "automation" is applied to different systems that automate different types of functions or tasks. For example, Control Automation refers to automation of tasks related to controlling some aspect of the aeroplane flight, such as AP and AT. Information Automation refers to functions for the calculation, integration, and presentation of information, such as on flight deck displays and Electronic Flight Bags (EFB). Management Automation refers to automation of management-related functions, such as the fuel management function in the FMS.

The term "monitoring" is used to describe both the role of PM and the task of monitoring the flight path. The material below discusses both aspects of monitoring.

Summary of Topic Areas for Findings. The findings provided below are grouped into the following topic areas:

- Automation

[6] For the purposes of this study report, a finding is defined as a conclusion based on the results of analyses of one or more data sources.

- MF
- Integration of automated and MFO
- Monitoring
- Operator policies
- Manufacturers' assumptions
- Regulatory
- Terminology

4.2 Automation

Finding 1: Automation Dependency

Based on the data and accidents/major incidents analyses, automation dependency continues to be a safety issue worldwide. Contributors to automation dependency can include operator policies, regulatory policies, and lack of confidence in pilot manual flight skills.

This finding is based on accident and major incident data, operator policy analyses, regulatory review, reference documents and research review.

Multiple definitions of automation dependency, automated system over-reliance and complacency were reviewed, to enable proper analysis of different data sources. The concept of automation dependency is complex and can be challenging to define. There is overlap in the use of the terms "automation dependency", "automation over-reliance", and "complacency" but there are some differences, and the terms were sometimes used interchangeably. It should be noted that the term "reliance on automation" is not inherently negative. Appropriate reliance on automated systems is expected flight crew behaviour.

The WG1 used the phrase "automation dependency" to characterize when pilots accept what aircraft automation is doing without adequately monitoring or confirming that the aircraft is doing what they expected or wanted it to do. The remainder of this report will use the term "automation dependency" to represent these terms.

Automation dependency is not measured directly. Instead, it is inferred from indicators, contributors, and consequences that have a strong basis for demonstrating or representing its existence. Descriptions and examples of each of those terms are:

- Indicator: A cue that may demonstrate that automation dependency is occurring, such as insufficient system parameter monitoring by the pilot (airspeed, altitude, ground track, fuel calculations, etc.) due to reliance on automated systems management/intervention.
- Contributor: A factor that is potentially causal to the occurrence of automation dependency, such as an operator policy requiring use of automated systems to conduct flight path management rather than conducting MFO at available opportunities, without any countermeasure such as additional MF training.

- Consequence: An effect of automation dependency, such as flight crew apprehension to conduct MFO due to reduced perceived competence in their MF skills.

The accidents and major incidents where indicators of automation dependency were present occurred worldwide in terms of operator origin and location of the actual event. The accidents/major incidents related to automation dependency took place from 1990-2021.

The final review of the accident reports showed 28 of 77 (36%) included indicators of automation dependency. From 2010-2021, 49% of the accident cases had indicators of automation dependency. Automation dependency indicators in accidents appear to have increased since 2009, as shown in Figure 7. Accident review summary for dependence on automated systems. It is unclear whether that is a result of increased use of automation, increased emphasis by investigative boards, or a combination of these or other factors. Many of the accident and major incident reports described indicators of automation dependency but did not list it as a contributing factor. The full list of accidents and major incidents reviewed that exhibited evidence of automation dependency can be found in Appendix B.

Date Range (based on occurrence of event)	**Included Dependence on Automated Systems**	**Number of Accident Reports Reviewed**
1990 – 2009	8 (22%)	36
2010 – 2021	20 (49%)	41
Total	28 (36%)	77

Figure 7. Accident Review Summary for Dependence on Automated Systems

Additional considerations include:

- MF errors sometimes co-occurred with dependence on automated systems. Some of this may be attributed to MF skill degradation, a concern related to lack of practice, and automation dependency can contribute to that lack of practice. See Finding 4 on Manual Flight Errors for more discussion.
- Control Automation systems, such as AP and AT systems, are not the only automated systems that are susceptible to dependency. The evidence shows that flight crews may demonstrate dependency on information and management automation systems as well. Examples are provided below:
  - An example of control automation dependence: Indonesia Air Asia, A320, December 28, 2014, accident – the Pilot Flying (PF) (who was the First Officer (FO)) was unable to manually fly the aircraft after uncommanded AP and AT disconnect following failure of rudder travel limiter. While resultant rudder deflection of 2 degrees did induce a consistent roll of six degrees per second, roll could be counteracted with manual control stick input by the flight crew. The Pilot in Command did not take over control as operator Standard Operating Procedure (SOP) required. The Flight Crew Training Manual stated that the effectiveness of fly-by-wire architecture and the existence of control laws

eliminated the need for upset recovery manoeuvres to be trained on protected Airbus aircraft. Contributing Factor: Subsequent flight crew action leading to an inability to control the aircraft in the Alternate Law resulted in the aircraft departing from the normal flight envelope and entering a prolonged stall condition that was beyond the capability of the flight crew to recover.

- An example of information automation dependence: Qantas Airways, A330, March 8, 2013, major incident - During a visual approach into Melbourne Airport the PF (Captain) was dependent on the Instrument Landing System (ILS) glideslope (GS) information which inaccurately indicated that the aircraft was above GS, which was consistent with the PF expectation. The aircraft was not established on the ILS localizer. The Enhanced Ground Proximity Warning System (EGPWS) activation caused the flight crew to conduct an EGPWS recovery manoeuvre and subsequently land via an instrument approach. The PF was reliant on inaccurate GS information for flight path management without referencing other available accurate data sources.

When considering why pilots may be dependent on automated systems, several factors have been identified that affect the pilots' decisions. These include, but are not limited to:

- High reliability of the systems (fostering insufficient cross verification, not recognizing AP or AT disengagement, or not maintaining target speed, heading, or altitude).
- Guidance included in the operator policies. Several of the operator policies analysed by WG1 used language that may discourage flight crews from flying manually. In policy guidance that used a preferred hierarchy, or levels, of automated systems, several policies required the flight crew to use the highest level (most extensive use) of automation. Most operator policies did not provide guidance for the flight crews' appropriate risk assessments process on when/whether to fly manually.
- Certain regulatory guidance or policies may discourage pilots to fly manually.

Over-reliance may increase in the future by some new airspace procedures that are so complex and require such precision that flying manually is impractical or not permitted, because of the likelihood of deviation. When these complex procedures are combined with policies that encourage use of automated systems over manual operations and supervision of pilots' compliance 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 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.

Finding 2: Additional Automation-Related Vulnerabilities and Lessons Learned

Additional automation-related vulnerabilities were identified. These include mode awareness/confusion, data entry errors and other Flight Management System (FMS)-related issues, and unexpected automation behaviour (automation surprises). In addition, lessons were learned that may be useful for other domains.

This finding is based on accident and major incident data, operator policy analyses, regulatory review, reference documents and research review.

Automation dependency is an important concern, but data show that there are other automation-related vulnerabilities. Several of them are discussed below.

Mode Awareness/Confusion: A 1996 Federal Aviation Administration (FAA) report[7] 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 aeroplane types; differences in the design implementation of modes intended to meet the same objective; proliferation in the number of modes; complexity in the flight crew interface (as perceived by the flight crew); and conflicting information provided by the control panel used for selecting autoflight modes.

CAA Paper 2004/10 Flight Crew Reliance on Automation, Section 1.5.2, says “Furthermore, recent studies (Mumaw, et al, 2003) have reported that autoflight/FMS mode awareness was affected by both failures to verify mode selections and an inability to understand the implications of autoflight mode on the aircraft’s performance.”

Some changes to flight deck equipment design have been made to address this vulnerability area (e.g. only showing selected target values or modes on the Primary Flight Display (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 pilot training through increased emphasis on mode awareness and in some operators’ flight crew 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, and therefore have not implemented this procedure.

These mitigations were only partially successful. The data analysis revealed that autoflight mode selection, awareness and understanding continue to be common vulnerabilities.

FMS/Data Entry Errors. In the Performance-based Operations Aviation Rulemaking Committee (PARC)/Commercial Aviation Safety Team (CAST) Flight Deck Automation Working Group (FltDAWG) report (FAA 2013), this issue was discussed extensively, including the following material:

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. 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

[7] FAA (1996). The human factors team report on the interfaces between flightcrews and modern flight deck systems. Washington, DC: Federal Aviation Administration.

on / idle / geometric segments, headwinds/tailwinds, crossing restrictions etc.); therefore, flight crews 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.

Unexpected Automation Behaviour (Automation Surprises). Pilots have identified that they can be surprised by the behaviour of the automated systems. This may occur for several reasons, including, but not limited to, insufficient feedback from system design about what the system is doing or lack of knowledge about how the systems work. In the PARC/CAST FltDAWG (FAA 2013) report, in one case study, the operator taught the use of the flight path management systems in an innovative way. This training concentrated on developing the flight path management skills using MF 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 programme. 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 have some limitations, it does demonstrate the potential of this type of approach and need for further research and investigation in the area.

Lessons Learned about Automated Systems. Operational experience has resulted in lessons learned about the benefits and vulnerabilities of automated systems and their use. These include topics such as:

- Different types of automated systems.
- Much of the discussion of automation has been focused on control automation systems.
- Training was not necessarily decreased when an automated system was introduced.
- Use of automated systems (especially automation of control tasks) may reduce workload during much of normal operations. However, during demanding situations, use of these automated systems may add complexity and workload to the pilots' tasks.

Appendix E includes more information about lessons learned, with an emphasis on lessons that may be valuable beyond flight deck applications.

Finding 3: Reporting of Automation Dependency in Accidents and Major Incidents

Automation dependency was under-reported in accidents and major incidents. While automation dependency is acknowledged within the field, it was not always fully identified in accident and major incident investigation reports as a contributing factor when

indicators of dependency were present. This makes it challenging to accurately track the frequency and any trends.

This finding is based on accident and major incident data, reference documents, and research review.

The automation dependency subgroup along with MITRE found numerous cases of accidents and major incidents which demonstrated indicators of automation dependency; however, the associated reports did not explicitly list automation dependency or over-reliance as a factor. In addition, one authority provided material that included examples of automation dependency cases that were not publicly reported as they do not meet the criteria to initiate an investigation. Therefore, such cases would not be used in analysis of publicly available data for the presence of automation dependency.

The PARC/CAST FltDAWG report (FAA 2013), in reference to accident investigation reports, stated "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."

4.3 Manual Flight

One finding was identified about MF. As a reminder, MF includes the cognitive skills necessary to conduct MFO, in addition to the motor skills.

Finding 4: Manual Flight Errors

Manual flight errors continue to be cited in accidents and major incidents, and sometimes co-occurred with dependence on automated systems.

This finding is based on accident and major incident data, reference documents and research review.

MF errors continue to be identified in accidents and major incidents. Some of these errors may be attributed to MF skill degradation, a concern related to lack of practice, and automation dependency can contribute to that lack of practice.

From the PARC/CAST FltDAWG report (FAA 2013):

Vulnerabilities were identified in pilot knowledge and skills for MFO, including:

- Prevention, recognition and recovery from upset conditions, stalls or unusual attitudes;
- Appropriate MF after transition from automated control;
- Inadequate energy management;

- Inappropriate control inputs for the situation;
- Flight crew coordination, especially about aircraft control; and
- Definition, development, and retention of such skills.

Some MF errors seemed to coincide with dependence on automated systems. The International Air Transport Association (IATA 2020) Aircraft Handling and Manual Flying Skills Report found similar evidence and stated, “it was found that continuous use of automation does not strengthen pilots’ knowledge and skills in MFO and in fact could lead to degradation of the pilot’s ability to quickly recover the aircraft from an undesired state.”

In operator policy language, MF was encouraged almost exclusively to “maintain proficiency”. Although some policies encouraged MF, placing emphasis on maintaining proficiency may not reinforce that MF is a normal and foundational part of effective flight path management.

Several policies listed the functions (roles and responsibilities) for which the PF and PM are responsible. However, the subgroup determined that such functions may not stress the importance of the monitoring role for both the PF and PM during MF. See section 4.5 Monitoring for more discussion on role of the PM.

In reviewing the regulatory material related to MF, it was found that many States discussed MF in terms of skills related to physical actions and inputs (i.e. aeroplane handling skills). Other States addressed the cognitive aspects of MF as well, such as managing information, information processing, decision-making, managing workload or performing calculations without the aid of automation.

Many of the States’ guidance materials that were analysed by the subgroup addressed MF in terms of a set of discrete skills related to defined manoeuvres and/or flying with specific automation features off. Some States provided definitions or descriptions of the appropriate operational conditions in which to conduct MF during flight operations. Other States did not define these conditions but recommended that operators should develop their own company-specific set of conditions.

Many of the skills included under MF were assumed to derive from Basic and Advanced Upset Prevention and Recovery Training (UPRT) such as recognition and recovery from approach to stall/full stalls; incipient spins; upset recovery; spiral dives, etc.

Examples of additional areas of focus that States included under MF:

Maximum crosswind takeoff/landing, rejected takeoff, one-engine inoperative takeoff, landing, approach and go around; Failures of the FD system, MF at different speeds and control laws, flying with AP off and various combinations of AT and FD.

4.4 Integration of Automated and Manual Flight

<u>Finding 5: Automation and Manual Flight Relationship</u>

Some operators, manufacturers, and regulators approached Automation Management and Manual Flight as separate and distinct tasks or skills, while others approached them more as elements of a continuum.

This finding is based on review of operator policies, manufacturers' assumptions, and regulatory review.

In operator policies, distinctions between "Manual Flight" and "Automated Flight" were referring to control automation and were often considered to be binary - i.e. the pilot is either flying "manually" or "automated". However, the combinations of different systems (e.g. AP, AT, FD, FMS, other support systems) and resulting complexity of actual flight path management set-up suggest that there are varying degrees of "manual-" and "automated-flight" along a rather wide spectrum.

Manufacturers assumed that the flight crew shall use an appropriate level of automation and that the automation is intended to assist the pilot. However, how to determine the appropriate "level" was not clear. Finding 17 on Levels/Combinations of Automation discusses this issue of defining levels of automation in more detail.

Several regulators approached MF and AM as more of a continuum, rather than as an 'either-or' choice. These regulators' guidance recommended that pilots identify combinations of automation and MF that are best suited to the operations, environmental conditions, pilot capabilities, and workload demands they are facing as they manage the flight path of the aeroplane.

An example of regulatory guidance combining automation and MF:

"Operator guidance should focus on use of all tools for Flight Path Management, including automated systems or combination of systems, including manual flight operations, and when to use/not use, and guidance on which combinations are best suited to different operational scenarios."

4.5 Monitoring

Finding 6: Role of Pilot Monitoring and Focus of Monitoring

Monitoring was often addressed in the context of tasks and responsibilities of the Pilot Monitoring (PM), but sometimes was described in relation to the monitoring of automation, monitoring of the flight path, or monitoring of the other pilot.

This finding is based on analysis of operator policies and regulatory review.

Some operator policies explicitly addressed PM duties, some operator policies addressed flight path monitoring, and some regulatory material defined what constitutes "good monitoring" on the part of all flight crew members. Monitoring other flight crew members was included in guidance material of some States but not all.

Training on the PM role was listed by all States as part of multi-crew cooperation (MCC) training which forms part of (integrated) Airline Transport Pilot License (ATPL) training as well as type-rating training and type-rating operator recurrent training.

Two States specifically identified the function of the PM as an important element in Flight Path Management and provided detailed guidance on what constitutes 'good monitoring.'

Definitions of the role of the PM varied across the guidance materials reviewed. In some guidance the role of the PM was defined in terms of high-level goals (e.g. support the PF), while in others it was defined in terms of specific tasks (e.g. calling out discrepancies to the PF). The definition of monitoring more generally was also frequently defined in task-based terms.

Monitoring was also often defined in the form of role-based competencies that may rely on an authority gradient that assigns the ability to intervene when necessary to certain flight crew members. However, some States provided detailed definitions of what constitutes "good monitoring" on the part of all flight crew members to include intervention by any or all flight crew members as necessary.

There was also variability regarding what was to be monitored. Sometimes it was described in relation to the monitoring of automation, or in relation to monitoring of the flight path, or monitoring the other pilot. Some States' guidance described the focus of monitoring as automation or automation features, while other State guidance included a focus on monitoring of other flight crew members as well.

Finding 7: When Intervention is Appropriate

When monitoring has identified a situation where intervention is appropriate, information on how and when for a pilot to intervene, with automation or another pilot, was addressed in some operator policies and States' regulatory material but not all.

This finding is based on analysis of operator policies and regulatory review.

Intervention may refer to taking over from an automated system or may refer to some type of intervention with another pilot.

Although operator policy language cannot account for every situation that would require flight crew intervention, much of the policy language used generalized statements such as "disengaging automation when the trajectory is in doubt", which may not provide enough guidance to flight crews to effectively manage the flight path.

The topic of intervention was addressed in a few, but not all, States.

Examples of regulatory guidance regarding intervention:

- Role of PM 'includes observation of other crew members and timely intervention in the event of a deviation'

- 'Monitoring includes crewmembers monitoring each other… The PM should recognize when the PF is not adequately controlling the flightpath and recognize the signs of diminished crewmember performance… If the PF does not correct flightpath deviations in a timely manner the PM should intervene based on operator policy and procedures.'
- 'A pilot is also expected to promptly intervene and/or may need to assume manual control of the aircraft in certain situations…'

4.6 Operator Policies

Finding 8: General Operator Policy Structure and Contents

Many of the operator policies identified how and when to conduct automated or manual flight, but did not define the terms in detail or describe them in the context of overall flight path management. Some operator policies provided conflicting guidance on the use of automated versus manual flight, and many did not address pilot monitoring.

This finding is based on analysis of operator policies.

Most policies followed a similar structure, starting with the title. "Automation Policy" was used by 39 operator policies. Alternatively, one policy was titled "Flight Path Management Policy". Of those titled "Automation Policy," many still incorporated language on various flight path management components. Following this, policies tended to set general expectations concerning the use of automation and often described its benefits. For example, some policies said the pilots should be proficient in using automation and recommended using automation to aid in workload and situation awareness. Although less common, some policies followed the general expectations with a cautionary note to the pilots stating that use of automation can lead to complacency. Further, these policies explained that the mismanagement of automation and the autoflight system could lead to a decrease in situation awareness or MF proficiency.

Of the total 40 operational policy excerpts:

- Thirty-one policies provided detail on **when** AM or MF should be conducted.
- Thirteen provided at least some guidance on the **how** AM and MF should be conducted.
- Eighteen had contradictory language – e.g. within one operator policy, one paragraph read "exercise manual flying to maintain proficiency" but another paragraph stated "use maximum level of automation".
- Seventeen addressed "pilot monitoring".

Generally, policies focused their guidance on how to control the aircraft using various autoflight and automated systems. This was often completed by referring to automation in terms of levels or stating what automated systems were required per phase of flight. It was noted that most policies focused on providing guidance on using automated systems to control the flight path. While this is important information, if the policy only addresses use of automated systems, it may discourage the pilot from conducting MF.

MF was referenced by over half of the operator policies, usually by way of encouraging or permitting pilots to fly manually to maintain proficiency. This was routinely followed by a list of factors, some more restrictive than others, that provided the conditions under which a pilot may disengage automation and fly manually. One policy had a designated "Manual Flight Operations" policy in addition to their Automation Policy.

One policy had a designated "Monitoring" policy in addition to their Automation Policy.

Considering philosophy language, five operators had an "Automation Philosophy", two operators had a "Manual Flying Philosophy", and one operator had a "Flight Path Management Philosophy".

Finding 9: Original Equipment Manufacturers (OEM) Recommendations related to Operator Policies

While the OEM recommendations offered a strong framework, they lacked the specificity and operational context that enable operators to construct a policy reflective of their flight operations.

This finding is based on review of operator policies.

Many operator policies replicated the OEM recommendations verbatim without adjusting for their flight operations. However, manufacturers provide these recommendations for all operators that fly their equipment, and their flight operations can vary widely.

Finding 10: Flight Path Management and Flight Path Control

A small number of policies provided guidance, albeit brief, on the entire concept of flight path management. Such guidance usually consisted of a sentence or two on elements related to flight path management such as cross-checking, monitoring, and intervention. However, most policies only addressed flight path control, omitting guidance on the overall concept of Flight Path Management.

This finding is based on review of operator policies and regulatory material.

The ICAO competencies refer to Flight Path Management – Manual Control and Flight Path Management – Automation, both referring to the control of flight path. Some regulators defined Flight Path Management as the planning, execution and assurance of guidance and control of aircraft trajectory and energy, inflight and on the ground. This latter definition includes flightpath control, but is broader.

Finding 11: Flight Crew Briefings

Flight crew briefings have advantages ranging from aiding in the development of a plan of action to a shared mental model. Several policies required briefings to include the intended use of automation systems. Both the content of briefings and their use are important. When reviewing operator policy language that addressed flight crew briefings, several vulnerability areas were identified.

