Fault Management and Systems Knowledge

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Pilots are asked to manage faults during flight operations. This leads to the training question of the type and depth of system knowledge required to respond to these faults. Based on discussions with multiple airline operators, there is agreement that instead of training deep system knowledge it is more beneficial to train operational use knowledge, how to respond to these faults.

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List of Abbreviations

Abbreviation	Term
ASRS	Aviation Safety Reporting System
EICAS	Engine Indication and Crew Alerting System
MEL	Minimum Equipment List
QRH	Quick Reference Handbook
SOP	Standard Operating Procedure

Foreword/Preface

Pilots are asked to manage faults during flight operations. This leads to the training question of the type and depth of system knowledge required to respond to these faults. Based on discussions with multiple airline operators, there is agreement that instead of training deep system knowledge it is more beneficial to train operational use knowledge, how to respond to these faults.

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Executive Summary

To understand how operators are approaching the training of systems knowledge, we conducted phone interviews and site visits to six operators—four majors and two regionals. We asked focused questions about their systems knowledge philosophy and what training on systems is provided and evaluated.

Today, operators train their pilots to know how to operate and interact with systems for normal procedures, supplementary, abnormal (Quick Reference Handbook (QRH)), and Minimum Equipment List (MEL) procedures. Most of systems training is presented via computer based training modules that describe controls and indications; this includes some abnormal situations training related to failure of the systems.

Systems knowledge training for normal operations is focused on system configuration and procedural flows. However, training systems knowledge for normal operations, or what does the system look like when the system is doing what it's supposed to be doing, versus what to do when subsystem fails or is inoperative, is a gap in current training. Operators reported that pilots are having difficulty in applying their system knowledge to normal operations.

Across six operators, the trend for all is moving away from detailed systems training to training system knowledge for operational use. Instead of requiring pilots to understand the hydraulic system at a schematic level, and evaluating them on their ability to draw detailed system diagrams, operators are instead focusing on training the mission consequences so pilots understand how a system failure would impact operations.

1. Introduction

Operators use manufacturer's published flight deck design and alerting philosophies as inputs into their training of system's knowledge and standard operating procedures (SOP). To understand fault management and the systems knowledge it requires on the part of the pilots, we asked four aircraft manufacturers to share their flight deck design and alerting philosophies with the aim of comparing them across Airbus, Boeing, Embraer, and Gulfstream. Embraer was the only respondent to provide materials.

Within a manufacturer, alerting philosophies are often at such a high level that their implementation can vary across aircraft models. For example, even though Boeing has an alerting philosophy, it is implemented differently on the 737 as opposed to the 787 aircraft. In our opinion, training pilots in manufacturer's alerting philosophy is not that helpful because the stated philosophy may be implemented differently across aircraft models. It is more important for crews to understand the implementation of the alerting system in training. In addition an operational policy for crew response to alerts and indications could be valuable for standardizing crew performance during an abnormal or emergency situation.

Our interest in the aircraft design philosophies was two-fold. First, we wanted to understand if the design philosophies diverge, converge, or conflict. If the philosophies were radically different we would expect operators to put more effort into standardizing and training their pilots which could impact the training and procedures developed at the airline. Second, operational policies and SOPs are derived from the design philosophy of the manufacturer. We wanted to know how this would impact the amount and nature of systems knowledge required of the pilots to operate the aircraft. Because we were unable to obtain the philosophies from the manufacturers, we asked four operators to share in detailed interviews, how they use the design philosophies (if they are provided) and how they impact the knowledge, skill, and training of their pilots.

The information manufacturers make available to the operators (if they make it available) is published in the flight operations manuals. Operators take the manufacturer's manuals' contents and adapt them according to the needs of their specific operations (e.g., aircraft fleets, routes, pilots, etc.) which then form the basis of the operator's operational policies and SOPs and are ultimately incorporated into their flightcrew training.

Early generation air transport jets were mechanical aircraft and were subject to frequent system faults and failures. Modern jets have transitioned to "fly by wire or light" systems that are exceptionally reliable and do not require the same depth of knowledge about their functioning or their architecture. Systems training for early jets required pilots to memorize detailed schematics, to be able to draw them, and know obscure details of the system components. Today, most pilots go an entire career without experiencing an abnormal or emergency situation due to a mechanical failure. Even though these are very rare events, operators are still required by regulation to train pilots to respond to and manage aircraft system malfunctions.

