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The Smart Cockpit Initiative

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Flight deck displays that automatically adapt themselves to changing operational conditions are referred to as mission adaptive displays, or smart cockpits. Most smart-enabling technology is already available in modern aircraft. To be operationally effective, however, mission adaptive displays should:

- Present mission critical information when it is most urgently needed.
- Be capable of responding to all mission critical events—single and multiple occurrences.
- Depict a rising risk profile based upon risk defining criteria.
- Utilize abstract clusters to reduce workload in high stress situations.
- Contain, whenever appropriate, performance aids so that precise maneuver execution is assured.

Mission performance aids (MPAs) possess what we call super-function attributes and, importantly, directly contribute to the precise execution of all known critical flight maneuvers. They should, as a priority, provide meaningful content for all known escape maneuvers. This escape display feature should receive urgent attention by the aviation industry.

A major supplier of software products, SAP, asserts that complexity is the most intractable problem of our age. They refer to this as the quagmire of complexity. This intractable quagmire is the result of a proliferation of technological silos across the industrial landscape—and unfortunately in our modern flight decks as well. This vertical orientation of discrete operating units makes cross-communication almost impossible. Arguably, it is the cause of much flight crew performance error detected by the aviation schoolhouse and professional instructors.

Human-caused design errors typically fall into three categories: (1) faulty, possibly unsafe design where a safety recall may be necessary, (2) poorly functioning design but not unsafe, and (3) design that appears to function, but resulting in operator confusion and workload often makes mission success questionable.

In his book *The Logic of Failure,* Dietrich Dorner (1996) says performance collapse in humans is due primarily to the application of a plausible but ineffective problem solving approach. This approach considers problems in isolation, ignoring their interactive properties, and thus losing the big picture. People have the greatest difficulty dealing with complex situations, focusing on *the what instead of the how.*

Similar studies by Daniel Kahnamen in his book *Thinking Fast and Slow* reveal the same: cognitive errors associated with judgment and choice typically fall into one or more of about twenty error categories. Significantly, when faced with a rather complex problem, most revert to rapid, ad hoc problem solving strategies that often prove ineffective.

Dr. Atul Gawande, in his book *The Checklist Manifesto,* examines the problem of complexity relating to medical surgery and asserts that we have reached the limits of reductionism, where everything is reduced to a singularity. Instead we must now enter “the century of the system.” Gawande claims we need a new emphasis, one that consider the system, its organizing principles, important interactions, and what is necessary for mission success.

Aviation has been challenged over the course of its history by complexity and its related effects. These are often referred to as degraded situation awareness (loss of the big picture), high workload, and poor judgment. Since the introduction of the B-17 Flying Fortress, checklists have been constantly in use and have become a major feature of the aviation profession, as a way to help avoid human error. Since that time complexity issues have intensified, encouraging the development of the automatic checklist for current generation airliners. Furthermore, Wickens (1984), Endsley (1995a, 1995b), Helmreich (1995), Smith (1993), Reising (1995), and others have addressed, over many years, various aspects of human performance in complex environments. These performance issues included refocused automation, individual and team performance, operational decision making, signal detection and perception, and advanced instructional methods. All of these initiatives attempted to address the problem of complexity.

After a series of high-profile accidents, crew resource management (CRM) was introduced into the aviation operational community. These accidents revealed that perfectly sound planes were crashing because of serious performance errors by the crew. Thus programs were put in place to improve the integration of crew member functions across the full spectrum of activities that relate to mission success, thus improving the operator's management of complexity.

Ultimately, what all this means is that how we think is how we build and how we build is how we perform. We have built this reality of functional singularities or silos in the cockpit because of how we think. Our thinking has largely been focused on discrete events or functions with little or no attention to the overall system. How we build is how things work—either well or poorly. Now it is time to question our thinking (meta-cognition) and build a new kind of system which incorporates much of what we have learned concerning human and system performance.

We must first consider how we think. Once we begin to embrace effective reasoning, then we can consider how to deal effectively with complexity. Dealing with complexity challenges us to develop an understanding of the organizing principles that take a loose collection of components and create a system. CRM helps us understand how crew members can organize themselves to improve mission success. Using this as a starting point, we can then adopt many of the principles of critical thinking, and begin to work on what will usher in this century of the system—namely the specification and design of the super-function.

In order to create super-functions that are horizontally aligned, possess advanced reasoning capabilities, and communicate seamlessly with one another, we need to adopt a system of thought that will permit such an objective. For super-functions in large-scale dynamic systems to work together, the primary objective is risk management and mission completion. Risk management, as well as resource management, trajectory management, and energy management, are key performance areas. As we are beginning to appreciate in aviation, it is not enough to know the current state of the vehicle, but its projected state as well. One of the most important features of a smart cockpit therefore is kinematics.