This finding is based on review of operator policies.

These vulnerabilities included:

- Minimal emphasis on MF, including what combination of automation and manual flight may be utilized as the approach progresses.
- Most policies have not adopted briefing the use of automation/MF on departure and arrival/approach.

Finding 12: TEM Principles in Operator Policies

Threat and Error Management (TEM) (or equivalent) principles and the description of the role of the pilot competencies and skills as countermeasures in the TEM framework varied within operator policies, when used. TEM was not always considered as a tool to mitigate operational and environmental threats.

This finding is based on review of operator policies.

Operator policies were analysed for the presence of the following terms: Threat, Error, Competency, Workload, Proficiency, Monitoring, Skill, Workload, and Situation Awareness. Their presence and use within the operator policies varied widely.

4.7 Manufacturers' Assumptions

Finding 13: Manufacturers' Assumptions

Manufacturers made many assumptions about manual flight, use of automated systems, and pilot training that were integrated into equipment design, manufacturer-recommended training programs, procedures, and documentation.

This finding is based on review of manufacturers' assumptions.

These assumptions may vary among manufacturers, but generally included:

- Prior piloting experience was assumed for all aircraft models.
- Detailed explanations of the manufacturers' automated flight systems were provided in their respective manual systems.
- Manufacturers assumed that the flight crew shall use an appropriate level of automation and that the automation is intended to assist the pilot.

- Manufacturers assumed that situation awareness will be maintained at all times.
- Manufacturers referred to current Crew Resource Management (CRM) techniques and practices as necessary for operational safety.
- Manufacturers stated that the level of flight crew intervention will vary accordingly with the available system capability, but the final authority remains on the flight crew to perform the abnormal procedures.

Automated flight and MF are sometimes viewed as differing skill sets or on opposite ends of a linear scale, with the degrees in between referred to as "levels of automation". While this term is generalized, some manufacturer automation systems may differ in philosophies so that "levels" may not fully describe every manufacturer automated flight system. A manufacturer may describe automation use in terms of combinations of automation which may differ in philosophy and utilization.

Further, what one manufacturer considers a "level" or "combination" of automation may differ compared to other manufacturers, so the assumption of uniformity of automation across all manufacturers may be incorrect.

Although automation use was recommended during normal operations, manufacturers expected an aircraft to be flown manually when necessary to ensure safe operation. Thus, flight crews were expected to operate aircraft with varying degrees of automation during non-normal (abnormal) operations.

However, analyses suggests that pilots and flight crews may not react in the expected manner to non-normal or startle/surprise scenarios. While automation may be used to assist with flight crew workload during abnormal (non-normal) situations, some data indicate that aircraft recovery may be impeded by pilots not assuming timely manual control when the aircraft is in a degraded state.

Manufacturers acknowledged that MF skill retention is important and did encourage MFO when conditions and workload permit. Manufacturers did provide limited guidance, but considered operators better suited to create operational policy based on their flight operations.

In further consultation, a manufacturer reported a recent trend of operators and regulators requesting the OEM to further interpret training requirements found in regulator reports. However, manufacturers are neither regulators nor operators.

4.8 Terms and Definitions

Multiple terms and definitions related to the topics in this report are used in various ways, not always consistently.

Finding 14: The terms automation over-reliance, dependency, and complacency.

The terms automation dependency, over-reliance, and complacency overlap, and dependency and over-reliance were used interchangeably in many documents.

This finding is based on accident and major incident data, operator policy analyses, regulatory review, reference documents and research review.

Each term has different specific meanings. This may lead to confusion about the application of the terms and the mitigation of associated safety issues. Examples include:

- Sriwijaya Air FLT 182 final report lists "automation complacency" as a contributing factor.
- The PARC/CAST FltDAWG report (FAA 2013) uses the terms "reliance" and "over-reliance" throughout to discuss the concept.
- The National Transportation Safety Board has pointed out that over-reliance on automation has been an issue leading to pilot error (2010, 2013, 2014).

Finding 15: Definitions of Flight Path Management, Manual Flight Operations, and Autoflight/Automated Systems.

There was a lack of standardized definitions of the terms Flight Path Management, Manual Flight Operations, Autoflight and Automated Systems.

This finding is based on review of operator policies and regulatory material.

The operator policy analysis determined the following vulnerabilities:

- Inconsistency or ambiguity in the use of similar vocabulary.
- Omission of definitions of regularly used terms.
- Wide array of definitions and concepts across operator policies.

Lack of, or inconsistent definitions, may cause a barrier between the operators' intent and flight crew interpretation. Without a definition, how to apply the guidance can become ambiguous. Providing definitions of commonly used terms offers a clarity into the intention of the terms used. Notably, the ambiguity and high variation in definitions made the analysis challenging, as different operators may base their policies on significantly different concepts and definitions. More detail on the most referenced terms are as follows:

Manual Flight Operations: MF and MFO were regularly used terms yet rarely defined in operator policy language. This is important to ensure the flight crew fully recognize and understand the context and intended use such that it is aligned with the operators' expectations. It was observed that 25 operator policies reference MF but provided no definition, and four operator policies referenced and defined MF or MFO.

Autoflight and Automated Systems: Many policies used the terms "autoflight" and "automated systems" interchangeably. Policy language would benefit from being specific and concise, where appropriate, to ensure the intention of the policy is consistent with what is written and reflected by the flight crew's actions.

Flight Path Management: Flight Path Management (and its automated and manual components) was scarcely discussed/defined. Two operator policies defined Flight Path Management and explained how it should be applied.

Finding 16: Regulatory Terminology

The regulatory guidance materials reviewed often used high-level terminology identical or similar to that used in ICAO guidance (e.g. "upset prevention and recovery training (UPRT)", "flight path management – automation (FPA)", "flight path management – manual control"). However, additional analysis showed that the technical content of the related training was not always the same and often varied across States.

This finding is based on regulatory review.

The table in Appendix D provides a detailed analysis of the terminology used across States.

Examples of areas of focus from different States included under the umbrella of AM:

- Function and limitations of Vertical and Lateral Automation modes; FD selections; Monitoring subtle Mode changes of Autothrottle/Autothrust (AT) protections-low speed/high angle of attack (AOA) and high speed; Approaches above GS; Go-around with all engines.
- AP; FMS input errors; autoflight; Flight Mode Annunciations; automation surprises; flight path warning systems; autoflight mode awareness.
- Detection of automation failures; complacency in automated environments; supervisory role of pilots; automation bias; philosophy on use of automation; control laws.

Finding 17: Levels/combinations of automation

The phrase "levels of automation" was often used to describe a simple linear hierarchy in a defined and prescribed fashion. While the concept of levels is useful conceptually and for communication, it may be difficult to operationalize.

This finding is based on operational data, review of operator policies, regulatory review, and research review.

Many operators defined levels of automation described as a simple linear hierarchy. However, a typical transport aeroplane may have 24 or more thrust, lateral, and vertical modes. These are modes of different automated systems (usually control automation systems). While the concept of levels is useful conceptually and for communication, it may be difficult to operationalize.

After gaining operational experience with training and operational use of these specific definitions, several operators concluded that such a description assumed that such a linear hierarchy is difficult to implement operationally. The various features of the automated system (for example AP, AT, FD, 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 automated system features for the situation, without defining them in terms of levels, except for a level where everything is on (often referred to as highest level) or everything is off (often referred to as lowest level). In general, the variability in types of automated systems goes beyond the concern about pilots managing the combination of automated systems and their modes.

5 Appendix A Survey Questions to States and to Manufacturers

The survey questions provided to the States and to the OEMs are included below.

5.1 Survey Questions to States

The questions that were asked in the State survey pertinent to automation dependency are described below, together with a summary of the responses.

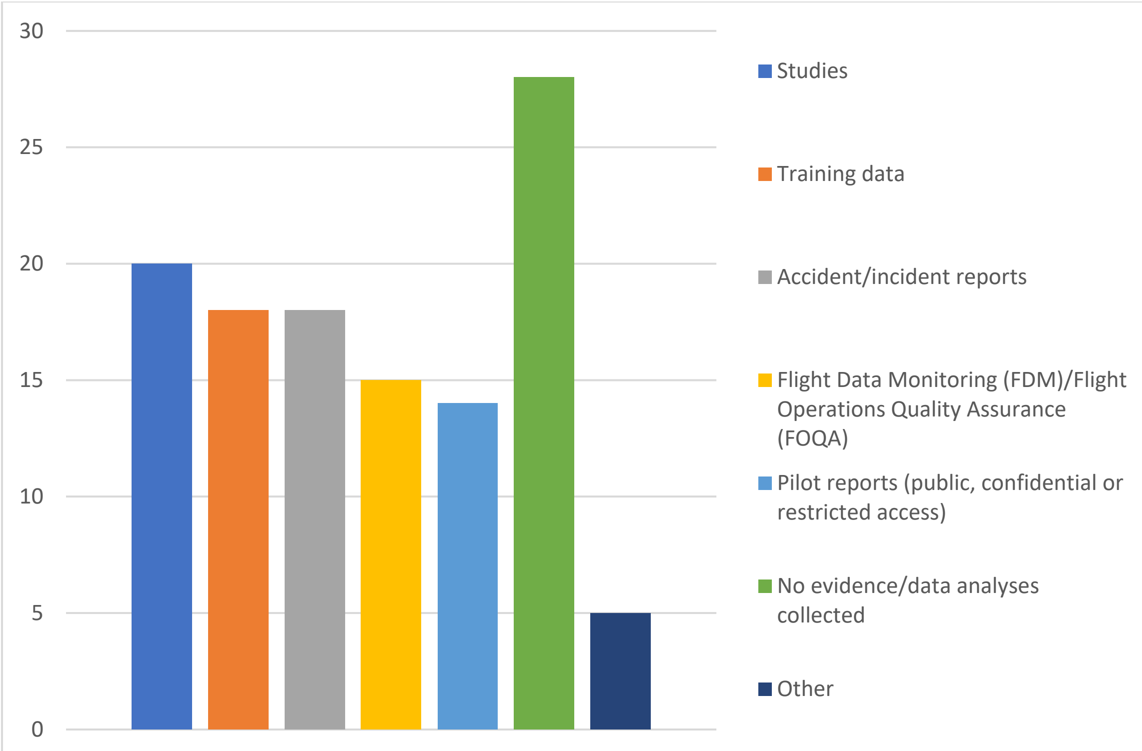
1. Provide the State name of your CAA.
   68 responses

2. Name of the focal point of your CAA assigned to manage the survey.
   68 responses

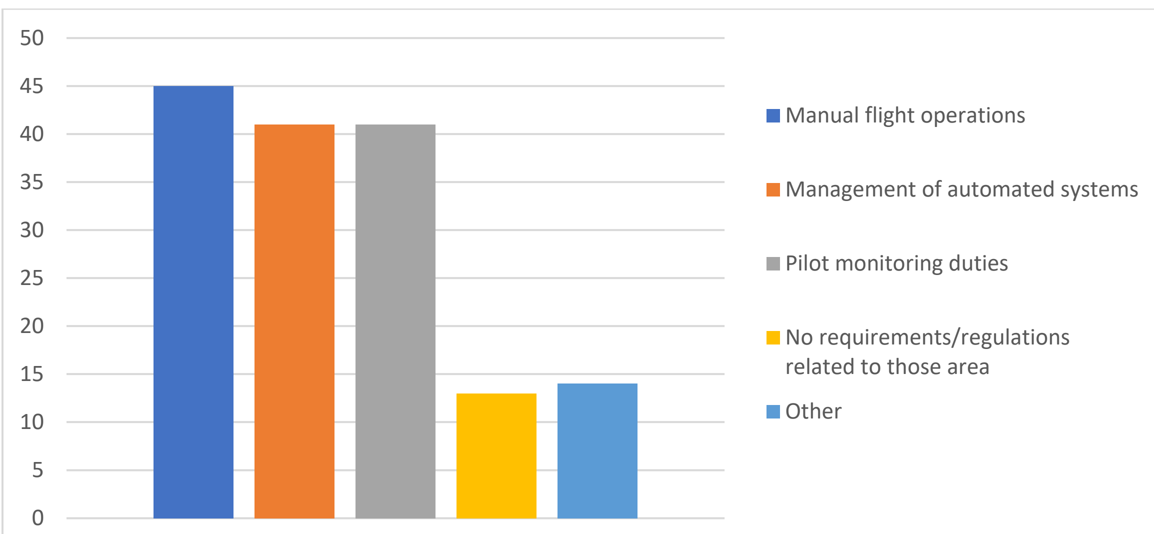
3. Function of the focal point at the CAA assigned to manage the survey.
   68 responses

4. Email address of the focal point assigned to manage the survey.
   68 responses

5. Please select any evidence/data analyses and/or reports your State has that can be shared related to pilot overreliance/dependency on automated systems?
   Please check all that apply



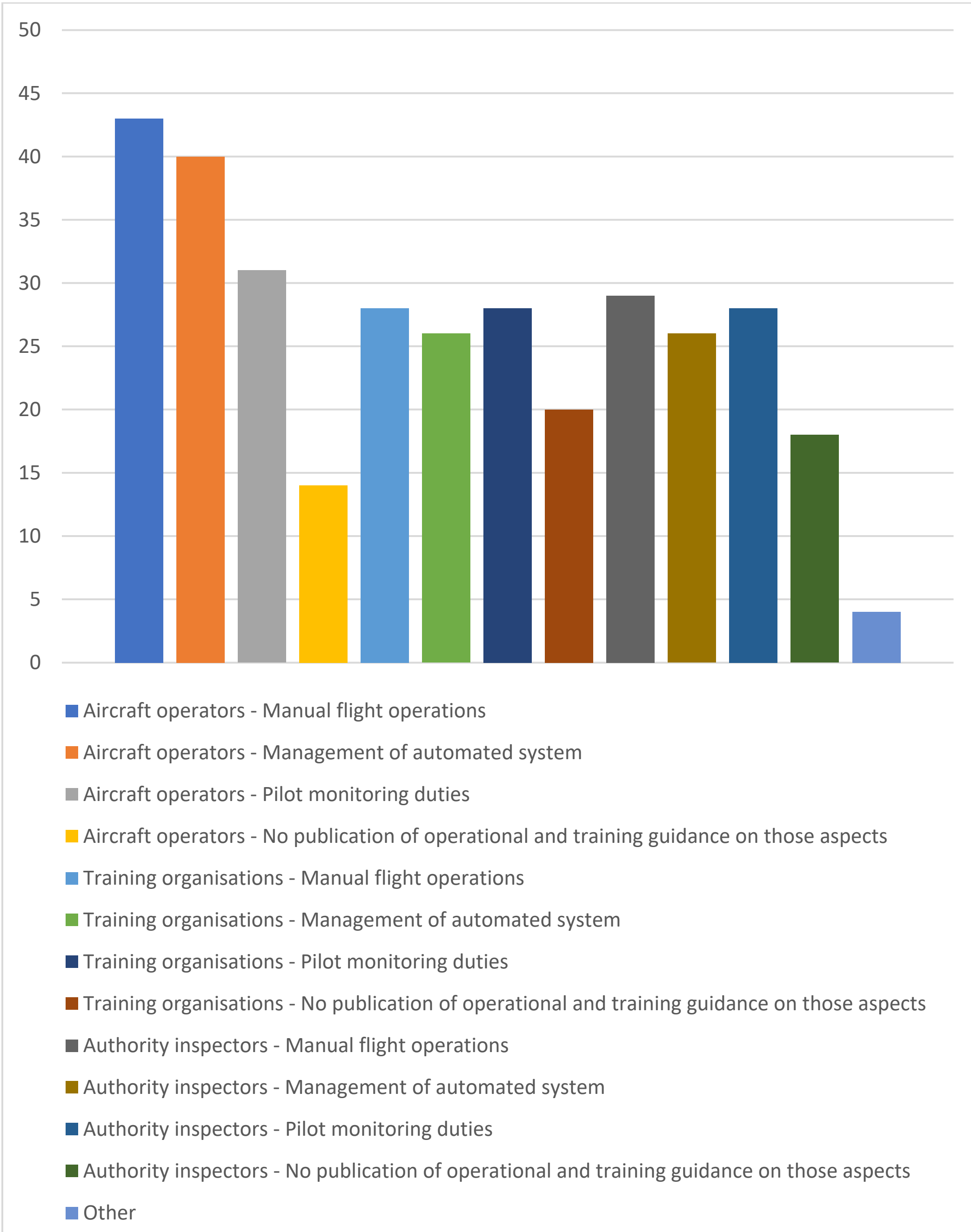
6. Please select any requirements/regulations your State has regarding Flight Path Management for training or flight crew operations addressing:
   Please check all that apply



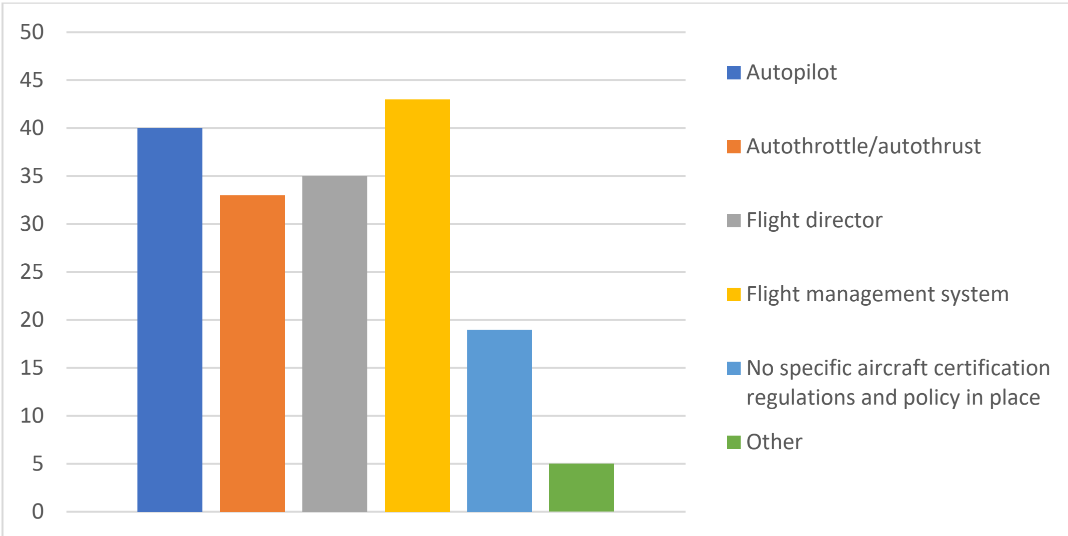
7. Please select any **operational and training guidance materials** (policies and recommendations) your State published regarding Flight Path Management for:
   - Aircraft operators;
   - Training organisations; and

- Authority inspectors;

On the following topics



8. Please select any **aircraft certification regulations and policy** your State has in place for airplane systems and equipment that assist in Flight Path Management such as:



9. Does the regulator make assumptions about performance/experience in those **aircraft certification regulations and policy.**

10. May your CAA be contacted to seek further information on the following topics

Although 68 CAAs responded with affirmative answers to the questions above, only two provided the additional information referenced.

5.2 Survey Questions to Manufacturers

The OEMs were queried for responses to the following questions:

1. What are assumed previous training and general experience levels?
2. What levels of automation are operators assumed to utilize and train crews accordingly?
3. Explain your assumptions about human performance capabilities; What is a reasonable expectation? What are your assumptions on how the flight crew will interact with each other?
4. What is your (the manufacturer) philosophy on automation? How does this influence airline training and commercial operations?
5. What are your (the manufacturer) assumptions on crew interaction and hierarchy?
6. What assumptions are made regarding pilot or flight crew reaction/performance/behaviour during a system failure or non-normal situation? What level of crew intervention is required upon failure of an automated system? (any system, not just automated flight)

Three OEMs responded. Their answers are de-identified and summarized in this report, rather than being described individually.

6 Appendix B Indicators of Automation Dependency and Accidents and Major Incidents Exhibiting Indicators of Automation Dependency

6.1 Indicators of Automation Dependency

*Not an exhaustive list

Mode monitoring/ system performance monitoring

- Insufficient monitoring of:
    - Instrumentation parameters (Airspeed, Attitude, Altitude, Vertical speed, Roll rate, Trim, Heading)
    - Flight path management
    - Modes
    - Hazards
    - System performance issues

Inadequate performance in responding to automated system performance

- Insufficient response to:
    - Decaying/increasing airspeed
    - Decaying/increasing altitude
    - Inadequate thrust on Takeoff/Landing
    - Deviations from intended flight path
    - Mode changes
    - Bias to automated system use

Inadequate performance during varying flight phase procedures

- Insufficient performance:
    - Setting up a stabilized approach
    - Managing manoeuvring changes at major airports
    - Deviations from intended flight path
    - Mode changes
    - Hazards
    - Decision making
    - Bias to automated system use over MFO

Use of systems when not appropriate

- Continuing to reprogram or change automated system inputs in time critical situations
- Use of automated system to make immediate responses to Ground Proximity Warning System (GPWS) or Terrain Awareness and Warning System (TAWS) alerts
- Exclusive use of information from an automated system when other information is available to cross-check

6.2 Twenty-eight Accidents and 47 Major Incidents Determined to Display Indicators of Automation Dependency.

Automation Dependency Accidents in Order of Report (28)

*Report cannot be located on Investigative Board website, but Final Report can be found here.