Modern jets also introduced centralized alerting for most abnormal and emergency system failures. The alerting system facilitates pilot response to the malfunction by attracting the attention of the flightcrew and directing it to the condition alerted, identifying its severity, providing a means to manage the system, and providing feedback to the flightcrew of the effectiveness of action taken. Managing the system is now mediated via checklists that guide pilot interaction with the system to correct or mitigate the failure. Because most operators in the U.S. use the manufacturers checklists as the basis for their checklist, the checklist and procedure philosophy of the manufacturer influence the operational philosophies and procedures at the operators. If a failure is something the flightcrew cannot address and it does not have a direct impact on the operation, malfunction messages may be sent to maintenance and will bypass the flightcrew. This is consistent with the system training philosophy articulated by one operator; to paraphrase, if pilots cannot effect the system from the flight deck, we will not require them to know that system in detail. Per this operator, this is consistent with Boeing's approach as well.

Methods

To understand how operators are approaching training systems knowledge, we conducted phone interviews with six operators—four majors and two regionals, and site visits to four operators. We asked focused questions about their systems knowledge philosophy and what training on systems is provided and evaluated.

2. Systems Knowledge

Emergency and Abnormal Operations

As aircraft systems became more automated, increased in complexity and included automatic self-configuration without pilot intervention, the system operating philosophy also changed. Instead of requiring a pilot to know and draw the detailed architecture of the system and all its subcomponents, manufacturers began limiting the systems information published in the operations manuals to high-level descriptions of how to interact with and operate the system rather than a detailed description of why it works the way it works.

Today, operators train their pilots to know how to operate and interact with systems for normal procedures, supplementary, abnormal (Quick Reference Handbook (QRH)), and Minimum Equipment List (MEL) procedures. Most system training is conducted via computer based training modules that present descriptions of controls and indications. These sessions are run individually and are not instructor supervised. Pilots are also exposed to abnormal events in subsequent full-motion simulator sessions that cover required events and operator-specific events. Operators have removed a lot of the detailed training material about how the system functions and why it functions that way.

The thinking behind this shift is they do not want the pilots to rely on memorized system knowledge, which is fallible and variable across pilots, but rather to use the checklist. They also do not want pilots troubleshooting a system in-flight so they do not train to the detailed engineering knowledge level. This reflects the content of one operator's QRH which provides guidance such that if a pilot cannot fix something from the flight deck, this is not a priority task. There has been a deliberate reduction in training for pneumatic, hydraulic, and electrical systems because today these systems are automated and highly reliable.

A potential risk of the shift in systems training is that pilots do not have a real understanding of the impact of a particular subsystem failure. However, this risk can be mitigated by enforcing adherence to checklists and focusing training on the operational and performance impact of failures. This new kind of knowledge needs to be correlated to operations at a practical level, what it means for the flight and the operation. For example, a crew may not need to know how specifically the hydraulic generator works but they should know how it relates to other sub-systems and its operational and performance impact. Recurrent training tends to refresh the qualification training and may result in some knowledge dissipation that is never really brought back up to the qualification level.

Normal Operations

Systems knowledge training for normal operations is focused on system configuration and procedural flows. However, training systems knowledge for normal operations, or what does the system look like when the system is doing what it's supposed to be doing, versus what to do when subsystem fails or is inoperative, is a gap in today's training. Operators reported that pilots are having difficulty in applying their system knowledge to normal operations, for example in cases like an MEL or any special procedure that changes the normal task sequence and expected system behavior, pilots' knowledge may not be activated; consequently, they do not know how these changes affects normal operations.

Although the training footprint for systems knowledge for abnormal operations is decreasing, systems knowledge training for normal operations is increasing for automation and flight instruments. Operators are expanding current training to include more flight-performance oriented learning for the purposes of improving flight path management performance.

Automation has taken a more active and authoritative role in system monitoring, diagnosis and recovery, such that the more serious consequences occur when the human-automation relationship breaks down. As systems become more complex and the authority and autonomy of the automation increases, human operators become relegated to the role of a system supervisor or administrator, a passive role not conducive to maintaining engagement and airplane state awareness. The consequence is that flightcrews often come to over rely on the automation, become less engaged in the human-machine interaction, and lose awareness of the automation mode under which the aircraft is operating. This is evident in altitude deviation events reported to NASA's Aviation Safety Reporting System (ASRS).