Challenges: Operational Engineering

Operational engineering is distinctly different than technology engineering, which is currently in use today. Technology engineering assumes the value of the technology so its functional utility is not analyzed. This approach adds to the proliferation of technological silos. In many cases it does not perform as intended and thus operator-developed workarounds become the norm.

Operational engineering, as an alternative, is informed by technology and, importantly, by what constitutes mission success. Mission critical events, therefore, become the major design drivers. Operational engineering recognizes risk can continue to rise up to a point beyond which catastrophic mission failure occurs. Such a point is called the critical event horizon. Knowing key points where mission failure can occur is some of the bedrock knowledge of a super-function.

Advanced Reasoning

A new type of intelligent system architecture is needed in order for the smart cockpit to possess advanced reasoning capabilities so that intelligent units communicate with one another and risk can be effectively managed. This leads us to the creation of the super-function. The first step is to engineer a system algorithm that detects, processes, and classifies mission critical events originating from both onboard and off-board sources. The dynamic aspects of the vehicle also need to be a continuous part of the information stream.

How do we inform the design process of operational engineering? If we can answer this, then we will be able to provide for the incorporation of the super-function in modern-day cockpits.

A smart cockpit with advanced reasoning features (super-functions) must keep track of all events during the course of the mission. An event is either mission critical or not. If an event is mission critical it is placed in the analysis pipeline. For events that are not critical, they are noted but not acted upon. Mission critical events are then classified by risk posture. For each risk posture there is a corresponding response category. So for example, if the risk posture is extreme, the event is designated as mission critical and is placed in the appropriate section that deals with extreme events. There is a direct correspondence between extreme risk and the escape response category. Similarly, there is a direct correspondence between each risk category and a response protocol. Here this must be a conscious effort; otherwise we are faced with a formless collection of data around random aspects of reality (Dorner, 1996). Selecting the proper response protocol with respect to a particular risk posture is crucial and is one of the most important features of a smart cockpit.

Challenges: Operation in Adverse Conditions

Operators in high-risk domains such as aviation often need to make decisions under time pressure and uncertainty. Time constraint reveals two dimensions; the first is the actual amount of time available to react to an event and the second is the perceived amount of time available to act. In the latter dimension, there is a “hurry up” syndrome well known among pilots, when a pilot’s performance is degraded by a perceived or actual need to hurry or rush tasks or duties for any reason. Some situations are so dire and time critical that all energy and attention must be given to controlling and landing the airplane with few resources to spare. This time pressure is drastically increased with the possible catastrophic consequence of (unpaired) actions.

Responding to Adverse Conditions

Many events a smart cockpit needs to respond to are generated by adverse conditions. Meteorological conditions are not the only category of problems crews have to face. In the complex cockpit environment, a lot of information is sent to the flight deck, some of which is contradictory or even ambiguous. Human limitations and team work are also essential issues in such a time-constrained environment. These factors, whether solely or combined, are adverse conditions with which pilots are confronted. These adverse conditions are threats, hazards, and factors that generate a level of risk pilots have to manage and mitigate.

Defining Risk in the Aviation Industry

Over the years the aviation industry has developed strategies, procedures, and improved systems to make air transportation safer. However, accidents still occur. According to the Flight Safety Foundation, “The global accident rate [in 2013] was 2.8 accidents per million departures” (Jackman, 2014). Despite technical developments or improvements, there are still hazards and risks present in nature. Risk is the probability of damage, injury, death, or any negative occurrence that is caused by external or internal vulnerabilities that may be avoided through preemptive actions. A risk is qualified by its likelihood of occurrence and severity of consequence.

Not all risks can be removed, nor are all possible risk mitigation measures economically practical. It is acceptable to society that there will be some risk of harm to people, property, or the environment in order for airplanes to fly. As risk managers, pilots play a vital role in addressing the risk in practical terms. It requires a coherent and consistent process of objective analysis, in particular for evaluating the operational risks.

Risk management consists of hazard identification, risk assessment, and risk mitigation. Hazard identification is identifying adverse events that can lead to a hazard and analyzing mechanisms by which these events may occur and cause harm. Hazards are ranked in order of their risk-bearing potential. If the risk is considered acceptable, operation continues without any intervention. If the risk is not acceptable, a risk mitigation process is engaged such that control measures are taken to fortify and increase the level of defenses or to avoid or remove the risk.