Event Date	Location	Aircraft Type	Operator/ Flight Number (If reported)	Source	Summary
December 20, 1995	Cali, Columbia	B757	American Airlines 965	University of Bielefeld	Controlled Flight Into Terrain (CFIT)
May 12, 1997	West Palm Beach, Florida	A300	American Airlines 903	National Transportation Safety Board (NTSB) NTSB	Inflight loss of control, about 10 miles north of HEATT intersection
November 22, 2004	Houston, Texas	G1159A	Business Jet Services	NTSB	Crash during approach to landing
January 1, 2007	East Java to Manado (MDC), Sulawesi	B737	AdamAir 574	NTSC	Loss of control while troubleshooting Inertial Navigation System
September 16, 2007	Phuket International Airport	MD82	One Two Go Airlines 269	AAIC	During a go-around the aircraft veered off and hit an embarkment
June 14, 2008	Raymond, Pennsylvania	MD10	FedEx 764	NTSB	Experienced aerodynamic buffet and stickshaker while descending. Damage occurred to both elevators and right horizontal stabilizer.
February 25, 2009	Near Amsterdam Schiphol Airport	B737	Turkish Airlines 1951	Dutch Safety Board	Crashed during approach at Amsterdam Schiphol airport.
June 1, 2009	3°03’57’’ N, 30°33’42’’ W, near the TASIL waypoint, in international waters, Atlantic Ocean	A330	Air France 447	Bureau d’Enquêtes et d’Analyses pour la sécurité de l’aviation civile (BEA) BEA	Obstruction of the pitot probes by ice crystals
July 28, 2010	Margalla Hills, Islamabad	A321	Air Blue 202	Pakistan Civil Aviation Authority Pakistan CAA	Executing a circling approach for runway 12 at Islamabad, aircraft flew into Margalla Hills
January 3, 2011	Los Angeles, California	B737	American Airlines 1586	NTSB	Tailstrike after entering V1 speed incorrectly into Flight Management Computer (FMC)
August 20, 2011	Resolute Bay, Nunavut	B737	Bradley Air Services (FirstAir) 6560	Transportation Safety Board (TSB) TSB	CFIT, off track approach due to inadvertent interference with the AP ILS

Event Date	Location	Aircraft Type	Operator/ Flight Number (If reported)	Source	Summary
April 20, 2012	Near BBIAP, Islamabad	B737	M/s Bhoja Air 213	Pakistan CAA Pakistan CAA	Impacted ground after the aircraft encountered windshear
July 6, 2013	San Francisco	B777	Asiana Airlines 214	NTSB	Descent below visual glidepath and impact with seawall
August 14, 2013	Birmingham, Alabama	A300	UPS 1354	NTSB	Crash during night time non-precision instrument approach to landing
*October 16, 2013	Island located on the Mekong River	ATR72	Lao Airlines	AAIC	Aircraft performed a missed approach but continued to descend and impacted the ground.
November 17, 2013	Kazan Airport, Russia	B737	Tatarstan Airlines 364	IAC	Crashed while conducting a go-around
March 13, 2014	Philadelphia, Pennsylvania	A320	US Airways 1702	NTSB	Entered the incorrect departure runway on FMC
July 24, 2014	80 km southeast of Gossi, Mali	MD83	Swiftair 5017	BEA	Aeroplane’s speed, piloted by the AT, decreased due to the obstruction of the pressure sensors on the engine nose cones
October 1, 2014	Amsterdam Airport Schiphol	ERJ190	Undisclosed	Dutch Safety Board	Hard landing after automatic approach
December 28, 2014	Karimata Strait Coordinate 3°37’19” S - 109°42’41” E Republic of Indonesia	A320	Indonesia Air Asia	KNKT	After two Flight Augmentation Computer faults, flight control went into alternate law and entered upset conditions and stalled
March 29, 2015	Halifax, Nova Scotia	A320	Air Canada 624	TSB	While conducting a non-precision approach to runway 5, aircraft severed power lines, struck snow covered ground before threshold
January 8, 2016	Oajevagge, Norrbotten County	CL-600	West Atlantic Sweden 294	SHK	Uncommanded AP disconnect after one PFD failed
March 19, 2016	Russian Federation, the Rostov region, the Rostov-on-Don aerodrome, reference position: 47º 15′54.7″ N, 039°49′43.8″ E	B737	Dubai Aviation Corporation Airlines (Flydubai) 981	IAC	Unstable in turbulent conditions on landing
August 3, 2016	Dubai International Airport	B77	Emirates 521	GCAA	Runway impact during attempted go-around

Event Date	Location	Aircraft Type	Operator/ Flight Number (If reported)	Source	Summary
January 16, 2017	Near Manas International Airport, Bishkek, Kyrgyz Republic, coordinates: N 43°03.248' E 074°2.271	B747	ACT Airlines 6491	IAC	Unsuccessful completion of a night-auto ILS Category II approach
September 1, 2018	Sochi Airport	B737	UTAir Airlines 579	IAC	The aircraft overrun the runway threshold at Sochi airport
November 3, 2019	Between VAKIN and DIRMU waypoints of the UN725 airway (Barcelona FIR/UIR)	B787	Avianca 018	CIAIAC	Actions taken by PF to prevent overspeed which resulted in injury to occupants
January 9, 2021	Kepulauan Seribu District, DKI Jakarta Republic of Indonesia	B737	Sriwijaya Air SJY182	KNKT	AT malfunction creating thrust asymmetry, wing drop which led to loss of control

Automation Dependency Major Incidents In order of Report (47)

*Report cannot be located on Investigative Board website, but Final Report can be found here

Event Date	Location	Aircraft Type	Operator/ Flight Number (If reported)	Source	Summary
October 20, 2002	Baltimore, Maryland	B757	Icelandair 662	RNSA SIA	Experienced a stall while climbing from Flight Level 330
April 15, 2004	Near Malaga, Spain	A320	Undisclosed	Air Accidents Investigation Board (AAIB)	Measures taken to prevent overspeed which resulted in injury to occupants
January 18, 2006	On approach to Manchester Airport	Dornier 328	EuroManx 328	AAIB	Aircraft descend after failing to capture GS triggering EGPWS
July 21, 2007	Melbourne Airport, Victoria	A320	Jetstar Airways	Australian Transportation Safety Board (ATSB) July 2007	Go-around at Melbourne airport
December 19, 2008	On approach to Oslo Airport	A320	Aeroflot Russian Airline 211	NSIA	Spatial disorientation after last minute runway change
December 23, 2008	On approach to Edinburgh Airport	DHC-8	Flybe	AAIB	Aircraft descended below a cleared altitude and then below the ILS GS
March 3, 2009	10 nm northeast of Southampton Airport, Hampshire	DHC-8	Flybe	AAIB	Aircraft decelerated below its minimum manoeuvring speed and the flight crew received a momentary stick shake warning

Event Date	Location	Aircraft Type	Operator/ Flight Number (If reported)	Source	Summary
May 4, 2009	Denver, Colorado	A320	Northwest Airlines 557	NTSB	Tailstrike due to excessive pitch up and landing in tailwind
October 21, 2009	Minneapolis, Minnesota	A320	Northwest Airlines 188	NTSB	Flight was operating with no radio communications for about 1 hour 17 minutes
February 7, 2010	On approach to Chambery Airport	B737	Jet2 247S	AAIB	On ILS approach, crew received EGPWS terrain and pull up warning
May 26, 2010	Near position PARAR in VABF	B737	Air India Charters	DGCA	Abnormal pitch and pitch changes
July 20, 2011	Zurich-Kloten Airport	AVRO 146	Swiss European Airline 5187	SUST	When lined up on localizer, the AP, AT, FD failed. A few seconds later “Bank angle” alert sounded
July 22, 2011	In cruise at flight level 350, north Atlantic Ocean	A340	Air France	BEA	Moderate turbulence which caused aircraft to overspeed
July 24, 2011	15 km south of Melbourne Airport, Victoria	B777	Thai Airways	ATSB	Operational non-compliance/ Aircraft was lower than required
April 3, 2012	Tel Aviv Ben Gurion Airport	A320	Air France	BEA	Deviation below manoeuvring airspeed on final, go-around, triggering of Alpha Floor protection
April 11, 2012	On approach to Lyons Saint-Expery Airport	A320	Hermes Airlines	BEA	Unstabilized approach, triggering of Ground Proximity Warning System (GPWS) and minimum safe altitude warnings, dual input, missed approach, at night
February 25, 2013	213 km south-southeast of Brisbane Airport, Queensland	B737	Qantas	ATSB	Aircraft AP unexpectedly commenced climb during approach
March 8, 2013	15 km north-northeast of Melbourne Airport Victoria	A330	Qantas	ATSB	Flight path management and ground proximity warning
October 20, 2013	80 nm southwest of Dublin, Ireland	B757	United Airlines	AAIU	Blockage of right main pitot probe due to ice crystal
April 28, 2014	4 nm north of Naha Airport	A320	Peach Aviation Co. 252	JTSB	Emergency operation to avoid crash into water surface
August 8, 2014	Turkish Airspace	B777	Jet Airways	DGCA	Loss of altitude when inadvertently carrying out level change while updating heading

Event Date	Location	Aircraft Type	Operator/ Flight Number (If reported)	Source	Summary
January 29, 2015	On approach to Bergerac-Roumaniere Airport (Dordogne)	B737	Ryanair	BEA	Descent below the minimum safe altitude during the approach, activation of ground proximity alerts, missed approach
April 24, 2015	Near Adelaide Airport, South Australia	DHC-8	Qantas Link 2274	ATSB	Uncommanded disengagement of FD, when engaged again the mode resulted in aircraft descending triggering Obstacle proximity warning
May 22, 2015	Paris – Charles-de-Gaulle Airport	B777	Air France	BEA	Calculation of take-off parameters with an erroneous weight, take-off at low speed, opposite threshold flown over at low height
September 12, 2015	Neat Perth Airport, Western Australia	A320	Virgin Australia	ATSB	Unreliable airspeed indication and stall warning
June 18, 2016	Meekatharra, Western Australia	PC-12	Undisclosed	ATSB	Synthetic vision display error
July 16, 2016	Fuerteventura Airport, Las Palmas, Canary Islands, Spain	A321	Germania 3700	CIAIAC	Conducted a go-around after an unstabilized approach and bounced landing
September 2, 2016	On approach to Dublin Airport	ATR72	Stobart Air	AAIU	Descended below cleared altitude
September 8, 2016	15 nm northwest of RILEX TCP (Bulgaria)	A321/B738	Atlasjet 3067/ Turkish Airlines 4771	AAIU	Loss of separation, aircraft climbed after receiving permission to descend
October 12, 2016	Horn Island Aerodrome, Queensland	Pilatus Britten-Norman LTD BN2A-20	McGilvray Aviation PTY LTD (Cape Air Transport	ATSB	Near collision
November 14, 2016	70 nm north-northeast of Bergen	ATR72	Jet Time 4144	NSIA	Control of aircraft was temporarily lost in severe icing
December 9, 2016	11 km east of Sydney Airport, New South Wales	DHC-8/B777	QantasLink/ Air New Zealand	ATSB	An unexpected AP mode change occurred, causing loss of separation
April 7, 2017	110 km southeast of Hong Kong Airport	B747	Qantas Airlines 29	ATSB	Aircraft aerodynamic stall warning stick shaker activated multiple times.
June 5, 2017	During climb after departure from Edinburgh Airport	Saab340	Loganair	AAIB	The stick shaker activated three times during severe icing and turbulence

Event Date	Location	Aircraft Type	Operator/ Flight Number (If reported)	Source	Summary
July 21, 2017	Belfast International Airport	B737	Sunwing Airlines	AAIB	Incorrect outside air temperature was entered into the FMC, which caused settings significantly below that required for the aircraft weight and environmental conditions
September 9, 2017	Vicinity of reporting point NARGO (Albacete-Spain)	ATR72	Swiftair 4050	CIAIAC	When aircraft was climbing through icing conditions, suffered uncommanded loss of altitude along with a series of uncommanded pitches and banks
September 10, 2017	Domodedovo International Airport	A380	Emirates 131	GCAA	Descent below cleared altitude during approach and FMS not reconfigured following reset during second approach
September 24, 2017	Lo Fu Tau, Lantau Island, Hong Kong	B747	Atlas Air 86	AAIA	CFIT marginally avoided
*January 28, 2019	Muscat International Airport of Oman	A320	Orange2Fly 104	AAIASB	Unstable approach with loss of thrust resulting in AT intervention
April 5, 2019	Getafe Air Base (Madrid)	B737	KlaseJet	CIAIAC	AP was unavailable and during climb the FO's AP became inoperative and aircraft made 2 go-around attempts in adverse weather before being diverted
August 22, 2019	Hyakuri Airfield, Ibaraki Prefecture, Japan	B737	Eastar Jet 8052	JTSB	Attempt of landing on a runway where a vehicle exists
August 29, 2019	Nice Cote d'Azur Airport, France	A319	EasyJet	AAIB	Identical error was made in performance calculations causing aircraft to use more runway
September 2, 2019	Climb out of Pudong Airport, Shanghai	B777	Singapore Airlines	TSIB	FMS input error led to AP triggering EGPWS alerts
September 16, 2019	Lisbon Airport, Portugal	A320	EasyJet	AAIB	Late takeoff after incorrectly selecting the runway full length during performance calculations
December 20, 2019	Close to Hyeres-Le-Palyvestre Airport	A318	Air France	BEA	Acquisition of false GS signal on approach, increase in pitch attitude with AP engaged, activation of the flight envelope protections
January 1, 2020	Frankfurt/Main Airport	A350	Thai Airways	BFU	Descent at a high rate below ILS GS

Event Date	Location	Aircraft Type	Operator/ Flight Number (If reported)	Source	Summary
February 28, 2020	London Gatwick Airport	B737	Royal Air Maroc	AAIB	V1 Automatic call did not occur, and takeoff speeds not displayed on PFD

7 Appendix C References

The items in the list below represent documents that were collected and provided supporting information for this Study Report. Note that items below with an asterisk are documents that received extra scrutiny.

Abbott, K. (2014). Some lessons learned about pilots and flight deck automated systems. HindSight 20, 38-40. Winter 2014.

Abbott, K. H. (2023). Automated systems in civil transport airplanes: Human factors considerations. In Human Factors in Aviation and Aerospace (pp. 373-397). Academic Press.

Abbott, K. H. (1991). Robust fault diagnosis of physical system in operation. PhD Dissertation, State University of New Jersey

Abbott, K., Slotte, S., Stimson, D., Amalberti, R. R., Bollin, G., Fabre, F., et al. (1996). The interfaces between flightcrews and modern flight deck systems (Report of the FAA Human Factors Team). Washington, DC: Federal Aviation Administration.

Ackerman, K. A., Seefeldt, B. D., Xargay, E., Talleur, D. A., Carbonari, R. S., Kirlik, A., Hovakimyan, N., Trujillo, A. C., Belcastro, C. M., & Gregory, I. M. (2015). Flight envelope information-augmented display for enhanced pilot situation awareness. Session: Intelligent Interactions between Humans and Machines, AIAA 2015-1112. https://doi.org/10.2514/6.2015-1112

Adriaensen, A., Patriarca, R., Smoker, A., & Bergström, J. (2019) A socio-technical analysis of functional properties in a joint cognitive system: a case study in an aircraft cockpit, Ergonomics, 62, 1598-1616. doi: 10.1080/00140139.2019.1661527

Allen, D. M. (1989). Investigation of Display Issues Relevant to the Presentation of Aircraft Fault Information. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 33, 61 - 65.

Allen, J. E., Guinn, C., & Horvtz, E. (1999). Mixed-initiative interaction. IEEE Intelligent Systems and Their Applications, 14, 14–23. doi:10.1109/5254.796083

Amershi, S., Weld, D., Vorvoreanu, M., Fourney, A., Nushi, B., Collisson, P., Horvitz, E. (2019). Guidelines for human-AI interaction. Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, 1–13.doi:10.1145/3290605.3300233

Atkins, E. M. (2010). Emergency landing automation aids: An evaluation inspired by US Airways Flight 1549. AIAA Infotech at Aerospace 2010.

Avril, E., Valéry, B., Navarro, J., Wioland, L., & Cegarra, J. (2021). Effect of Imperfect Information and Action Automation on Attentional Allocation, International Journal of Human–Computer Interaction, 37:11, 1063-1073, doi: 10.1080/10447318.2020.187081

Bailey, R. E., Kramer, L. J., Kennedy, K. D., Stephens, C. L., & Etherington, T. J. (2017). An assessment of reduced crew and single pilot operations in commercial transport aircraft operations. AIAA/IEEE digital avionics systems conference - Proceedings.

Bainbridge, L. (1983). Ironies of Automation: Increasing levels of automation can increase, rather than decrease, the problems of supporting the human operator. Automatica, 19, 775-779.

Barnes, M., Chen, J., & Jentsch, F. (2015). Designing for mixed-initiative interactions between human and autonomous systems in complex environments. Systems, Man, and Cybernetics (SMC), 2015 IEEE international conference (pp. 1386–1390).

*BEA. (2013) Study on Aeroplane State Awareness during Go-Around. August 2013 Le Bourget, France

Billings, C. E. (1991). Human-Centered Aircraft Automation: A Concept and Guidelines. (NASA Technical Memorandum 103885). Moffett Field, CA: NASA-Ames Research Center. Handbook of Human Factors & Ergonomics, second edition, G. Salvendy (Ed.), Wiley, 1997

Billings, C. E. (1997). Aviation automation: The search for a human-centered approach (Human Factors in Transportation). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Billman, D., Mumaw, R., & Feary, M. (2020, December). A Model of Monitoring as Sensemaking: Application to Flight Path Management and Pilot Training. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 64, No. 1, pp. 244-248). Sage CA: Los Angeles, CA: SAGE Publications.

Björklund, C. M., Alfredson, J., & Dekker, S. W. A. (2006). Mode monitoring and call-outs: An eye-tracking study of two-crew automated flight deck operations. International Journal of Aviation Psychology, 16, 263–275.

Blackhurst, J. L.; Gresham, J. S.; and Stone, M. O. 2011. The Autonomy Paradox. *Armed Forces Journal*, October 1, 2011. www.armedforcesjournal.com/2011/10/

Bove, T., & Andersen, H. B. (1999). The effect of an advisory system on pilots' go/no-go decision during takeoff. Reliability Engineering and System Safety, 75, 179–191.

Bradshaw, J. M., Hoffman, R. R., Woods, D. D., & Johnson, M. (2013). The seven deadly myths of "Autonomous Systems". IEEE Intelligent Systems, 3, 54–61.

Brand, Y., & Schulte, A. (2021). Workload-adaptive and task-specific support for cockpit crews: design and evaluation of an adaptive associate system. Human-Intelligent Systems Integration. doi.org/10.1007/s42454-020-00018-8

Brandt, S. L., Lachter, J., Russell, R., & Shively, R. J. (2018). A human-autonomy teaming approach for a flight-following task. In Advances in intelligent systems and computing (pp. 12–22). Cham: Springer.

Burdick, M. D., Skitka, L. J., Mosier, K. L., Heers, S. (1996). The ameliorating effects of accountability on automation bias. In Proceedings of the 3rd Symposium on Human Interaction with Complex Systems (HICS '96) (HICS '96). IEEE Computer Society, USA, 142.

Bush, S.F., Hershey, J., & Vosburgh, K. (1999). Brittle system analysis. http://arxiv.org/pdf/cs/9904016.pdf

CAA (2013) Monitoring matters, Guidance on the Development of Pilot Monitoring Skills. Civil Aviation Authority, Sussex

*CAA Paper 2004/10 Flight Crew Reliance on Automation

Carim, G. C., Saurin, T. A. & Dekker, S. W. A. (2020). How the cockpit manages anomalies: revisiting the dynamic fault management model for aviation. Cognition, Technology & Work, 22, 143–157.

*Casner, S. M. (2003b). Teaching cockpit automation in the classroom (NASA/TM-2003-211865).

Casner, S. M., & Schooler, J. W. (2014). Thoughts in flight: automation use and pilots' task-related and task-unrelated thought. Human Factors, 56, 433-442.

Casner, S. M., 2003a. Learning about cockpit automation: From piston trainer to jet transport (NASA/TM-2003-2 12260).