Cognitive mismatches are breakdowns in the pilot's mental model of the situation, aircraft orientation, or system/automation state. Mismatches between pilot's mental model and system state can develop in a variety of ways. Many incidents and accidents are related to pilots losing awareness of the modes of subsystems, also known as mode confusion or automation surprises. A common theme among incidents and accidents is that the pilot's mental model of the aircraft state became de-synchronized, i.e. the pilot's mental model of the aircraft's state did not accurately reflect the actual state.

Consequently, operators are increasing training and evaluation on the flight instruments, flight modes, flight management system, autopilot, and auto thrust/throttles with the hope that a deeper understanding of how the automation is controlling the aircraft will result in better decisions and actions for overall flight path management. Because the manufacturers do not provide detailed descriptions of the automation, operators are generating these materials on their own.

Given the highly reliable mechanical systems and current training focus on specific abnormal situations, it is the opinion of some operators that "amber/red" systems failures are not the biggest threat to operations in general, and flight path management in particular; instead, difficulty with understanding automation that is performing as designed and routine, unexpected changes pose a greater threat since they tax the most precious resource on the flight deck, pilots' attention. As a result, monitoring the flight path is compromised.

3. Training systems knowledge

Across six operators, the trend for all is to move away from detailed systems training to training system knowledge for operational use. Instead of requiring pilots to understand the hydraulic system at a schematic level, and evaluating them on their ability to draw detailed system diagrams, operators are focusing on training the mission consequences so pilots understand how a system failure would impact operations. For example, pilots would be expected to know that a center hydraulic low pressure failure would impact landing gear, flaps and main gear steering. Further, they could be flaps-limited which results in a new reference airspeed for the approach. This information is often included in the operational notes of the associated checklist; however, pilots often run the checklist hours before they need to act upon operational consequences, which introduces the potential for memory failure. Operational use training would reinforce retention and recall of these consequences.

One exception to this trend in systems training is that most operators reported a preference to increase automated systems training, and in particular the flight management systems, flight modes, autothrottle, and autopilot. In particular, there is a shift in training to develop understanding of the operational use of these systems. This is in response to the many reported difficulties with flight mode confusion and surprises. Given the large role of automation in managing the flight path, unexpected and anomalous automation behaviors can disrupt effective flight path monitoring and complicate task management.

If automated behavior is unexpected, pilots could become distracted. For example, the 787 electrical subsystem performs automatic load shedding during engine start-up sequence to manage the high load. As a result, subsystems will drop off and confuse pilots who become distracted by this, interrupting their workflow and negatively impacting their task management. At a minimum, pilots should be trained to expect this behavior so they are not distracted by it. Even better, the startup procedure should be designed to accommodate automation system timing to protect pilot workflows and task management during this high workload period.

Far more productive and practical to training detailed systems knowledge, would be having operators standardize pilot response, as much as possible, to non-normal situations across their fleets; this would facilitate transition training and reduce possible negative transfer between fleets. Knowing what to do in response to a non-normal is more useful in insuring successful outcomes than understanding why and how alerts are generated.

Glossary

Automation – one general definition of automation is "the use of control systems and information technologies that reduce the need for human intervention." Within the context of aviation there are a number of levels of automation from complete system control, where the pilot has no need of awareness of the automation and is not informed as to the status or intent of the automation, to levels in which the pilot needs to be kept continuously informed as to the status and intent of the automation. Where the term automation is used in this report it is generally referring to the later level of automation such as an autopilot system, autothrottle function, or auto-braking system where the pilot needs to understand the status of automation as well as the intent in some cases.

Flight Path Management – the planning, execution, and assurance of the guidance and control of aircraft trajectory and energy, in flight or on the ground.

Monitoring – the on-going observation and assessment of various components of the mission. This includes monitoring of systems, flight path, external situation, completion of tasks, etc.

Task Management - the strategic orchestration and tactical adaption of pilot tasks performed over the course of a flight, to ultimately protect the aircraft flight path, while balancing other operational objectives.

Workload –is defined by operators as the ratio between the number of tasks and the available time and resources available to complete them; however, the literature defines it as the mental effort required to complete the task, which could be the same thing but oftentimes is not.