Weather Conditions

The obvious adverse events are bad weather conditions. Passengers consider price, comfort, and punctuality when planning their journey. As a consequence, airlines fly almost anytime whatever the weather conditions are. However, landing in fog or on a snowy airfield contain a level of risk managed by the aviation industry.

Today’s crew preparation is mainly devoted to weather report analysis and the availability of airport facilities. For example, some aircraft may be certified for CAT-2/3 approaches, which means they can land with very low minimum visibility in foggy conditions, but some airports are eligible for CAT-2/3 approaches and some are not. The level of risk is different when analyzing the weather report for different aircraft and airports. Each preparation is unique and is context dependent. The crew weather reports should not be considered as just a list of weather conditions, but as potential mission critical events encountered in a real environment.

The main challenge with meteorological events is for the pilot to detect their existence and to have sufficient cognitive abilities to react to their cumulative effects. Indeed, landing on a wet and short runway is a demanding activity and requires accurate flying skills. It could become critical if an additional event, such as a tail wind, has not been taken into account by flying personnel, because then the workload becomes too high.

Human Factor Limitations

Flying a large jet aircraft with high-technology automated flight and guidance systems is a complex task, so much so that two crew members are still required. These crew members' activities are highly interdependent: monitoring systems and each other's actions, entering data into flight management computers, updating weather and airport information, communicating with Air Traffic Control, company operations, working with cabin crew, dealing with passengers, and anticipating future events in case of abnormal or emergency situations. When an emergency occurs, the crew must understand what the problem is, judge the level of risk and the time pressure, plan for contingencies, and decide and implement a course of action. These tasks increase the crew workload.

In high workload situations, crew errors and non-optimal responses can be linked directly to inherent limitations in human cognitive processes. Studies of human performance reveal that cognitive performance is significantly compromised under stress. When experiencing stress, human performance narrows. This phenomenon is called tunneling (Bundesen, 1990). When someone is tunneling they focus narrowly on what are perceived to be the most salient or threatening cues (Wickens, 1984). A pilot may focus on a single cockpit indicator and not notice other indications also relevant to their situation.

Toward a Solution: The Smart Cockpit Initiative

The primary (terminal) mission objective for all air transport operations is to plan and execute a mission that is at once operationally sound (safe), flown within established parameters, and executed with precision.

The Smart Cockpit

The basic idea behind the smart cockpit is to optimize mission success despite adverse conditions, extreme complexity, and increased time compression. This requires, as a top priority, the ability to optimize operational decision making (ODM), through the employment of the super-function. Decisions are tough things to deal with. As Kahnamen (2011) and others have pointed out, humans typically do not do this very well. This points to the need to develop means and measures to support and improve this difficult but necessary activity. With respect to ODM, this is only the beginning. Much work needs to be done in the area of decision support systems (DSS) in a whole range of operational arenas.

We have focused on reducing the complexity in large-scale dynamic systems—thus the introduction of the mission critical event and its management by the smart cockpit. Once we understand clearly the operational impact of the mission critical event, we can then formulate effective responses.

An important aspect of optimizing system performance (leading to mission success) is to provide the operators with the right information at the right time. Often this informational package needs to be delivered when a mission critical event has occurred and something needs to be done without delay. The timely delivery of an informational package containing mission critical information with easy opening features is our aim. Furthermore, we believe that in many cases, if not most, the informational packages should open automatically, thus ushering in truly intelligent systems (like the smart cockpit). Such an intelligent system knows (1) where it is, (2) what is happening, (3) when and how to respond, and (4) when response is complete. Notice we have made no distinction between man and machine.

A major feature of a smart cockpit is mission adaptive displays. These can automatically adapt themselves to changing operational conditions and thus can be called intelligent systems. Software giant SAP, the authors, and others such as Dr. Gawande believe we can build such systems and teach them to be intelligent. This machine intelligence not only deals with internal functions, but includes intelligent communications between significant numbers of intelligent agents. These intelligent agents can be human operators, performance aids, decision support functions, performance monitoring, kinematic prediction, and so forth. All of these comprise a set of super-functions.

Our technology can be much smarter than it is now, ushering in the century of the system. Given that the aircraft's intelligent systems (human and avionics) know that the aircraft is approaching the final approach course, then a super-function called the intelligent kinematic adviser, for example, can alert the crew when and where the onset of instability is likely to occur, and thus early crew-directed intervention can occur. Here we can see the immense value of the meaningful communications between intelligent systems. Having a kinematic adviser working with the flight crew when preparing to fly the final approach segment of the mission will significantly improve mission success and reduce complexity and workload in a high-stress, time-compressed portion of the mission. Currently, this task is done manually without aids, relying exclusively on memory and often fraught with errors.