Casner, S. M., Geven, R. W., Recker, M. P., & Schooler, J. W. (2014). The retention of manual flying skills in the automated cockpit. Human Factors: The Journal of the Human Factors and Ergonomics Society, 56, 1506–1516.

*CAST SE Revision 2008 Mode Awareness and Energy State Management Aspects of Flight Deck Automation

Chandra, D. C. & Mangold S. J. (2000a). Human factors considerations in the design and evaluation of electronic flight bags (EFBs) Version 1: Basic functions. (Report No. DOTVNTSC-FAA-00-22). Cambridge, MA: USDOT Volpe Center.

Chandra, D. C. & Mangold S. J. (2000b) Human factors considerations for the design and evaluation of Electronic Flight Bags. Proceedings of the 19th Digital Avionics Systems Conference. 10-12 October 2000, Philadelphia, PA.

Chandra, D. C. (2002). Human Factors Evaluation of Electronic Flight Bags. Proceedings of HCI-Aero 2002. 23-25 October. Cambridge, MA.

Chandra, D. C. (2003). A tool for structured evaluation of electronic flight bag usability. In Proceedings of the 22nd Digital Avionics Systems Conference. 12-16 October 2003, Indianapolis, IN.

Chandra, D. C., & Yeh, M. (2006a). Evaluating Electronic Flight Bags in the Real World. Proceedings of the International Conference on Human-Computer Interaction in Aeronautics (HCI-Aero 2006). 20-22 September. Seattle, WA.

Chandra, D. C., & Yeh, M. (2006b). A Tool Kit for Evaluating Electronic Flight Bags. Report Nos. DOT/FAA/AR-06/44. DOT-VNTSC-FAA-06-21. Washington, DC. US Department of Transportation, Federal Aviation Administration.

Chandra, D. C., Yeh M., & Riley, V. (2004). Designing a Tool to Assess the Usability of Electronic Flight Bags (EFBs), Report No. DOT/FAA/AR-04/38, USDOT Volpe Center: Cambridge, MA.

Chandra, D. C., Yeh M., Riley, V., & Mangold, S.J. (2003). Human factors considerations in the design and evaluation of Electronic Flight Bags (EFBs), Version 2. DOT-VNTSC-FAA-03-07. USDOT Volpe Center: Cambridge, MA.

Chappell, A. R., Crowther, E. G., Mitchell, C. M., & Govindaraj, T. (1997). The Vertical Navigation (VNAV) tutor: Addressing a mode awareness difficulty for pilots of glass cockpit aircraft. IEEE Transactions on Systems, Man and Cybernetics—Part A: Systems and Humans, 27, 372–385.

Chen, J. Y. C, Lakhmani, S. G., Stowers, K., Selkowitz, A. R., Wright, J. L., & Barnes, M. (2018) Situation awareness-based agent transparency and human-autonomy teaming effectiveness, Theoretical Issues in Ergonomics Science, 19, 259-282, doi: 10.1080/1463922X.2017.1315750

Chen, J., Barnes, M., Wright, J., Stowers, K., & Lakhmani, S. (2017). Situation awareness-based agent transparency for human-autonomy teaming effectiveness. Micro- and nanotechnology sensors, systems and applications IX. International Society for Optics and Photonics (Vol. 10194, pp. 1019–1041).

Chen, T. L., & Pritchett, A. R. (2001). Cockpit decision aids for emergency flight planning. Journal of Aircraft, 38, 935–943.

Chialastri, A., & Pozzi, S. (2008). Resilience in the aviation system. In Harrison M.D., Sujan MA. (Eds.) Computer Safety, Reliability, and Security. SAFECOMP 2008. Lecture Notes in Computer Science, vol 5219. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-87698-4_10

Chidester T. (1999). Introducing FMS aircraft into airline operations. In S. Dekker and E. Hollnagel (Eds), Coping with Computers in the Cockpit, Ashgate, Aldershot, UK.

Chiou, E. K., & Lee, J. D. (2016). Cooperation in human-agent systems to support resilience: A microworld experiment. Human Factors, 58, 846-863.

Chiou, E. K., & Lee, J. D. (2021). Trusting automation: designing for responsivity and resilience. Human Factors, https://doi.org/10.1177/00187208211009995

Christoffersen, K. and Woods, D.D. (2002), How to make automated systems team players. Advances in Human Performance and Cognitive Engineering Research (Advances in Human Performance and Cognitive Engineering Research, Vol. 2), Emerald Group Publishing Limited, Bingley, pp. 1-12. https://doi.org/10.1016/S1479-3601(02)02003-9

Elias, B. (2020). Cockpit automation, flight systems complexity, and aircraft certification ([Library of Congress public edition].). Congressional Research Service.

Commercial Aviation Safety Team (2008). Mode Awareness and Energy State Management Aspects of Flight Deck Automation. Final Report, Safety Enhancement 30, August, 2008.

Commercial Aviation Safety Team (2014). Airplane State Awareness Joint Safety Analysis Team (JSAT) Final Report.

Courteney, H. (1999). Human factors of automation: The Regulator's challenge. In Dekker, S and Hollnagel, E. (Eds.) Coping with computers in the cockpit (pp 7-27). Aldershot, UK: Ashgate.

Cox, J. M. (2010). Prioritizing Mitigations in Flight Path Management Accidents. CAPSTONE PROJECT report submitted to Daniel Webster College, June 2010.

Dalcher, D. (2007). Why the pilot cannot be blamed: A cautionary note about excessive reliance on technology. International Journal of Risk Assessment and Management, 7, 350-366.

*De Boer, R. & Dekker, S. (2017). Models of Automation Surprise: Results of a Field Survey in Aviation. Safety, 3, 1-11.

de Visser, E. J., Cohen, M., Freedy, A., & Parasuraman, R. (2014). A Design Methodology for Trust Cue Calibration in Cognitive Agents. In Virtual, Augmented and Mixed Reality. Designing and Developing Virtual and Augmented Environments, edited by R. Shumaker, S. Lackey, 251–262. Cham, Swtizerland: Springer International Publishing. doi: 10.1007/978-3-319-07458-0_24.

de Visser, W. J., Pak, R., & Shaw, T. H. (2018). From ‘automation’ to ‘autonomy’: the importance of trust repair in human-machine interaction. Ergonomics, 61, 1409-1427.

Dearden, A., Harrison, M., & Wright, P. (2000). Allocation of function: scenarios, context and the economics of effort. International Journal of Human-Computer Studies, 52, 289-318.

De Boer, R., & Dekker, S. (2017). Models of automation surprise: results of a field survey in aviation. Safety, 3(3), 20.

Degani, A., & Wiener, E. L. (1994). On the design of flight-deck procedures (NASA Contractor Report 177642). Moffett Field, CA: NASA Ames Research Center.

Degani, A., Shafto, M., & Kirlik, A. (1999). Modes in human-machine systems: Constructs, representation, and classification. International Journal of Aviation Psychology, 9, 125-138.

Degani, A., Shafto, M., Kirlik, A. (2006). What makes vicarious functioning work? Exploring the geometry of human-technology interaction. In A. Kirlik (Ed), Adaptive perspectives on human-technology interaction: Methods and models for cognitive engineering and human-computer interaction. New York: Oxford University Press, pp 179-196.

Degani, A., Barshi, I., & Shafto, M. G. (2013). Information organization in the airline cockpit: Lessons from flight 236. Journal of cognitive engineering and decision making, 7(4), 330-352.

Dekker, S. W. A., & Woods, D. D. (2002). MABA-MABA or Abracadabra: Progress on human automation co-operation. Journal of Cognition, Technology and Work, 4, 240-244.

Dekker, S., & Orasanu, J. (1999). Automation and situation awareness – pushing the research frontier. In Dekker, S and Hollnagel, E. (Eds.) Coping with computers in the cockpit (pp 69-85). Aldershot, UK: Ashgate.

Dekker, S., & Woods, D. (1999a). Automation and its impact on human cognition. In Dekker, S and Hollnagel, E. (Eds.) Coping with computers in the cockpit (pp 7-27). Aldershot, UK: Ashgate.

Dekker, S., & Woods, D. (1999b). Extracting data from the future – Assessment and certification of envisioned systems. In Dekker, S and Hollnagel, E. (Eds.) Coping with computers in the cockpit (pp 7-27). Aldershot, UK: Ashgate.

Dismukes, K. (2001). The challenge of managing interruptions, distractions, and deferred tasks. In Proceedings of the 11th International Symposium on Aviation Psychology. Columbus, OH: Ohio State University.

Dixon, S. R., Wickens, C. D., & McCarly, J. M. (2007). On the independence of reliance and compliance: Are automation false alarms worse than misses. Human Factors, 49, 564-572.

Dowell, J., & Long, J. (1998). Conception of the cognitive engineering design problem. Ergonomics, 41, 126–139.

*European Union Aviation Safety Agency (EASA) Cockpit Automation Survey 2012

*EASA Cockpit Survey 2012 Working Document prepared for the ICAO PTLP WG1 Automation

*EASA Research Report Startle Effect Management (EASA_REP_RESEA_2015_3) (contracted to the NLR) https://www.easa.europa.eu/document-library/research-reports/easarepresea20153

*EASA Safety Information Bulleting SIB 2010-33R1 Automation Policy https://ad.easa.europa.eu/ad/2010-33R1

*EASA SIB 2013-02 Stall and Stick Pusher Training https://ad.easa.europa.eu/ad/2013-02

*EASA SIB 2013-05 Manual Flight Training and Operations https://ad.easa.europa.eu/ad/2013-05

*EASA UPRT Summary and Appendices 1 and 2, 2021 Working Documents prepared for the ICAO PTLP WG1 Automation

Ebbatson, M., Harris, D., Huddlestone, J. & Sears R. (2010). The relationship between manual handling performance and recent flying experience in air transport pilots. Ergonomics, 53, 268-277.

Edland, A., & Svenson, O. (1993). Judgment and decision making under time pressure In G. A. Klein, J. Orasanu, R. Calderwood, & C. Zsambok (Eds.) Decision Making in Action: Models and Methods. (pp. 27-40). Norwood, NJ: Ablex.

Eldredge, D., Dodd, R. S., & Mangold, S. J. (1991). A Review and Discussion of Flight Management System Incidents Reported to the Aviation Safety Reporting System. (Battelle Report, prepared for the Department of Transportation). Columbus, OH: Volpe National Transportation Systems Center.

Endsley, M. R. (2017). From here to autonomy: Lessons learned from human-automation research. Human Factors, 59, 5–27.

Endsley, M. R. (2017). Level of automation forms a key aspect of autonomy design. Journal of Cognitive Engineering and Decision Making, 12, 29-34.

Endsley, M. R., & Kaber, D. B. (1999). Level of automation effects on performance, situation awareness and workload in a dynamic control task. Ergonomics, 42, 462-492.

Endsley, M. R., & Kiris, E. O. (1995). The out-of-the-loop performance problem and level of control in automation. Human Factors, 37, 381-394.

*Elias B. (2020). *Cockpit Automation, Flight Systems Complexity, and Aircraft Certification / Bart Elias.* [Library of Congress public edition]. Congressional Research Service.

*EU Research Programme Horizon 2020: 68 projects (ref. Jan 2022) mention Cockpit Automation

Evjemo, T. E., & Johnsen, S. (2019). Lessons Learned from Increased Automation in Aviation: The Paradox Related to the High Degree of Safety and Implications for Future Research. In Proceedings of the 29th European Safety and Reliability Conference (ESREL), 3076-3083.

*FAA (1996). The human factors team report on the interfaces between flightcrews and modern flight deck systems. Washington, DC: Federal Aviation Administration.

*FAA (2013). Operational use of flight path management systems. Report of the PARC/CAST Flight Deck Automation Working Group.

*FAA Advisory Circular (AC) 120-109A Stall Prevention and Recovery Training

*FAA AC 120-111 Upset Prevention and Recovery Training

*FAA AC 120-123 Flightpath Management

*FAA Safety Alert For Operators (SAFO) 13002 Manual Flight Operations

*FAA SAFO 17007 Manual Flight Operations Proficiency

Farjadian, A. B., Thomsen, B., Annaswamy, A. M., & D. D. Woods, D. D. (2021). Resilient flight control: An architecture for human supervision of automation. IEEE Transactions on Control Systems Technology, 29, 29-42. doi: 10.1109/TCST.2019.2959542.

Feigh, K. M., & Pritchett, A. R. (2013). Requirements for effective function allocation: A critical review. Journal of Cognitive Engineering and Decision Making, 8, 23-32.

Feltovich, P. J. (2004). Keeping It Too Simple: How the Reductive Tendency Affects Cognitive Engineering. IEEE Intelligent Systems, 19, 90-94.

Feltovich, P. J., Spiro, R. J., & Coulson, R. L. (1991). Learning, Teaching and Testing for Complex

Ferris, T., Wickens, C. D., & Sarter, N. (2010). Cockpit Automation: Still Struggling to Catch Up. In E. Salas and D. Maurino (Eds.), Human Factors in Aviation (2nd edition; pp. 79-502). New York, NY: Elsevier Publishers.

Flach, J. M., & Dominguez, C. O. (1995). USE – Centered design: Integrating the user, instrument, and goal. Ergonomics in Design the Quarterly of Human Factors Applications 3, 19-24. doi:10.1177/106480469500300306

Flight Deck Disturbance Management: A Simulator Study of Diagnosis and Recovery Automation Coordination

Flight Operations Briefing Notes Standard Operating Procedures Optimum Use of Automation

Flight Safety Foundation (2014). A practical guide for improving flight path monitoring. Final Report of the Active Pilot Monitoring Working Group.

Flight Systems Complexity, and Aircraft Certification: Background and Issues for Congress

Flying the Needles: Flight deck automation erodes fine-motor flying skills among airline pilots

Funk, K., Lyall, B., Wilson, J., Vint, R., Niemczyk, M., Suroteguh, C., & Owen, G. (1999) Flight deck automation issues, The International Journal of Aviation Psychology, 9, 109-123, doi: 10.1207/s15327108ijap0902_2

Geiselman, E. E., Johnson, C. M., & Buck, D. R. (2013a). Flight deck automation: Invaluable collaborator or insidious enabler? Ergonomics in Design: The Quarterly of Human Factors Applications, 21, 22–26.

Geiselman, E. E., Johnson, C. M., Buck, D. R., & Patrick, T. (2013b). Flight deck automation: A call for context-aware logic to improve safety. Ergonomics in Design: The Quarterly of Human Factors Applications, 21, 13-18.

General Perspectives and Guidance for Design of Modes and Alerts

Gopher, D. (1993). The Skill of Attention Control: Acquisition And Execution of Attention Strategies. In D. Meyer and S. Kornblum (Eds.), Attention and Performance XIV. Hillsdale, NJ: Erlbaum.

Hahn, E. C., & Hansman, R. J. (1992). Experimental studies on the effect of automation on pilot situational awareness in the datalink ATC environment. (SAE technical Report 851956). Warrendale, PA: SAE.

Haight, J. M. (2020). Adaptive automation and its health and safety challenges. Journal of Safety Research, 74, 149-152. doi.org/10.1016/j.jsr.2020.06.014

*Haslbeck, A. & Hoermann, H-J. (2016). Flying the Needles: Flight deck automation erodes fine-motor flying skills among airline pilots. Human Factors: The Journal of the Human Factors and Ergonomics Society, 58, 533-545.

Herndon, A. A., Cramer, M., & Nicholson, T. (2009). Analysis of Advanced Flight Management Systems (FMSs), FMC Field Observations Trials, Lateral and Vertical Path Integration, F064-L09-049-001, The MITRE Corporation, McLean, VA, September 1, 2009.

Herndon, A. A., Cramer, M., Nicholson, T. (2009). Analysis of Advanced Flight Management Systems (FMSs), FMC Field Observations Trials, Lateral and Vertical Path Integration, F064-L09-049-001, The MITRE Corporation, McLean, VA, September 1, 2009.

Herndon, A. A., Cramer, M., Nicholson, T., & Miller, S. (2012) Analysis of Advanced Flight Management Systems (FMSs), FMC Field Observations Trials, Standard Instrument Departure with Radius-to-Fix (RF) Path Terminators, F03L-L12-013, The MITRE Corporation, McLean, VA, July 31, 2012.

Herndon, A. A., Cramer, M., Nicholson, T., Miller, S. (2010). Analysis of Advanced Flight Management Systems (FMSs), FMC Field Observations Trials, Standard Instrument Departures, F064-L10-030-001, The MITRE Corporation, McLean, VA, September 1, 2010.

Herndon, A. A., Cramer, M., Nicholson, T., Miller, S. (2011). Analysis of Advanced Flight Management Systems (FMSs), FMC Field Observations Trials, Area Navigation (RNAV) Holding, F064-L11-027-001, The MITRE Corporation, McLean, VA, July 31, 2011.

Herndon, A. A., Cramer, M., Sprong, K. (2008). Analysis of Advanced Flight Management Systems (FMSs), FMC Field Observations Trials, Radius-to-Fix Path Terminators, F083-L08-047-001, The MITRE Corporation, McLean, VA, July 31, 2008.

Herndon, A. A., Cramer, M., Sprong, K., Mayer, R. (2007). Analysis of Advanced Flight Management Systems (FMSs), FMC Field Observations Trials, Vertical Path, F083-L07-001, The MITRE Corporation, McLean, VA, July 31, 2007.

Hew, P. C. (2017). Detecting occurrences of the “substitution myth”: A systems engineering template for modeling the supervision of automation. Journal of Cognitive Engineering and Decision Making, 11(2), 184-199.

Hoff, K. A., & Bashir, M. (2015). Trust in automation: Integrating empirical evidence on factors that influence trust. Human Factors, 57, 407–434.

Hollnagel, E. (1999). From function allocation to function congruence. In Dekker, S and Hollnagel, E. (Eds.) Coping with computers in the cockpit. (pp 29-53). Aldershot, UK: Ashgate.

Hollnagel, E., & Bye, A. (2000). Principles for modelling function allocation. International Journal of Human-Computer Studies, 52, 253–265.

Hollnagel, E., Woods, D.D., and Leveson, N. (2006). Resilience Engineering: Concepts and Precepts. Ashgate.

Howard, M. (1999). Visualising automation behaviour. In Dekker, S and Hollnagel, E. (Eds.) Coping with computers in the cockpit (pp 55-67). Aldershot, UK: Ashgate.

https://safetyfirst.airbus.com/app/themes/mh_newsdesk/documents/archives/the-golden-rules-for-pilots.pdf

https://www.smartcockpit.com/docs/Optimum_Use_Of_Automation.pdf

Human-Machine Interaction in the Cockpit and Applicable Design Changes Towards Better Collaboration. In Advances in Human Factors and System Interactions

IATA (2011). Flight Crew Computer Errors (FMS, EFB) Case Studies, Montreal, Quebec, October 2011.

IATA (2015). FMS data entry error prevention best practices. Montreal, Quebec.

IATA (2016). Guidance material for improving flight crew monitoring. Montreal, Quebec.

*IATA (2020) Aircraft Handling and Manual Flying Skills Report

*ICAO (2019). Pilot training improvements to address automation dependency. A40-WP/296 TE/120.

*ICAO A40 WP 296 US, EASA SIB 2013-05

*ICAO AN-Conf/12-WP/3 EU

*ICAO Doc 10011 Manual on Aeroplane Upset Prevention and Recovery Training

Ijtsma, M., Ma, L. M., Pritchett, A. R., & Feigh, K. M. (2019). Computational methodology for the allocation of work and interaction in human-robot teams. Journal of Cognitive Engineering and Decision Making, 13, 221-241.

Investigating Mode Errors on Automated Flight Decks

Janssen, C. P., Donker, S. F., Brumby, D. P., & Kun, A. L. (2019). History and future of human-automation interaction. International Journal of Human-Computer Studies, 131, 99-107. https://doi.org/10.1016/j.ijhcs.2019.05.006.

Jipp, M., & Ackerman, P. L. (2016). The impact of higher levels of automation on performance and situation awareness: A function of information-processing ability and working-memory capacity. Journal of Cognitive Engineering and Decision Making, 10, 138-166.

Johnson, A., Duda, K., Sheridan, T., & Oman, C. (2017). A Closed-Loop Model of Operator Visual Attention, Situation Awareness, and Performance Across Automation Mode Transitions. Human Factors: The Journal of Human Factors and Ergonomics Society, 59, 229 - 241.

Johnson, M., & Vera, A. (2019). No AI is an island: the case for teaming intelligence. AI Magazine, 40(1), 16-28.

Jordan, N. (1963). Allocation of Functions Between Man and Machines in Automated Systems. Journal of Applied Psychology, 47, 161-165.

Kaber, D. B. (2017). Issues in human-automation interaction modeling: Presumptive aspects of frameworks of types and levels of automation. Journal of Cognitive Engineering and Decision Making, 12, 7-24.

Kaber, D. B., & Endsley, M. R. (2004). The effects of level of automation and adaptive automation on human performance, situation awareness and workload in a dynamic control task. Theoretical Issues in Ergonomics Science, 5, 113-153.

Klein, G., Woods, D. D., Bradshaw, J. M., Hoffman, R. R., & Feltovich, P. J. (2004). Ten challenges for making automation a "team player" in joint human-agent activity. In IEEE Intelligent Systems, 19, 91-95. doi: 10.1109/MIS.2004.74.

Körte, J. (2003). Risk-based emergency decision support. Reliability Engineering & System Safety, 82, 235-246.

Lancaster, J. A. & Casali, J. G. (2008). Investigating pilot performance using mixed-modality simulated data link. Human Factors, 50, 183-193.

Landman, A., Groen, E. L., van Paassen M. M. R., Bronkhorst, A. W., & Mulder, M. (2017). Dealing With Unexpected Events on the Flight Deck: A Conceptual Model of Startle and Surprise. Human Factors, 59, 1161-1172. doi: 10.1177/0018720817723428. Epub 2017 Aug 4. PMID: 28777917; PMCID: PMC5682572.

Layton, C., Smith, P. J., & McCoy, E. (1994). The design of a cooperative problem solving system for enroute flight planning: An empirical evaluation. Human Factors, 36, 94-119.

Lazaro, M. J., Kang, Y., Yun, M. H., & Kim, S. (2021). The effects of visual complexity and decluttering methods on visual search and target detection in cockpit displays. International Journal of Human-Computer Interaction, 37, 588-600.

Lee, J. D., See, K. A. (2004). Trust in automation: Designing for appropriate reliance. Human Factors, 46, 50–80.

Lee, J., & Moray, N. (1992). Trust, control strategies and allocation of function in human-machine systems. Ergonomics, 35, 1243-1270.

Levenson, N. G. (2001). The role of software in recent aerospace accidents. Proceedings of the 19th International Systems Safety Conference.

Li, W., Zhang, J., Minh, T.L., Cao, J., & Wang, L. (2019). Visual scan patterns reflect to human-computer interactions on processing different types of messages in the flight deck. International Journal of Industrial Ergonomics, 72, 54-60.

Li, W-C., Horn, A., Sun, Z., Zhang, J., & Braithwaite, G. (2020) Augmented visualization cues on primary flight display facilitating pilot's monitoring performance. International Journal of Human-Computer Studies, 135, 102377.

Lu, S., Wickens, C., Sarter, N., Thomas, L., Nikolic, M., & Sebok, A. (2012). Redundancy Gains in Communication Tasks: A Comparison of Auditory, Visual, and Redundant Auditory-Visual Information Presentation on NextGen Flight Decks. In Proceedings of the 56th Annual Meeting of the Human Factors Society.

Lyall-Wilson, E., Serber, M., Jarrott, B., Baker, R., Herndon, A., Miller, S., McKenney, D., Reed, C. (2017). Update to 2013 Performance-Based Aviation Rulemaking Committee and Commercial Aviation Safety Team (PARC/CAST) Flight Deck Automation Working Group - Accident and Major Incident Analysis. MITRE Technical Report MTR170068.

Lyall-Wilson, E., McKenney, D., Wyatt, P. (2023) Update 2 to 2013 Performance-Based Aviation Rulemaking Committee and Commercial Aviation Safety Team (PARC/CAST) Flight Deck Automation Working Group Accident and Major Incident Analyses. MITRE Technical Report MTR230094.

Lyall-Wilson, E, et. al. (2023) Pilot Dependence on Flight Deck Automated Systems for Flight Path Management. MITRE Technical Report MTR230091.

Lyons J. B. et al. (2017) Shaping Trust Through Transparent Design: Theoretical and Experimental Guidelines. In: Savage-Knepshield P., Chen J. (eds) Advances in Human Factors in Robots and Unmanned Systems. Advances in Intelligent Systems and Computing, vol 499. Springer, Cham. https://doi.org/10.1007/978-3-319-41959-6_11

Lyons, J. B., Koltai, K. S., Ho, N. T., Johnson, W. B., Smith, D. E., & Shively, J. (2016). Engineering trust in complex automated systems. Ergonomics in Design: The Quarterly of Human Factors Applications, 24, 13-17.

Maiwald, F., & Schulte, A. (2014). Enhancing military helicopter pilot assistant system through resource adaptive dialogue management. In Vidulich, M.A., Tsang, P.S., und Flach, J.M. (Hrsg.) Advances in Aviation Psychology. 177–196. Ashgate Studies in Human Factors and Flight Operations

Malin, J., Schreckenghost, D., Woods, D., Potter, S., Johannesen, L., Holloway, M., and Forbus, K. (1991) Making intelligent Systems team players: Case studies and design issues. (NASA Tech Memo 104738). Houston, TX: NASA Johnson Space Center.

Márquez, J., & Gore, B. (2017). Measuring Safety and Performance in Human–Automation Systems. Human Factors: The Journal of Human Factors and Ergonomics Society, 59, 169 - 171. https://journals.sagepub.com/doi/full/10.1177/0018720817696300

Mastering automation: New airline pilots’ perspective

McDermott, P., Dominguez, C., Kasdaglis, N., Ryan, M., Trahan, I., & Nelson, A. (2018). Human-machine teaming systems engineering guide. The MITRE Corporation, 17-4208.

Miller, C. A. (2021). Trust, transparency, explanation, and planning: Why we need a lifecycle perspective on human-automation interaction. In C. S. Nam, & J. B. Lyons, (Eds.) Trust in Human-Robot Interaction, Academic Press, 233-257.

Miller, C. A., & Parasuraman, R. (2003). Beyond levels of automation: an architecture for more flexible human-automation collaboration. HFES, 47, 182–186.

Miller, C., & Parasuraman, R. (2007). Designing for flexible interaction between humans and automation: Delegation interfaces for supervisory control. Human Factors, 49, 7-63.

*Miller, S. P., Barber, S., Carlson, T. M., Lempia, D. L., & Tribble, A. C. (2002). A methodology for improving mode awareness in flight guidance design. In proceedings of the 21st Digital Avionics Systems Conference, 2002, pp. 7D1-7D1, doi: 10.1109/DASC.2002.1052928.

Mindell, D. A. (2015). Our robots, ourselves: Robotics and the myths of autonomy. Viking.

Molloy, R., & Parasuraman, R. (1996). Monitoring an automated system for a single failure: Vigilance and task complexity effects. Human Factors, 38, 311–322.

Mosier, K. L., Fischer, U., Morrow, D., Feigh, K. M., Durso, F. T., Sullivan, K., & Pop, V. (2013). Automation, task, and context features: Impacts on pilots' judgments of human-automation interaction. Journal of Cognitive Engineering and Decision Making, 7, 377-399.

Mouloua, M., & Hancock, P. A. (2019). Human performance in automated systems: Current theory and methods (1st Edition). CRC Press.

Muir, B. M. (1987). Trust between humans and machines, and the design of decision aids. International Journal of Man-Machine Studies, 27, 527-539.

Mumaw, R. J. (2017). Analysis of alerting system failures in commercial aviation accidents. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 61, 110-114.

Mumaw, R., Billman, D. and Feary, M. (2020) Analysis of Pilot Monitoring Skills and a Review of Training Effectiveness. NASA TM–20210000047.

Murphy, E. D., & Mitchell, C. (1986). Cognitive attributes: Implications for display design in supervisory control systems. International Journal of Man-Machine Studies, 25, 411-438.

National Transportation Safety Board (NTSB). (2010). Loss of control on approach

Colgan Air, Inc. operating as Continental connection flight 3407 Bombardier DHC-8-400, N200WQ (NTSB/AAR-10/01). Retrieved from https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR1001.pdf

National Transportation Safety Board (NTSB). (2013). Crash during a nighttime nonprecision instrument approach to landing UPS flight 1354 Airbus A300-600, N155UP (NTSB/AAR-14/02). Retrieved from https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR1402.pdf

National Transportation Safety Board (NTSB). (2014). Descent below visual glidepath and impact with seawall Asiana Airlines flight 214, Boeing 777-200ER, HL7742 - San Francisco, California (NTSB/AAR-14/01 PB2014-105984). Retrieved from https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR1401.pdf

National Academy of Sciences. (2014). Autonomy Research for Civil Aviation: Toward a New Era of Flight. Committee on Autonomy Research for Civil Aviation; Aeronautics and Space Engineering Board; Division on Engineering and Physical Sciences; National Research Council.

*Nikolic, M. I., & Sarter, N. B. (2007). Flight deck disturbance management: a simulator study of diagnosis and recovery from breakdowns in pilot-automation coordination. Human Factors, 49, 553-563.

Nikolic, M. I., Orr, J. M., & Sarter, N. B. (2004). Why Pilots Miss the Green Box: How Display Context Undermines Attention Capture. The International Journal of Aviation Psychology, 14, 39–52.

Norman, D. A. (1988). The Psychology of Everyday Things. New York, Basic Books.

Norman, D. A. (1990). The 'Problem' with Automation: Inappropriate Feedback and Interaction, not 'Over-Automation'. Philosophical Transactions of the Royal Society of London, B 327, 585-593.

Norman, D. A. (1993). Things That Make Us Smart: Defending Human Attributes in the Age of the Machine. Reading MA: Addison-Wesley.

Nunes, I. (2017). Advances in Human Factors and System Interactions: Proceedings of the AHFE 2016 International Conference on Human Factors and System Interactions, July 27-31, 2016, Walt Disney World®, Florida, USA. 10.1007/978-3-319-41956-5.

Olson, W. A. (1999). Supporting Coordination in Widely Distributed Cognitive Systems: The Role of Conflict Type, Time Pressure, Display Design, and Trust. Ph.D. Dissertation, Champaign, IL: University of Illinois.

Olson, W. A. (2000). Identifying and mitigating the risks of cockpit automation. Air Command and Staff College, AU/ACSC/138/2000-04.

Olson, W. A., & Sarter, N. B. (2001). Management by consent in human-machine systems: When and why it breaks down. Human Factors: The Journal of the Human Factors and Ergonomics Society, 43, 255-266.

Onken, R., & Schulte, A. (2010). System-ergonomic design of cognitive automation: dual-mode cognitive design of vehicle guidance and control work systems. Springer-Verlag, Berlin

Onnasch, L. (2015). Crossing the boundaries of automation—Function allocation and reliability. International Journal of Human-Computer Studies, 76, 12-21.

Onnasch, L., Wickens, C., Li, H., & Manzey, D. (2014). Human Performance Consequences of Stages and Levels of Automation. Human Factors: The Journal of Human Factors and Ergonomics Society, 56, 476 - 488.

Ormerod, P., & Colbaugh, R. (2006). Cascades of failure and extinction in evolving complex systems. Journal of Artificial Societies and Social Simulation, 9. http://jasss.soc.surrey.ac.uk/9/4/9.html

Owen, David (2013) The Golden Rules for Pilots Moving from PNF to PM, by David Owen, in the Airbus Safety First magazine - issue 15 Feb. 2013

Palmer, M. T., & Abbott, K. (1994). Effects of expected-value information and display format on recognition of aircraft subsystem abnormalities. NASA TP-3395. NASA Langley Research Center.

Papadimitriou, E., Schneider, C., Tello, J. A., Damen, W., Vrouenraets, M. L. & ten Broeke, A. (2020). Transport safety and human factors in the era of automation: What can transport modes learn from each other? Accident Analysis & Prevention, 144, 105656.

Parasuraman, R. (2000). Designing automation for human use: empirical studies and quantitative models. Ergonomics, 43, 931-951.

Parasuraman, R., & Manzey, D. H. (2010). Complacency and bias in human use of automation: an attentional integration. Human Factors, 52, 381-410.

Parasuraman, R., & Riley, V. (1997). Humans and Automation: Use, Misuse, Disuse, Abuse. Human Factors, 39, 230-253.

Parasuraman, R., & Wickens, C. (2008). Humans: Still vital after all these years of automation. Human Factors, 50, 511-520.

Parasuraman, R., Mouloua, M., & Molloy, R. (1996). Effects of adaptive task allocation on monitoring of automated systems. Human Factors, 38, 665-679.

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans, 30, 286–297.

Parasuraman, R., Sheridan, T., & Wickens, C. (2008). Situation awareness, mental workload, and trust in automation: Viable, empirically supported cognitive engineering constructs. Journal of Cognitive Engineering and Decision Making, 2, 140–160.

Parnell, K. J., Wynne, R. A., Griffin, T. G. C., Plant, K. L., & Stanton, N. A. (2021) Generating design requirements for flight deck applications: Applying the perceptual cycle model to engine failures on take-off. International Journal of Human–Computer Interaction, 37, 611-629. doi: 10.1080/10447318.2021.1890488

Patterson, R. E., & Eggleston R. G. (2019) The Blending of Human and Autonomous-Machine Cognition. In Vallverdú J., Müller V. (eds) Blended Cognition. Springer Series in Cognitive and

Neural Systems, vol 12. Springer, Cham. https://doi.org/10.1007/978-3-030-03104-6_8Perrow, Charles. Normal Accidents: Living with High-risk Technologies. New York: Basic, 1984.

Pilot Dependence on Flight Deck Automated Systems for Flight Path Management MITRE Technical Report MTR230091

Prevot, T., Palmer, E., & B. Crane, B. (1997). Flight crew support for automated negotiation of descent and arrival clearances. Proceedings of the 7th International Symposium on Aviation Psychology. Columbus, OH: Ohio State University. 697 – 702.

*Pritchett, A. R. (2009). Aviation automation: General perspectives and specific guidance for the design of modes and alerts. In F. T. Durso (ed.), Reviews of human factors and ergonomics, Vol. 5. (pp. 82-113). Santa Monica: Human Factors and Ergonomics Society.

Pritchett, A. R., Kim, S. Y., & Feigh, K. M. (2013). Modeling human-automation function allocation. Journal of Cognitive Engineering and Decision Making, 8, 33-51.

*Rankin, A., Woltjer, R., & Field, J. (2016). Sensemaking following surprise in the cockpit—A re-framing problem. Cognition, Technology, & Work, 18, 623-642.

Rasmussen, J. (1985). The role of hierarchical knowledge representation in decisionmaking and system management. IEEE Transactions on Systems, Man, and Cybernetics, SMC-15, 234-243.

Rignér, J. & Dekker, S. W. A. (1999). Modern flight training – managing automation or learning to fly? In Dekker, S and Hollnagel, E. (Eds.) Coping with computers in the cockpit (pp 145-151). Aldershot, UK: Ashgate.

Rosen, H. (2004). Designing for anticipation: a graphical representation of automation behavior. Thesis Linköping University, Department of Computer and Information Science.

*Sarter, N. (2008). Investigating mode errors on automated flight decks: illustrating the problem-driven, cumulative, and interdisciplinary nature of human factors research. Human Factors, 50, 506-510.

Sarter, N. B. & Woods, D. D. (1994a). Pilot Interaction with Cockpit Automation II: An Experimental Study of Pilots' Model and Awareness of the Flight Management and Guidance System. International Journal of Aviation Psychology, 4, 1-28.

Sarter, N. B., & Woods, D. D. (1995). How in the world did we ever get into that mode? Mode error and awareness in supervisory control. Human factors, 37(1), 5-19.

Sarter, N. B. (1996). Cockpit automation: From Quantity to Quality, From Individual Pilot to Multiple Agents, In R. Parasuraman and M. Mouloula, editors, Automation Technology and Human Performance, Erlbaum.

*Sarter, N. B., & Woods, D. D. (1997a). Teamplay with A Powerful and Independent Agent: A Corpus of Operational Experiences and Automation Surprises on the Airbus A-320. Human Factors, 39, 553-569. (Article was reprinted in Journal of Human Performance in Extreme Report of the PARC/CAST Flight Deck Automation WG Environments, 4(2), April 2000).

Sarter, N. B., Mumaw, R. J., & Wickens, C. D. (2007). Pilots' monitoring strategies and performance on automated flight decks: an empirical study combining behavioral and eye-tracking data. Human Factors, 49, 347-357.

*Sarter, N.B. and Woods, D.D. (2000). Teamplay with a Powerful and Independent Agent: A Full-Mission Simulation Study. Human Factors, 42, 390-402.

Schutte, P.C. (2017). How to make the most of your human: design considerations for human-machine interactions. Cognition, Technology and Work, 19, 2-3.

Sensemaking following surprise in the cockpit—A re-framing problem

*SKYbrary Automated Cockpit Guidelines (Operator's Guide to Human Factors in Aviation (OGHFA) Briefing Note) https://skybrary.aero/articles/automated-cockpit-guidelines-oghfa-bn

*SKYbrary Cockpit Automation Advantages and Safety Challenges https://skybrary.aero/articles/cockpit-automation-advantages-and-safety-challenges

*SKYbrary EUROCONTROL Hindsight 20 Automation, 2014 https://skybrary.aero/articles/hindsight-20

*SKYbrary FSF, ERA, EUROCONTROL Automation and Safety Forum, 2015 https://skybrary.aero/themes/annual-safety-forums/automation-and-safety

*Soo, K. K. Y., Mavin, T. J., & Kikkawa, Y. (2021). Mastering automation: New airline pilots' perspective. International Journal of Human-Computer Interaction, 37, 717-727.

*Strauch, B. (2017). The Automation-by-Expertise-by-Training Interaction: Why Automation-Related Accidents Continue to Occur in Sociotechnical Systems

Sumwalt, R., Cross, D., & Lessard, D. (2015). Examining how breakdowns in pilot monitoring of the aircraft flight path. International Journal of Aviation, Aeronautics, and Aerospace, 2(3), 8.

*Taylor, A. (2017). Human-Machine Interaction in the Cockpit and Applicable Design Changes Towards Better Collaboration. In Advances in Human Factors and System Interactions (pp. 271-279).

Team Play with a Powerful and Independent Agent: A Full-Mission Simulation Study

Team Play with a Powerful and Independent Agent: Operational Experiences and Automation Surprises on the Airbus A-320

The Automation-by-Expertise-by-Training Interaction: Why Automation-Related Accidents Continue to Occur in Sociotechnical Systems

Tokadli, G., Dorneich, M. C., & Matessa, M. (2021) Evaluation of playbook delegation approach in human-autonomy teaming for single pilot operations. International Journal of Human–Computer Interaction, 37, 703-716. doi: 10.1080/10447318.2021.1890485

Veillette, P. R. (1995). Differences in aircrew manual skills in automated and conventional flight decks. Transportation Research Record, 1480, 43-50.

Wickens, C. D. (2018). Automation stages & levels, 20 years after. Journal of Cognitive Engineering and Decision Making, 12, 35-41.

Wickens, C., & Colcombe, A. (2007). Dual-task performance consequences of imperfect alerting associated with a cockpit display of traffic information. Human Factors, 49, 839-850.

Wickens, C., Hooey, B., Gore, B., Sebok, A., & Koenicke, C.S. (2009). Identifying Black Swans in NextGen: Predicting Human Performance in Off-Nominal Conditions. Human Factors: The Journal of Human Factors and Ergonomics Society, 51, 638 - 651.

Wies, Matthias. (2016). Analysing and Improving Pilots' Auto Flight System Mode Awareness.

Woods D. D. (1996). Decomposing Automation: Apparent Simplicity, Real Complexity. In Parasuraman, R. and Mouloua, M. (Eds.) Automation and Human Performance: Theory and Applications (pp. 3-17). Hillsdale, NJ, USA: Lawrence Erlbaum Associates.

Woods, D. D. & Sarter, N. B. (1998). Learning from automation surprises and 'going sour' accidents: Progress on human-centered automation (report ERGO-CSEL-98-02). Columbus, OH, USA: Institute for ergonomics, The Ohio State University.

Woods, D. D., & Sarter, N. B. (2000). Learning from automation surprises and ‘going sour’ accidents. In N. Sarter, R. Amalberti (Eds.) Cognitive Engineering in the Aviation Domain, Mahwah, NJ: Erlbaum, pp 327-353

8 Appendix D Regulatory Material

Topic		**Regulatory Guidance Analysis**		
		Authority from a State affiliated with APAC		
AM	Keywords	**Basic UPRT** **Flight Path Management (automation)** (theory and flight training) **Automation management** theory and flight training **Aircraft automation systems**-theory **Automation management as part of MCC**	Areas of focus	Required Navigation Performance (RNP) Approaches, Gen 4- emergency descent, Traffic Alert and Collision Avoidance System (TCAS) Autopilot
MF	Keywords	**Basic UPRT** **Advanced UPRT** **Flight Path Management (manual control)** **Flight Path Monitoring** **UPRT**	Areas of focus	Failures of FD system, MF without FD guidance, ILS without FD one-engine inoperative, maximum crosswind, rejected takeoff Stall, Nose-high, Nose-low, Spiral dives, Incipient spin
PM	Keywords	**MCC** **Type-specific UPRT** **CRM**	Areas of focus	
		Second authority from a State affiliated with APAC		
AM	Keywords	**UPRT scenarios** **Flight path management - Manual** competence **Flight Path Management-Automation** competence **UPRT** scenarios	Areas of focus	proper management of the automation system importance of flight path management – manual and FPA competence
MF	Keywords	**UPRT** scenarios	Areas of focus	MF Description: Flying with AP off and with AT and FD in all possible combinations of ON/OFF: AP off, FD on, AT on AP off, FD on, AT off AP off, FD off, AT on AP off, FD off, AT off Stated goal: to maintain and improve pilots' MF competency

Topic		**Regulatory Guidance Analysis**		
				to minimize related human factor risks. Manual control for ILS approach, including single engine Rejected Takeoff V1 cut Go-around Time-based metrics for MF in operations: -MF time in any single flight leg should not be less than 6 minutes -Recommended 40 hours minimum MF time before Captain upgrade Conditions for MF in operations: Left to operator to define based on operational features and copilot's flying skills in different stages.
PM	Keywords	**PF** **PM**	Areas of focus	
		Third authority from a State affiliated with APAC		
AM	Keywords	**Flight Path Management** **TEM** **Use of technology to reduce workload, improve cognitive and manipulative activities** **Non-Technical Skills** **Automation competency** **Flight Path Management (automation management)**	Areas of focus	**Normal, non-normal, and emergency conditions** Low-visibility operations
MF	Keywords	**Flight Path Management (MF)** to include UPRT requirements **UPRT**	Areas of focus	Unusual attitude and upset Approach to stall Full stall consistent with UPRT guidance, Flight with unreliable airspeed, Emergency descent Stall recovery in accordance with UPRT guidance
PM	Keywords	**Non-Technical Skills** **Human Factors principles** **Active Flight Path Monitoring** **Flight Path Monitoring -Aircraft performance/configuring and systems**	Areas of focus	
		Authority from a State affiliated with EUR/NAT		

Topic		**Regulatory Guidance Analysis**		
AM	Keywords	**Complacency in automated environments** **Supervisory role (pilots)** **Detection of automation failures** **Automation Bias** **Reduction in manual skills correlated with use of automation** **Properly monitor automated functions** **Intervention** (with automation) **Automation tasks** **Lack of practice in direct control** **Basic UPRT** **Flight Path Management (automation)** **Aircraft automation systems** **Automation management** as part of MCC **CRM-Automation and philosophy on use of automation** **Monitoring and Intervention** **Control laws**	Areas of focus	Discussion on research of effects of automation, e.g.: -how availability of automation/decision aids encourages tendency to choose options of least cognitive effort. -discernible reduction in manual flying skills correlated w/use of automation…impact to both long and short haul flying. -Detection of automation failures is poor even after catastrophic failures Current training fails to adequately prepare crews to properly monitor automated functions nor when to intervene nor prepare (crews) to conduct an adequate range of automation tasks. Automated environments-complacency where pilot role has become supervisory and pilots lack practice in direct control. Recognition that different manufacturers and operators may stipulate different automation philosophies/policies Controls the aircraft flight path through automation, including appropriate use of FMS(s) and guidance. Behavioral indicators for Aircraft FPA: - Controls the aircraft using automation with accuracy and smoothness as appropriate to the situation - Detects deviations from the desired aircraft trajectory and takes appropriate action - Contains the aircraft within the normal flight envelope - Manages the flight path to achieve optimum operational performance - Maintains the desired flight path during flight using automation whilst managing other tasks and distractions

Topic		**Regulatory Guidance Analysis**		
				- Selects appropriate level and mode of automation in a timely manner considering phase of flight and workload - Effectively monitors automation, including engagement and automatic mode transitions Operator proficiency checks- should be used to encourage appropriate use of automation and normal operational procedures
MF	Keywords	**Basic UPRT- Flight Path Management** (theory and flight training) **Advanced UPRT for different flight conditions** (theory and flight training) **Aeroplane flight path management (manual control)** **UPRT- type-specific** **Flight Path Management (MF)** **Manual flight path management** **MFO** **Control laws** **Speeds**	Areas of focus	Acknowledges difficulty in even defining 'manual flying skills' Recognizes that different manufacturers and operators may stipulate different policies/philosophies that stipulate what should/should not be done Advanced UPRT flight conditions: Stall, Nose-high, Nose-low, Spiral dives, Incipient spin MF at different speeds and control laws: steep turns, UPRT (type specific) Operators include MF in flight operations only under certain conditions to be clearly described in their Operations Manual such as: - workload, -weather, - traffic density, etc. License proficiency checks – suggest focus on operation of aircraft in MF Flight Path Management – Manual Control - Controls the aircraft flight path through MF, including appropriate use of FMS(s) and flight guidance systems.

Topic		Regulatory Guidance Analysis		
				Behavioral markers for Flight Path Management Manual Control: - Controls the aircraft manually with accuracy and smoothness as appropriate to the situation - Detects deviations from the desired aircraft trajectory and takes appropriate action - Contains the aircraft within the normal flight envelope - Controls the aircraft safely using only the relationship between aircraft attitude, speed and thrust - Manages the flight path to achieve optimum operational performance - Maintains the desired flight path during MF whilst managing other tasks and distractions - Selects appropriate level and mode of flight guidance systems in a timely manner considering phase of flight and workload - Effectively monitors flight guidance systems including engagement and automatic mode transitions
PM	Keywords	**MCC** **PM/PF and interaction between the two roles** **UPRT- type specific** **CRM-** both PM and PF roles in specific operational environment **Intervention**	Areas of focus	Definition of PM: the observations and interpretation of - the flight path data, - configuration status, - automation modes and on-board systems appropriate to the phase of flight. It involves a cognitive comparison against the expected values, modes, and procedures. It also includes: observation of the other crew members and timely intervention in the event of deviation Also used to describe good monitoring generally
		Authority from a State affiliated with NACC		

Topic		Regulatory Guidance Analysis		
AM	Keywords	**Appropriate Use of Automation** **Automation Policy** **Core Philosophy** **Use of Automation** **Automation and Technology management** **Time-based metrics** **Flight Path Management** **Workload**	Areas of focus	Core philosophy: 'fly the aircraft' Definition of Appropriate Use of Automation: The pilot should decide what level of automation (e.g., AP or AT) to use that is consistent with operator's automation policy. Selected level of automation should provide best increase in safety and reduce workload appropriate to phase of flight Automation Policy should cover 7 topics: Philosophy, Levels of automation, Situation Awareness, Communication and Coordination, Verification, Systems and Crew monitoring, Workload and Systems use. Use of Automation training should emphasize: -Function and limitations of Vertical and Lateral -Automation modes; -FD selections; -Monitoring subtle mode changes regarding flight path management and ATs; -Protections-low speed/high Angle of Attack (AOA) and high speed; -Approaches above GS; -Go-around with all engines Time-based metrics-for Commercial Pilot Licence (CPL)/ATPL: -five hours in -Complex or Technically Advanced aeroplanes defined as having: -Glass flight deck -Global Positioning System (GPS) with Moving Map -Automated engine and system management.

Topic		**Regulatory Guidance Analysis**		
				-integrated autoflight/AP system for IFR and VFR operations Typical circumstances under which Automated Systems should be used: -high workload conditions, -operations in traffic_congested airspaces, -when specific airspace procedures (e.g., reduced vertical separation minima (RVSM)) or approach procedures (e.g., Category II/III) require use of AP for precise operations
MF	Keywords	**Manual Flying Skills** **Abnormal flight characteristics** **Intervention**	Areas of focus	Pilots need to maintain manual flying skills to a high degree of proficiency and must develop confidence in their ability to do so. The maintenance of manual flying skills will ensure that pilots are able to safely and accurately control the aircraft in all phases of flight and will be capable of responding to unforeseen events and circumstances. Slow flight, stalls, spins, slips Abnormal flight characteristics: Dutch roll, Buffet boundary onset, Aircraft upset Pilot expected to promptly intervene and/or may need to assume manual control of the aircraft in certain situations such as: Stall, Upset, Terrain Avoidance, or Windshear events. Entire CPL syllabus trained/tested in MF mode.

Topic		**Regulatory Guidance Analysis**		
PM	Keywords	**Pilot Not Flying**	Areas of focus	
		Second Authority from a State affiliated with NACC		
AM	Keywords	**Automation management** **Autopilot** **FMS** **Autoflight** **Automation systems** **Navigation** **Flight Path warning systems** **Flight Path Management** **Energy Management** **Flight Mode Annunciations** **Autoflight Mode awareness** **Intervention** **Automation surprises** **Input errors (FMS)** **Rare-normal operations** **CRM** **TEM**	Areas of focus	Flight Path Management definition: The planning, execution, and assurance of the guidance and control of aircraft trajectory and energy, in flight or on the ground Ensuring aircraft is on safe and correct flightpath is highest priority. This includes actions necessary to check/verify flightpath is correct, and to intervene as necessary if not correct. Controlling Flight Path defined as: Adjusting trajectory and energy state using any appropriate combination of manual or autoflight inputs. Other pilots on crew should be ready and able to intervene as necessary. Responsibility for flight path management should remain with the pilots at all times. Flight path management is the responsibility of the entire flightcrew and highest priority for all crew members. Onboard systems for flight path management: AP AT FD FMS Associated crew interfaces Also includes Envelope Protection Systems Flight path management guidance should customize for operator, consider manufacturer

Topic		Regulatory Guidance Analysis		
				recommendations, and be adapted to: Operational environment Equipment being operated Demographics of pilot group Operational safety data Operator's policies/organizational culture Attention to Flight Mode Annunciations and awareness of concepts of: Speed on pitch Speed on thrust Awareness of FMS input errors Training should include: Rare-normal conditions Conditions that do not have Checklists Operator guidance should focus on use of all tools for flight path management including automated systems or combination of systems, including MFO, and when to use/not use, and guidance on which combinations are best suited to different operational scenarios. Flight path management involves comparing actual flightpath to what is expected/desired. Anytime the aircraft is in motion, including during taxi, Flight path management requires pilots to observe and interpret: Flightpath data Aircraft configuration status Automated system modes Onboard systems as appropriate to phase of flight Progressive intervention strategies Reasonableness checks Unintended Autoflight states Unexpected disengagement

Topic		**Regulatory Guidance Analysis**		
MF	Keywords	**MFO** **Upset Recovery techniques** **Upset Prevention and Recovery** **Cognitive skills** **Psychomotor skills** **Normal and Non-normal events** **Stall prevention and recovery**	Areas of focus	Recovery from unusual attitudes Stall prevention and recovery Spin awareness Manually controlled: Slow flight Loss of reliable airspeed Instrument departure and arrival Upset prevention and recovery Stall prevention Hands-on full stall recovery Low-energy states/stalls Upset recovery techniques Recovery from bounced landing Takeoff with simulated engine failure Manually controlled ILS approach with simulated engine failure Manually flown takeoff, departure to cruise Manually flown descent, arrival, approach, and landing Definition of MFO: Those operations where the pilot is performing flight path management while physically controlling pitch, yaw, and/or thrust. MFO covers a broad range of situations, including where some automated systems are engaged or operating, not only when all automated systems are off. Examples of combinations of automation systems: FD on, AP off, AT on FD on, AP off, AT off FD off, AP off, AT off FD on, AP on, AT off FD off, AP off, AT on Subtle degradations of control and guidance systems. MFO includes flight path management using raw data which may require pilots to perform cognitive tasks without

Topic		Regulatory Guidance Analysis		
				the assistance of onboard systems like FD, AM, FMS MFO involves: - Cognitive skills- retaining/combining knowledge and applying it to perform complex mental tasks, problem solving, decision-making, Situation Awareness, system monitoring, calculations, visualizing flight path - Psychomotor skills - physical actions - Communications skills – meaningful interchange with other persons such as other crew, Air Traffic Control (ATC), dispatch Operator Policy should include appropriate opportunities for MFO in flight operations to maintain proficiency. These should consider: Weather conditions Workload conditions Time of day Crew experience Environment/ATC or procedural conditions Traffic Aircraft condition Operational threats Non-normal conditions Psychological or physical factors Quotas should be avoided (e.g., X amount of MFO per time period) unless there is scientific data to back it up. Augmented crew should be provided opportunities to get hands-on MFO experience MFO includes proficiency during expected and unexpected non-normal events that challenge cognitive as well as psychomotor skills.

Topic		Regulatory Guidance Analysis		
PM	Keywords	**PM** **PF** **Monitoring** **Flight Path management** **Projected flightpath** **Flightpath Deviations** **Aircraft state** **System status** **Displayed information** **Energy management** **Intervention** **Flight Mode Annunciators (FMA)** **Autoflight modes** **Attention** **Information** **Communication** **Crewmember performance** **Awareness of changes**	Areas of focus	Monitoring: Flight Path Displayed information Aircraft state System status Monitoring is an important aspect of ensuring flightpath. It is integral to flight path management and not a stand-alone. Monitoring includes crewmembers monitoring each other. The PM should recognize when the PF is not adequately controlling the flightpath and recognize the signs of diminished crewmember performance. Duties of PM: Effectively monitor flightpath Communicate with other pilot(s) when there is a flightpath deviation Know when and how to intervene when necessary PM is responsible for monitoring current and projected flightpath and energy of aircraft at all times (along with PF). PM supports the PF at all times, and stays abreast of aircraft state and ATC instructions and clearances. PM should stay in the loop even when the other pilot is PF. PM should monitor flight instruments just as if manually flying. PM should monitor: Flightpath changes System modes Aircraft responses PM should check: FMAs after changes selected FMAs and flight instruments after distractions PM should maintain: Awareness of automated changes (FMS) Awareness of capabilities of autoflight modes

Topic		Regulatory Guidance Analysis		
				PF's primary duty is to control the flightpath, and PM's duty is to: Monitor/ensure flightpath Assist the PF by assessing any actual or potential deviations from the flightpath Help to correct the autoflight settings as needed to restore desired behavior PF is responsible for control of flightpath. PM should be ready and able to intervene if necessary in Normal and Non-normal situations. PM should be fully capable of manually flying the aircraft to achieve desired flightpath. Proper monitoring of flightpath and allocation of tasks between PF and PM includes: Monitoring flightpath during all combinations of manual and/or automated flight Task allocation, workload, and system management strategies Methods to address malfunctions including malfunctions with no specific procedure If PF does not correct flightpath deviations in a timely manner the PM should intervene based on operator policy and procedures. -Flight path management policies and procedures should clearly define roles and responsibilities of all flightcrew (PF, PM, Captain, FO, any other required crew). -Protect PF ability to maintain focus on flight path management. -Non-flight path management tasks should be performed by other flightcrew members (e.g., PM) to maximum extent possible.

9 Appendix E Lessons Learned

Several lessons learned from automated systems may be useful for other domains. While the topics discussed below are derived from operational experience with aircraft systems, the lessons can be generalized to other domains. Additional information about lessons learned may be found in Abbott (2023); Cockpit Automation Advantages and Safety Challenges; EASA Automation Policy; Hindsight 20: Safety and Automation; among others that address the topics.

There are different types of automated systems. Use of the term "automation" may imply that we are talking about a single system (or a single type of system), when the reality is that there are many different automated systems on an aircraft, and those systems represent automation of different types of tasks. Billings (1997) described three categories of aircraft automation. The first was "control automation" or automation whose functions are the control and direction of an aeroplane (a system such as the AP is an example of control automation). The second category was "information automation" or automation devoted to the calculation, management and presentation of relevant information to flight crew members (for example, moving map displays or alerting systems). The third category was "management automation," or automation of the management tasks. For example, FMSs on aircraft use this type of automation for performance management, etc. Each type of automation has its own characteristics and considerations, and its own benefits and vulnerabilities.

While there is increasing implementation of automated systems in civil aircraft overall, there is considerable growth in the use of information automation systems. For example, EFBs are a mechanism to introduce applications of information automation (e.g. electronic navigation charts) into the flight deck. The number of EFBs is growing, and the number and types of applications implemented on these devices are increasing also.

Human factors issues can occur in use of information automation systems if the system characteristics and human performance considerations are not considered during development of system designs, training, and procedures. Billings (1991) was concerned that information automation could lead to too much information being presented to the flight crew and displays that are too cluttered. Billings also pointed out that information automation, which enables more information to be presented, has a potential cost in terms of the amount of workload and human information processing required for monitoring the functions and behaviour of the information automation system. Degani et al. (2013) also found that increased automation results in more information being needed, not less. The information automation characteristics and human performance constructs described above could lead to potential human factors concerns that are particularly relevant to information automation or may manifest themselves in unique ways relative to other types of automation.

EFBs (and future "information automation" systems) 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, such systems may have negative side effects if not implemented appropriately. They could increase pilot workload, increase head-down time, distract the flight crew from higher priority tasks, and contribute to flight crew communication and coordination issues. These potential impacts of EFBs and other "information automation" systems need to be addressed during both design and evaluation.[8]

Note that systems that include different types of automation may be used together. For example, a runway change while a flight is on arrival or approach to an airport may involve reprogramming the FMS, which calculates the new desired path based on flight performance/management objectives, and provides the input for the AP to follow. This is a combination of different types of automation and may combine benefits and vulnerabilities.

Considering the variability, integration, and combined uses of different types of automation is important to their successful design, approval, and operational use, from the pilots' perspective. Each type of automation has the potential for different benefits and vulnerabilities.

Mode confusion has long been identified as a potential vulnerability since the introduction of the modern flight deck (Sarter & Woods, 1995; etc.). While the FAA Human Factors Team Report on the Interfaces Between Flightcrews and Modern Flight Deck Systems (1996) identified insufficient autoflight mode awareness as an important vulnerability area, mode awareness is important in other aspects of aircraft systems (e.g. north-up versus track up display mode on the moving map display) and in many domains. 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 aeroplane types.
- Differences in the design implementation of modes intended to meet the same objective.
- Proliferation in the number of modes.
- Complexity in the flight crew interface (as perceived by the flight crew).
- 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 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, pilot training has addressed the issue through increased emphasis on mode awareness. Some operators' flight crew procedures attempt to mitigate the risk 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, and therefore have not implemented this procedure.

These mitigations were only partially successful. The data analysis in PARC/CAST FltDAWG report (2013) and in Lyall-Wilson et. al. (2017) revealed that autoflight mode selection,

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

awareness and understanding continue to be common vulnerabilities. Data from the "Accident/Incident Comparison" indicated that "mode selection errors" were cited in 27 % of the accidents reviewed. 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 narrative data.

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

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. These 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.

Replacement myth. One of the stated motivations for introducing automated systems is to replace a function or task done by a pilot. However, operational experience has shown that replacement is rarely what actually happens (Mindell, 2015; Johnson & Vera, 2019). Dekker and Woods (2002) argue that substitution-based function allocation methods (such as MABA-MABA, or Men-Are-Better-At/Machines-Are-Better-At lists) do not consider that the real effects of automation are qualitative: it transforms human practice and forces people to adapt their skills and routines. When the problem is viewed as replacement, it fosters "the idea that new technology can be introduced as a simple substitution of machines for people — preserving the basic system while improving it on some output measure (lower workload, better economy, fewer errors, higher accuracy)" (Dekker & Woods, 2002). This viewpoint is one of the myths of autonomous systems (Bradshaw et al., 2013) and it can lead to undesirable consequences, including clumsy automation[9] (Wiener, 1989) and automation surprises (Woods; 1996; Sarter, Woods, and Billings, 1997). Hew (2017) refers to this as the substitution myth and points out that if work is reallocated from a human to a machine, then there is work incurred to ensure that the machine is working properly—it must be supervised.

Another consideration of the motivation to replace a human with an automated system is that introduction of increasingly automated or autonomous systems has been shown to potentially increase staffing requirements for an operation (Blackhurst, 2011; Mindell, 2015; Johnson &

[9] Clumsy automation refers to the situation where automation makes easy tasks easier and hard tasks harder. With clumsy automation, the users' understanding of the context and situation awareness is reduced due to being out-of-the-loop. Consequently, workload reduces in an already low workload environment and increases during high workload situations.

Vera, 2019) and, when it does reduce staffing requirements, potentially increases the level of expertise required in the staff that remains.

Training related to automated systems. Related to the replacement myth is the misperception that introducing an automated system to "replace" the pilot means that the pilot no longer needs to be trained on that task or function. In fact, experience has shown that introducing an automated system often may increase training requirements, because there are additional knowledge and skills that the pilots need to know:

- How the system works (a mental model of the system and its operation)
- How to operate the system
- How to monitor the system
- How to recover or manage an unintended state or malfunction. This may involve reverting to operation without the automated system.

In addition, the pilots still need to know about the aircraft systems overall, and how to operate in the airspace. The transition from classic flight instruments and ground-based navigation to modern flight decks began in the early 1980s with the introduction of the Boeing 757, 767 and Airbus 320. These aeroplane types incorporated features such as integrated "glass" displays, flight guidance systems and FMSs, all integrated with the autoflight 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 revised.

Airspace operations are evolving (FAA 2013). 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. More recently, technologies such as Global Navigation Satellite System (GNSS) and Required Navigation Performance (RNP) have enabled approaches with vertical guidance. As a result, 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 have evolved. This has resulted in a corresponding increase in the set of required skills and knowledge that pilots need for flight operations. Therefore, the need for training has correspondingly increased.

Pilot monitoring has been identified as critical for aviation safety (Sumwalt et. Al. 2002; FAA 2013; Sumwalt et. al. 2015). The commercial aviation industry worldwide has identified a need for improved PM and awareness (e.g., FAA, 2013; IATA, 2016). More specifically, aviation safety data indicate that failures in pilots' flight path management monitoring and awareness (including monitoring of associated automated systems) have contributed to a range of undesired outcomes: accidents, major upsets, and non-compliance with air traffic control (ATC) guidance.

Sarter, Mumaw, and Wickens (2007) describe PM strategies and performance in automated aircraft.

The FAA has further stated that these types of issues are likely to worsen with the increasingly complex air traffic control systems and flight path management concepts proposed for NextGen (https://www.faa. gov/nextgen/what_is_nextgen/) operations (e.g., see Hah et al., 2017). Adding to this complexity is the introduction of increasingly automated aircraft systems that can increase monitoring burdens (Billman, Mumaw, & Feary 2020; Mumaw, Billman & Feary, 2020).

Based on these concerns, equipment design, pilot training and operational policies and procedures should be improved to support the pilots' ability to monitor the systems.

Operational policies. One practical consideration for operators concerns the operational policy and procedures they develop for the pilots to follow. Many operators had an automation policy, though these can vary significantly. Some policies allowed pilots to use whatever automation they consider appropriate, while others required use of the highest level of automation possible for the circumstances. Even operators of the same aeroplane type, which is supported by a common, manufacturer-based philosophy and procedures, differed markedly from each other in some cases. These differences are due to a variety of valid reasons including each operator's unique history, culture and operational environment.

However, the focus on management of automated systems was not always well integrated with the focus on managing the flight path of the aircraft, which is the primary job of the pilots. Too much focus on managing the automated systems may distract from the tasks associated with flight path management.

Degradation of basic skills. In the flight deck, MF skills are basic and foundational. Concerns with pilot MF skills have been identified since the introduction of modern flight automated systems ((Veillette 1995; FAA, 1996); Field and Lemmer, 2014; Casner et. al., 2014a; Casner & Schooler, 2014b). The concern has been expressed that automated systems in the flight deck have caused this degradation of basic flying skills. The data do show that pilot knowledge and skills for MFO (including both "stick and rudder" and cognitive skills), are a vulnerability area in some cases. However, automated systems do not directly cause degradation in knowledge and skills for MFO – but lack of practice does. Therefore, opportunities to practice basic skills are important for development and maintenance of those skills.

10 Appendix F Results and Observations

This Appendix contains results from analyses and observations by subgroup.

10.1 Automation Dependency Subgroup

The review of the accidents/major incidents report reviews identified 28 of 77 (36%) accidents reports and 47/309 (15%) major incidents reports from 1990 to 2021 demonstrating clear indicators of automation dependency. The accidents and major incidents where indicators of automation dependency are present occurred worldwide in terms of operator origin and location of the actual mishap. The identification of automation dependency indicators in accidents and major incidents appears to have increased in more recent years. It is unclear whether that is a result of increased use of automation, increased emphasis by investigative boards, or a combination of these or other factors. Many of the accident and major incident reports described indicators of automation dependency but did not list them explicitly as a contributing factor.

Indicators included both *contributors* (looking into why automation dependency occurs) and *consequences* of automation dependency. Note, however, that the indications identified in the accident and major incident reports were typically consequences as listed below. Also note that some indicators could be both contributors and consequences of automation dependency (e.g., low proficiency in MFO skills). In many cases the contributors were not identified in the accident and major incident reports, but WG1 reviewed the other data sources for additional insight into contributors to automation dependency. Indicators included:

Contributors

Operational impacts on pilot performance:

- Operator policies/procedures requiring use of automated systems and limiting MF during flight operations.
- Pilot training focused primarily on automated systems, excluding MF.
- Insufficient pilot training for flight path management and MFO.
- Air traffic procedure design requirements (e.g. flight path precision requirements that mandate the use of automation).

General pilot characteristics

- MFO skills
  - Low proficiency
  - Low confidence
- Automated system(s)
  - High trust
  - High proficiency
  - High confidence
  - Insufficient MF during flight operations

- Lack of knowledge about when it is appropriate to use automated systems/modes
- Predisposition for automation bias

Flight-specific pilot characteristics

- Complacency
- Fatigue
- High workload
- Focus on only one source of information
- Focus on only one operational goal
- Task sharing difficulties

<u>Consequences</u>

Mode monitoring/ system performance monitoring

- Insufficient monitoring of:
    - Airspeed
    - Flight path
    - Modes
    - Hazards
    - System performance

Use of systems when not appropriate

- Continuing to reprogram or change automated system inputs in time critical situations
- Use of automated system to make immediate responses to Ground Proximity Warning System (GPWS) or Terrain Awareness and Warning System (TAWS) alerts
- Exclusive use of information from an automated system when other information is available to cross-check

Pilot performance degradation

- Complacency
- Decision biases
- Reduced confidence in MFO skills
- Reduced proficiency in MFO skills
    - Ability to stay ahead of the aeroplane ((knowing exactly where you are, where you are going at all times and what you will do next)
    - Establishing a stabilized approach
    - Airport manoeuvring
    - Using pitch trim
    - Identifying and responding to decaying airspeed
    - Responding to system failures
    - Identifying and responding to programming errors

In 25 (89%) of the 28 accidents where automation was in use and the accident exhibited indicators of automation dependency, the investigative boards found both the PF and PM dependent on at least one automated system. In 28 (60%) of the 47 major incidents where automation was in use and the major incident exhibited indicators of automation dependency, both the PF and PM were dependent on at least one automated system.

MITRE (2023) found in update 2 to the PARC/CAST analysis that 90 (59%) of 152 accidents and major incidents from a sample of final reports spanning 1990 to 2021 are related to MF errors. Moreover, the MF errors are not decreasing over time as a percentage of accidents and incidents.

Figures 8 and 9 from MITRE Technical Report MTR230091 show specific systems where pilots displayed automation dependence. The numbers are reported in the raw rate of occurrence observed in accident and major incident reports and grouped by dates of coverage of the reports as described in Figure 9.

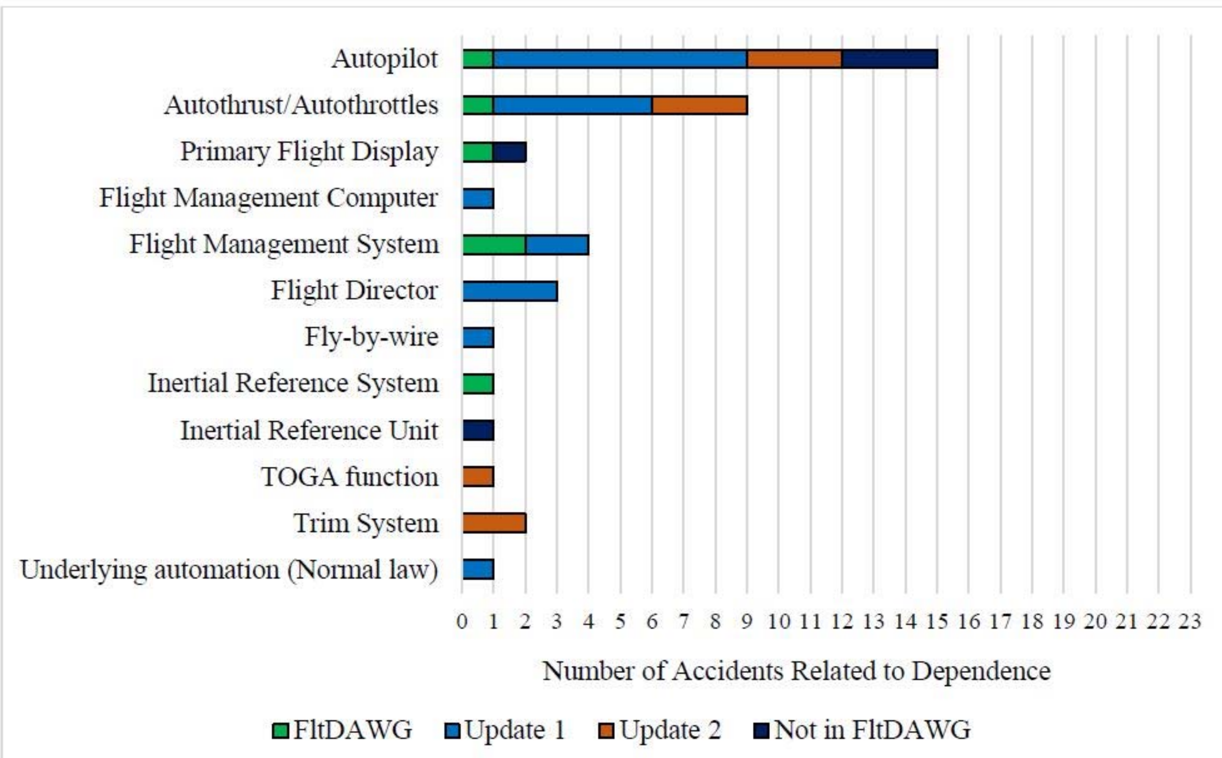


Figure 8. Accidents: Automated systems upon which pilots showed dependence (28 Accidents) Data from MITRE analysis.

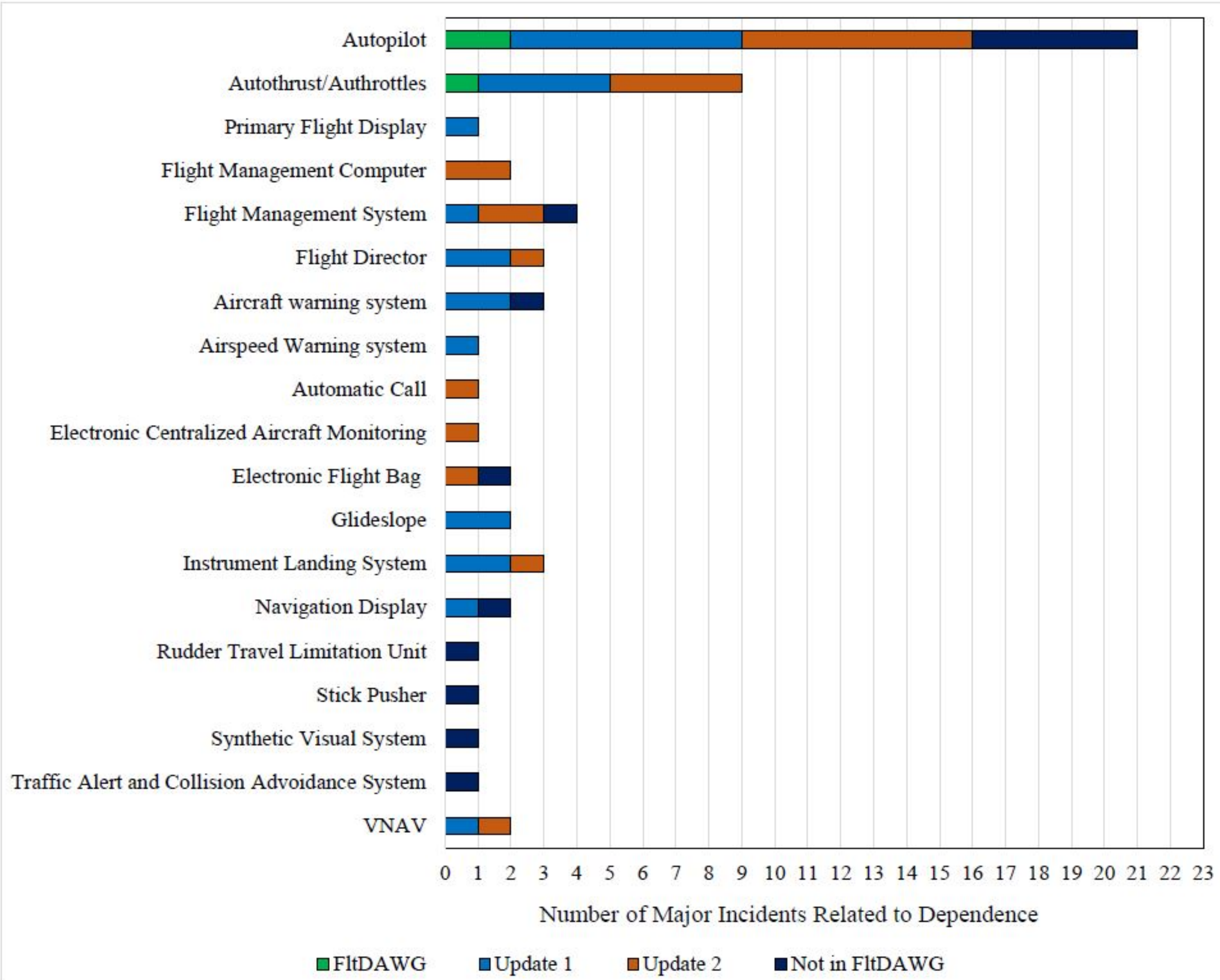


Figure 9. Major Incidents: Automated systems upon which pilots showed dependence (47 Major Incidents)

State Survey Responses. 68 State survey responses were received. Of the 68 responses, 31 (42%) responded affirmatively to the question "Please select any evidence/data analyses and/or reports your State has that can be shared related to pilot over-reliance/dependency on automated systems?" Upon request of additional documentation, supplemental materials were received from two States.

The issue of automation dependency has existed for decades, has been documented in various forms of literature and even driven training guidance. Despite these changes, mishaps involving automation dependency continue to occur, even as flight decks are becoming even more automated and automation use is frequently the prioritized method of flight path management over MFO.

There are different types of automated systems; e.g. control automation and information automation. These different types of automated systems may have different indicators and consequences of automation dependency. Indicators of automation dependency related to control automation and information automation have been observed in accidents and major incidents.

An example of control automation is an AT system. An example of a consequence of dependency on the AT system could be a flight crew member conducting insufficient airspeed monitoring during critical phases of flight and not noticing an inappropriate airspeed because they rely on the AT to manage it as needed.

An example of information automation is the FMS. An example of a consequence of dependency with the FMS could be a flight crew member entering incorrect data into the FMS such as the wrong radial for a holding pattern and accepting what the system provides due to a degraded mental model of what the holding pattern should look like rather than questioning if they made a data entry error.

There may be gaps in the knowledge of how to manage such dependency. While some literature exists in terms of addressing dependency through training and operational practices, strong similarities exist between recent accidents and major incidents with those that occurred decades ago. It should be noted that there are existing training practices that are intended to address proper use of automated systems, such as competency-based training, evidence-based training, CRM, and UPRT.

The research and operational data reviewed show indications that automated system dependency has been contributing or causal in accidents and major incidents all over the world. The indications do not appear to be specific to operator, manufacturer, country, or region.

10.2 Operator Policy

The two following independent analyses were conducted:

- The first analysis focused on reviewing operators' automation policies and assessing the extent to which flight path management components (AM, MFO and manual control, and PM) were addressed in the policies.
- The second analysis focused on reviewing operators' automation policies and assessing the extent to which the human performance components (TEM, flight crew countermeasures, risk assessments, etc.) were addressed in the policies in regards of the flight path management.

The analyses showed that there was a wide array of definitions and concepts surrounding automation. This made the analysis challenging, as different operators appeared to base their policies on significantly different concepts and definitions. In addition, distinctions must be made between "control automation" (i.e., automation performs actual aircraft control tasks) and "information automation" (i.e., automation provides information that is then used by pilots to perform the actual control).

It was also found that a distinction between "flight path management" versus "flight path control" is important. Flight path management is the overarching concept and entails everything that goes into the management of the flight path, including performance calculations, trajectory information, etc. Flight path control is part of flight path management, but it relates to the control of the flight path through automation or manual control.

Most of the policies related to the control of the flight path through automation or through manual control. Only a few of the operator policies elaborated on the entire concept of flight path management and relevant aircraft equipment or systems supporting the flight crew managing the flight path (e.g. advanced navigation displays with moving map functions).

10.2.1 Policy Title Choice

All policies (except one) used the title Automation Policy to cover all the components of flight path management:

- 39 operators had an Automation Policy.
- One operator had a Flight Path Management policy instead of an Automation Policy.

10.2.2 Coverage of Advanced Automated System Components in Modern Aircraft

The policies that were reviewed offered limited guidance on how to appropriately manage, where necessary, the full range of automated system components instead of only the autoflight system.

10.2.3 Automation/Manual Flight Philosophies

Five operator policies included an automation philosophy, two operator policies had a MF philosophy, and one operator policy had a flight path management philosophy.

10.2.4 Flight Path Management Components

10.2.4.1 Disengaging Automation When Trajectory in Doubt or System Failure

None of the policies offered guidance on the decision-making process involved in disengaging automation when the trajectory of the aircraft is in doubt. Although policy language cannot account for every situation, “disengaging automation when the trajectory is in question” is a largely generalized statement that may not provide enough guidance to flight crews.

10.2.4.2 Manual Flight Policy Language

Some policies had language that restricted or prohibited the flight crew from flying manually. This may be problematic in policies that require the flight crew to immediately transition to MF if the flight path trajectory is in doubt.

- Thirteen policies required pilots to disengage automation/immediately transition to MF if trajectory of the aircraft is in doubt.

- Twenty-five policies encouraged or authorized MF to maintain proficiency.
- Six policies had no language on encouraging or permitting MFO.

10.2.5 OEM Procedures

Many operator policies adopted the manufacturer procedures as their own automation policy, without adjusting to the operational and environmental differences specific to their respective operations. Additionally, much of the OEM language lacks specificity; thus, if copied, so may the operator policies.

Policies lacked guidance on PM and PF duties specific to managing the flight path under manual and/or automated control.

- Zero operator policies offered guidance on managing the flight path using manual and automated components when monitoring (PM) and managing (PF) a wide range of automated systems.
- Many of the operator policies reviewed listed several functions (roles and responsibilities) the PM is responsible for. The subgroup determined, by way of the analyses, that such functions do not stress the importance of the monitoring role for both PF and PM across all combinations of automated and manual flight. The operator policies expectations in terms of monitoring for both PF and PM were often diluted, and the area of vulnerability was mentioned only twice.

10.2.6 Terminology and Definitions

10.2.6.1 Variation in Definitions of Flight Path Management, MFO, and Automated Systems.

Most of the policies related to the control of the flight path through automation or through manual control. Only a few of the operator policy samples elaborated on the entire concept of flight path management and relevant aircraft equipment or systems supporting the flight crew managing the flight path (e.g., advanced navigation displays with moving map functions).

Two operator policies defined Flight Path Management and explained how it should be applied.

10.2.5.2 MF/MFO were regularly used terms yet were rarely defined in operator policy language. Defining terms within the policy document allows for the flight crew to fully recognize and understand the context and intended use such that it is aligned with operators' expectations.

- One operator policy had a MFO policy.
- Four operator policies defined MFO.
- 25 operator policies referenced MF but did not define it.

10.2.6.3 Variation and ambiguity is high in the use of similar vocabulary across policies. Similarly, many policies used the terms "autoflight" and "automated systems" interchangeably in instances that might not be appropriate, creating confusion in intent and intended use.

10.2.6.4 The subgroup also discovered that the abbreviation "FPM" is used differently within the operator policies, depending on the respective training framework within which the operators were conducting their training. For some operators the abbreviation "FPM" represented Flight Path Management in its entirety, including both automated and manual components. For other operators, especially those using the Competency-Based Training and Assessment (CBTA) Framework, "FPM" stood for "flight path management manual control". The ICAO CBTA framework covers the automated aspects of flight path management by a separate competency – Flight Path Management Automation – which is abbreviated as "FPA".

- No operator policies referred to Flight Path Management as Flight Path Management Automated and Flight Path Management Manual.

10.2.7 Variation in Terminology Regarding Combination and Levels

In some policies that used a preferred hierarchy, or levels, of automated systems, several policies did not define those levels.

- Fifteen policies referred to the levels but did not define levels of automation.
- Eight policies defined the levels of automation.

In the policies that used a preferred hierarchy, or levels, of automated systems, several policies required the flight crew to use the highest level of automation.

- Twelve policies required the flight crew to use the highest level of automation.
- Sixteen policies required the flight crew to use the most appropriate level of automation.
- Several policies used ambiguous language (typical example: "*Requiring the flight crew to use the "highest level of automation appropriate for the task*").

10.2.8 Communications and Briefings

Several operator policies required the crew to brief prior to disengaging automation. Beyond that, no language existed on communication elements during MF, or the expectations of the PM when the PF is managing the flight path manually. Sixteen policies required a briefing of the intended use of automation/MF during an approach.

10.2.9 Second Analysis: Human Performance Components

The second analysis focused on reviewing operator policies and assessing the extent to which some human performance components (TEM, flight crew countermeasures, risk assessment) were addressed in the policies in regards of the flight path management.

The goal of this analysis was to evaluate the policies content under the light of the TEM principles. This analysis reviewed policies from operators who have implemented CBTA and from those who use traditional training methods.

The TEM model is a conceptual framework that assists in understanding, from an operational perspective, the interrelationship between safety and human performance in dynamic and challenging operational contexts.

Since the 1990s, the TEM model has been used in several ways:

- Safety Analysis Tool: Can focus on a single event, as is the case with accident/incident analysis, or can be used to understand systemic patterns within a large set of events, as is the case with operational audits;
- Licensing Tool: Helps clarify human performance needs, strengths and vulnerabilities, allowing the definition of competencies from a broader safety management perspective;
- Training Tool: Helps an organization improve the effectiveness of its training interventions and, consequently, of its organizational safeguards; and
- Operational Tool: Helps an organization to increase its safety margins by providing the operational personnel tools as well as strategies and tactics to manage potential threats and errors.

10.2.10 Analysis

The wording "Threat" was mentioned nine times. The following presents relevant examples of operator policy using the word "Threat":

- Two operators indicated that the use of the autoflight system (autopilot) should be based on perceived threats.
- One operator indicated that "when flying manually, crews shall apply basic TEM principles that include environmental threats".
- One operator indicated that "opportunities to maintain handling skills shall only be taken after proper TEM has been made and included in the briefings".

The wording "Error" was mentioned eight times. The following presents relevant examples of operator policy using the word "Error":

- One operator indicated that it is recommended that the AP is engaged to reduce workload and exposure to errors.
- One operator indicated that "effective monitoring permits to corrects flight path management errors".

- One operator indicated that “automation increases the timeliness and precision of routine procedures thus reducing the opportunity for errors and contributing substantially to the sustained improvement of flight safety”.
- One operator indicated that “opportunities to maintain handling skills shall only be taken after proper TEM has been made and included in the briefings”.

The wording” Undesired Aircraft State” was mentioned four times. The following presents relevant examples of operator policy using the word “Undesired Aircraft State”:

- One operator indicated that “effectively monitoring the flight path is a critical TEM task that discovers and corrects flight path management errors that might lead to flightpath deviations or undesired aircraft states”.
- One operator indicated that “continuous use of such systems (automation) does not reinforce a pilot’s knowledge and skills in MFO thus leading to degradation of the pilot’s ability to quickly recover from an Undesired Aircraft State (UAS)”.
- One operator indicated that “continuous use of autoflight systems could lead to degradation of the pilot’s ability to quickly recover the aircraft from an undesired state”.

The wording “Competency” was mentioned two times. The following presents relevant examples of operator policy using the word “Competency”:

- One operator indicated that “the airline recognizes the need to maintain manual flying competencies. It is permitted and recommended for crews to fly manually on a regular basis”.
- One operator indicated that “Our Automatic Flight Control Pilot Competency (used in all our training and examining) has appropriate use of automation as a performance indicator” (observed behaviour).

The wording “Proficient/Proficiency” was mentioned 72 times. Most of the operator polices significantly used the words proficient or proficiency to:

- Stress the importance of maintaining proficiency during MFO and/or AM, (typical example: “Manual aircraft control proficiency is critical to the safety and effectiveness of aircraft operation”).
- Remind the pilots specifically that they must be proficient in operating the aircraft among all combinations of automation including the manual aircraft operations (typical example: “Pilots must be proficient in operating their aircraft in all levels of automation and must have the skills needed to move throughout all combinations”).

Note the terms proficient and proficiency are not defined in ICAO Annex 1, Annex 6 and ICAO Doc 9868 Procedures for Air Navigation Services-Training.

The wording “Monitoring” was mentioned by 17 different operators:

- Twelve operators emphasized the monitoring when the pilots are using automation.
- Five operators addressed the monitoring whatever the level of automation used. Four of them addressed monitoring when pilots are flying manually.

The wording "Skill" was mentioned 65 times. When used in the operator policies, "skill" referred mainly to the three following competencies:

- Flight Path Management -Manual Control (FPM)
- Flight Path Management - Automation (FPA)
- Communication (COM)

When the operator policies use "skill" in reference to FPM and FPA, or Flight Path Management for those operators that do not differentiate, it was often to:

- Encourage MF and/or the usage of all levels of automation (positive guidance)
- State neutral guidance about MF and/or the usage of all levels of automation
- Not encourage (discourage) MF and/or the usage of all levels of automation (not positive or negative guidance)

When the operator policies used the wording "skill" in reference to COM (18 times) it was mainly to remind the importance of this skill in regard of:

- Flight crew coordination when the automation is used (eight times)
- Flight crew coordination when one of the pilots is flying manually (two times)
- Monitoring activities (six times)

The wording "Workload" (referring to competency WLM) was mentioned 126 times. Most of the operator polices significantly used the word workload to:

- Elaborate about the benefits of using automation (typical example: "When used properly, automation enhances safety, improves operational capabilities and efficiencies, and reduces workload")
- Impose the use of automation when workload is high (typical example: "Pilots should use automated systems during high workload conditions")
- Limit MF to periods of low workload (typical example: "Manual flight should normally be exercised under low workload conditions")

Among the 126 mentions of "workload" only 20 of them were related to the maintenance of a suitable level of workload to conduct safely MF.

The wording "Situation awareness" (referring to competency SAW) was mentioned 41 times. Most of the operator polices significantly used the wording "situation awareness" to elaborate about:

- The benefits of using automation by reducing the workload and consequently permit the pilot to maintain sufficient cognitive resources to ensure proper situation awareness. (Typical example: "The level of automation used shall permit flight crew members to maintain a comfortable workload distribution and a high level of situation awareness")
- The potential risks associated to automation dependency (typical example: "Be aware that the use of automation can also lead to complacency and a lack of situation awareness")

- Among the 41 mentions of “situation awareness” only one was used to describe that the pilot will choose the appropriate level of automation based on situation awareness.

Additional Observations

- The competency Problem solving and decision making (PSD) was mentioned once for the selection of the appropriate level of automation.
- The term confidence was used twice, for automation and MF policy and for training policy.
- Mitigation and countermeasures were never used.

10.3 Manufacturers’ Assumptions Results

Manufacturer Responses constitute the results, the following is a summary of the respondents.

Question 1: What are assumed previous training and general experience levels? Manufacturers stated that prior piloting experience was assumed for all aircraft models. Meaning, previous multi-engine jet aircraft experience with basic jet aeroplane systems and basic pilot techniques was assumed and that aircraft were designed for a pilot of “average” skill level.

Question 2: What levels of automation are operators assumed to utilize and train crews accordingly? Manufacturers assumed that the crew shall use an appropriate level of automation and that the automation is intended to assist the pilot. Comments included to use automation when workload increases and manually control the aeroplane when needed. OEM Operations Manuals stated the normal procedures were written for the trained flight crew and assumed full use of all automated features. This statement was not intended to prevent pilots from flying the aeroplane manually. MF was encouraged to maintain pilot proficiency, but only when conditions and workload for both the PF and PM are such that safe operations are maintained. Another comment noted seeking the proper balance between flight crew workload and adequate situation awareness of aircraft operation. AP engagement should only be attempted when the aeroplane is in trim.

Question 3: Assumptions about human performance capability. Manufacturers assumed that situation awareness will be maintained at all times by the flight crew. A succinct comment stated that systems are designed considering that computers are more efficient to monitor parameters while humans are better able to make decisions, in which those decisions are based upon information provided by the systems/computers.

Question 4: Manufacturers philosophy on automation and how it influences training and operations. Manufacturers provided detailed explanations in their respective manual systems. Two respondents stated that automation is designed to aid, not replace, the flight crew. Two respondents stated that normal procedures are written for a trained flight crew and assumed that all systems operate normally and full use of automated systems. However, this does not preclude the possibility of MF for pilot proficiency where allowed. A respondent stated their training motto is “train like you fly, fly like you train”.

Question 5: Assumptions on crew interaction and hierarchy. Manufacturers referred to current Crew Resource Management (CRM) techniques and Threat and Error Management (TEM) practices as necessary for operational safety. Crews were expected to take positive control of the aircraft if automated flight is not performing as needed. Automated systems were designed to fulfil certain functions that are dependent upon operating environment, phase of flight, equipment, etc. In other words, the operational context was factored through the company's product development process.

Question 6: Assumption made about the pilot reactions/performance/behavior with system failure; crew intervention when automated systems fail. Manufacturers assumed that the training programs, pilot qualifications and CRM training will prepare the flight crew for a system failure / non-normal situation. Manufacturers stated that the autoflight system is not certified nor designed to correct a significant out of trim condition or to recover the aeroplane from an abnormal flight condition and/or unusual attitude. The level of crew intervention will vary accordingly with the available system capability, but the final authority remains on the flight crew to perform the abnormal procedures.

10.3.1 Summary Points

In review of the responses, several summary points may be considered.

Question 1: Previous training assumptions. Manufacturers' assumptions of previous training infer that licensed pilots already possess the capability to learn a specific type of transport category aircraft. With such training and operating experience, it was expected that a candidate will be able to learn the aircraft systems to operate the aircraft safely.

Question 2: Levels of automation that operators are assumed to utilize and train crews – Manufacturers' assumptions were integrated into operator training programs via evaluations from certain regulators. Those regulators published the results of the evaluation in reports which define the requirements for type rating training, recurrent training, and operational suitability for specific aircraft types and their variants.

While the use of automation during normal procedures was expected, manufacturers accounted for MF to be conducted when workload and conditions permit. Manufacturers' statement on the appropriate use of automation and that MF may be performed to maintain proficiency assumed that operators concurred and aligned their training and operations to accommodate this philosophy.

Question 3: Human performance capability. Statement that computers (or systems) are better able to monitor parameters while humans are better equipped to make decisions underscores the belief that pilots are the final authority on how the aircraft is to be flown during operations.

Question 4: Manufacturers' automation philosophy influences operators and training. Statement that automation is designed to aid, not replace, the flight crew is an indication that the flight crew is expected to fly the aeroplane manually when required. Thus, MF skills were considered as important as automated flight skills. While manufacturers provided training courseware as part of the aircraft certification process, it was assumed that operator training programs were designed to maintain MF proficiency of their pilots.

Question 5: Crew Interactions and hierarchy. Manufacturers designed aircraft for PM and PF responsibilities to be executed by either pilot, however it is the pilot-in-command that has the final authority. Operational environment or phase of flight may influence the use of automation or if MF is considered by the flight crew. While PM and PF responsibilities would remain consistent, increased workload during MF is inevitable.

CRM and TEM practices are necessary regardless of how the aircraft is controlled (auto vs. MF). The level of crew intervention will vary accordingly with the available system capability (operational context). This infers flight crew intervention to gain manual aircraft control, when necessary, as opposed to just correcting automation during an undesired condition.

Question 6: Pilot reactions/performance/behavior during system failure, including automation failure. Manufacturers stated that the autoflight system is not certified nor designed to correct a significant out of trim condition or to recover the aeroplane from an abnormal flight condition or attitude. This statement indicates that autoflight systems are not a “last resort” for aeroplanes in unstable or upset conditions. This assumed that the flight crew has the requisite skill and training to recover from an unusual attitude or upset condition via MF. This assumption is supported by an earlier statement that the AP should only be engaged when the aircraft is in trim.

10.3.2 Analysis

Automated flight and MF are sometimes viewed as differing skill sets or on opposite ends of a linear scale, with the degrees in between referred to as “levels of automation”. While this term is generalized, some manufacturer automation systems may differ in philosophies so that “levels” may not fully describe every manufacturer automated flight system. A manufacturer may describe automation use in terms of combinations of automation which may differ in philosophy and utilization.

Further, what one manufacturer considers a “level” or “combination” of automation may differ compared to other manufacturers, so the assumption of uniformity of automation across all manufacturers may be incorrect.

Although automation use was recommended during normal operations, manufacturers expect an aircraft to be flown manually when necessary to ensure safe operation. Thus, flight crews were expected to operate aircraft with varying degrees of automation during non-normal (abnormal) operations.

However, evidence suggests that pilots and flight crews may not react in the expected manner to non-normal or startle/surprise scenarios. While automation may be used to assist with crew workload during abnormal (non-normal) situations, some data indicate that aircraft recovery may be impeded by pilots not assuming timely manual control when the aircraft is in a degraded state.

Manufacturers acknowledged that MF skill retention is important and do encourage MFO when conditions and workload permit. Manufacturers did provide limited guidance, but consider operators better suited to create operational policy based on their flight operations.

In further consultation, a manufacturer reported a recent trend of operators and regulators requesting the OEM to further interpret training requirements found in regulator reports. However, manufacturers are neither regulators nor operators.

10.4 Regulatory Review Results

10.4.1 Overview

The following sections summarize the results of the Regulatory review.

10.4.2 Review of ICAO Framework[10]

Annex 1 to the Convention on International Civil Aviation, *Personnel Licensing*, requires pilots with an ATPL to be trained in flight path management via automation. The defined ATPL skills include the operation of the aircraft "in the mode of automation appropriate to the phase of flight" and the ability "to maintain awareness of the active mode of automation" (Chapter 2, paragraph 2.6.1.3.1.2 c). Additionally, for the Multi-crew Pilot Licence (MPL), the comprehensive CBTA framework in the *Procedures for Air Navigation Services — Training* (PANS-TRG, Doc 9868) includes the competency "Flight path management – automation". Finally, during type rating training and recurrent training, AM needs to be addressed as part of UPRT (Annex 1, Chapter 2, paragraph 2.1.5.2a; Annex 6 Part I, paragraph 9.3.1d; with references to Doc 9868 and the *Manual on Aeroplane Upset Prevention and Recovery Training* (Doc 10011).

Annex 1 requires pilots with a CPL to be trained in flight path management via manual flight. Concretely, the defined CPL skills include the operation of the aircraft in critical flight conditions (Chapter 2, paragraph 2.4.3.2.1g and j). Additionally, the comprehensive CBTA framework in Doc 9868 includes the competency "Flight path management – manual control". During type rating training and recurrent training, MF skills need to be addressed as part of UPRT (Annex 1, Chapter 2, paragraph 2.1.5.2a; Annex 6 Part I, paragraph 9.3.1d; with references to Doc 9868 and Doc 10011).

Annex 1 requires applicants for the MPL to demonstrate competence in the roles of both the PF and the PM (Chapter 2, paragraph 2.5.1.2.2). Additionally, the tasks of the PM are included in the comprehensive CBTA framework in Doc 9868, mainly in the competencies "Flight path management – automation"; "Flight path management – manual control"; and "Situational awareness and management of information". During type rating training and recurrent training, effective scanning and monitoring needs to be addressed as part of UPRT (Annex 1, Chapter 2,

[10] Within section 10.4.2: Annex 1 refers to the Fourteenth Edition, July 2022; Annex 6 Part I refers to the Twelfth Edition, July 2022; Doc 9868 refers to the Third Edition, 2020; and Doc 10011 refers to the First Edition, 2014.

paragraph 2.1.5.2a; Annex 6 Part I, paragraph 9.3.1d; with references to Doc 9868 and Doc 10011).

10.4.3 Review of States' Regulatory Framework

The initial review of States' regulatory and guidance material to identify where in the various licensing levels the three topics AM, MF, and PM were covered revealed the following:

- **AM** and **MF** were listed as part of initial licensing training (for professional pilots), type rating training and type rating operator recurrent training in all analysed States. Most states addressed these topics in the context of UPRT. Three regulators recommended the inclusion of MF exercises into recurrent training and checking of pilots. In one case, it was recommended that licence proficiency checks should focus on MF while operator proficiency checks should focus on AM. Two States provided guidance material on the appropriate use of automation systems and the maintenance of MF skills and one included guidance on training, testing and checking of stall manoeuvres.
- Two of the regulators recommended that operators establish a flight path management policy in their SOPs that also sets out conditions for MF during operations. Those SOPs should reflect the related safety risk assessments and should be monitored by the operator's safety management system (SMS).
- Training on the PM role was listed by all States as part of MCC training which forms part of (integrated) ATPL training and specifically during type rating training and type rating operator recurrent training which recommended comprehensive training as PF and PM, including active monitoring of flight path.
- Two States specifically identified the function of the PM as an important element in flight path management and provided detailed guidance on what constitutes good monitoring.
- Several regulators approached MF and AM as part of a continuum, rather than as an 'either-or' choice. In such guidance material pilots were encouraged to consider the range of options or combinations of automation use and MF to determine the combination best suited to the operational conditions, environmental conditions, pilot capabilities, and workload demands they are facing as they manage the flight path of the aeroplane.
- Many of the guidance materials focused on Automation Management as a set of discrete skills related to managing specific automation features and/or knowledge of how particular automation systems work. Some discussed automation use in terms of automation features being either On or Off. Others recommended also addressing modes and mode changes or differences in control laws as well.
- Some regulators recommended development of automation policies that define how to use certain automation features in different types of situations or conditions. These included recommendations regarding the conditions under which Automation or Automated Systems should be used/not used considering factors such as operational conditions, environment, traffic density, precision of procedures, and workload levels.
- Similarly, many of the guidance materials addressed MF in terms of a set of discrete skills related to defined manoeuvres and/or flying with specific automation features off. While some States provided definitions or descriptions of the appropriate operational

conditions in which to conduct MF during flight operations, some did not provide such definitions or made recommendations that operators develop their own company-specific set of conditions.

- In many of the materials reviewed, the role of the PM varied. In some cases, the role of the PM was not well-defined beyond high-level goals (e.g. “support the PF”) or was defined at a task level (e.g. “call out discrepancies”). Monitoring more generally was often defined in task-based terms, and was often described in role-based competencies that may rely on an authority gradient that assigns the ability to intervene when necessary to only certain flight crew members. However, there were States that provided detailed definitions of what constitutes “good monitoring” on the part of all flight crew members and included recommendations to include the topic of intervention by any or all flight crew members as necessary.
- The topic of Intervention, either intervention in terms of taking over from Automation or intervention in terms of taking over from another pilot was not addressed in all States.
- Some States included time-based metrics as part of training or competency for manual skills, e.g. number of minutes or hours of MF.

11 Appendix G Acronyms and Abbreviations

AAIB	Air Accidents Investigation Branch
AC	Advisory Circular
AM	Automation Management
ANC	Air Navigation Commission
AOA	Angle of Attack
AP	Autopilot
APAC	Pacific and Asia
ASRS	Aviation Safety Reporting System
AT	Autothrottle/Autothrust
ATC	Air Traffic Control
ATPL	Airline Transport Pilot License
ATSB	Australian Transportation Safety Board
BEA	Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile
CAA	Civil Aviation Authority
CAASD	Center for Advanced Aviation System Development
CAST	Commercial Aviation Safety Team
CBTA	Competency-Based Training and Assessment
CFIT	Controlled Flight Into Terrain
CPL	Commercial Pilot Licence
CRM	Crew Resource Management
EASA	European Union Aviation Safety Agency
EFB	Electronic Flight Bag
EGPWS	Enhanced Ground Proximity Warning System
ESAF	Eastern and Southern Africa
EURNAT	European and Northern Atlantic
FAA	Federal Aviation Administration
FD	Flight Director

FltDAWG	Flight Deck Automation Working Group
FMA	Flight Mode Annunciator
FMC	Flight Management Computer
FMS	Flight Management System
FO	First Officer
FPA	Flight Path Management Automation
GNSS	Global Navigation Satellite System
GPWS	Ground Proximity Warning System
GS	Glideslope
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICCAIA	International Coordinating Council of Aerospace Industries Associations
ILS	Instrument Landing System
MCC	Multi-crew Cooperation
MF	Manual Flight
MFO	Manual Flight Operations
MID	Middle East
MPL	Multi-crew Pilot License
NACC	North American and Caribbean
NTSB	National Transportation Safety Board
OEM	Original Equipment Manufacturer
OGHFA	Operators Guide to Human Factors in Aviation
PARC	Performance-based Operations Aviation Rulemaking Committee
PF	Pilot Flying
PFD	Primary Flight Display
PM	Pilot Monitoring
PTLP	Personnel Training and Licensing Panel
RNAV	Area Navigation

RNP	Required Navigation Performance
SAM	South American
SMS	Safety Management System
SIB	Safety Information Bulletin
SOP	Standard Operating Procedure
TAWS	Terrain Awareness and Warning System
TCAS	Traffic Alert and Collision Avoidance System
TEM	Threat and Error Management
TSB	Transportation Safety Board
UPRT	Upset Prevention and Recovery Training
VNAV	Vertical Navigation
WACAF	Western and Central Africa
WG	Working Group
WG1	Automation Working Group
WP	Working Paper
WPE	Work Programme Element