Takeoff Operations with a Smart Cockpit

In this case the flight crew has made their final preparations for takeoff. Included in this preparation is the contingency briefing for an engine failure on takeoff—the terrain escape maneuver. The smart cockpit provides a pull-up feature for the crew to aid in the briefing exercise.

During takeoff roll a representation of the runway is automatically displayed on the center mode flight display (MFD). This display contains the exact location in which the three primary takeoff speeds (V1, VR, and V2) occur on the runway and the delayed VR speed, which is being used during this flight because of potential wind shear. If an engine failure occurs during takeoff roll at or above the takeoff refusal speed (V1), the center MFD display will automatically provide a swerve correction target to aid the crew in trajectory management. Additional display information is presented on the navigation display (ND) during takeoff roll and extending until completion of second segment climb. This pertains to the engine failure on takeoff route information. It is represented as a picture-in-picture (PIP) in the upper right hand corner of the ND and is made available for reference purposes.

The smart cockpit provides another significant feature during takeoff operations. The following critical flight maneuvers have been initialized and are ready to be automatically activated at the triggering event. These are displayed on the lower MFD and are shown in the table below.

Table 1.
Critical Flight Maneuvers

Escape Maneuver	Operational Concern
SE terrain escape	Terrain critical airport
V2 engine failure	Always possible
Wind shear recovery	LLWS advisories in effect
Upset recovery	Proceeding “heavy”

The single engine (SE) terrain escape maneuver and procedure are listed because the departure airport is terrain critical. In this case the maneuver requires a turn to 030 degrees shortly after takeoff in order to avoid a range of mountains to the west. Engine failure on takeoff, during second segment climb (V2 engine failure) is always in the takeoff and departure queue. This procedure is the most difficult maneuver to perform and is a situation judged to be the most dangerous and unforgiving of mistakes. *It is the authors' contention that all aircraft should be retrofitted with this performance aid as soon as practicable.*

Terrain Escape Maneuver

This maneuver, in the smart cockpit era, is aided by an onboard performance aid. This mission performance aid (MPA), a super-function, is automatically activated and displayed to the flight crew. This particular performance aid consists of two components. The first is the ordered representation of all components of the maneuver. The second is the route display.

The maneuver component portion of the MPA consists of five distinct maneuver elements. These are represented in Table 2. The first maneuver element depicts a turn point at 1.6 nautical miles from the VOR location. At this point a right turn must be performed to a heading of 020 degrees. The second element is triggered at an altitude of 3,200 feet. After passing this altitude, the right turn should continue to 060 degrees. This heading represents an intercept heading for the 031 degree radial of the Las Vegas VOR. Approaching the 031 degree radial, turn left and track outbound on the 031 degree radial. Track outbound on the 031 degree radial until 20 nautical miles. If the aircraft is not above 6,000 feet at this point it must enter a holding pattern until 6,000 feet is reached. Once the aircraft is above 6,000 feet and beyond 20 nautical miles, then it may proceed on course or activate and fly another route segment.

Table 2.
Terrain Escape Maneuver

WP	L-NAV	V-NAV	PWR	Configuration
@ 1.6 DME	RT 020 degrees	C—800' AGL	MAX	F-5
(Turn)	To—020 degrees	Accel—CMS	MAX	F-1; F-U
@ 3200'	RT 060 degrees	Climb @ CMS	MCT	F-U
+ 031 R	TR—031 R	Climb to 6000'	MCT	F-U
031/20	Hold	Climb to 6000'	MCT	F-U

Commentary on the Maneuver

Taken by itself, the maneuver appears to be flyable as a horizontal procedure, although it clearly is complex. However, when one considers that there is an important vertical element to the maneuver, its complexity becomes not only recognizable, but concerning. The greatest challenge comes in the area of 1.6 nautical miles where a turn must commence. This point is where the acceleration altitude will be reached and the pitch attitude must be lowered to the acceleration target pitch. This point of the maneuver, where a turn and a pitch change must occur simultaneously, is where operational error is likely to happen. Other portions of the maneuver are similar and it is strongly suggested that a smart cockpit equipped with a terrain escape maneuver performance aid be developed as soon as practical.

Conclusion

Mission performance aids (MPAs) are a major part of the smart cockpit. They are defined as a set of flight deck attributes and crew station display features that possess the built-in capability to automatically adjust themselves to changing operational conditions. These functional attributes have been referred to as super-functions that cross traditional boundaries and thus provide for a more comprehensive response to mission critical events. The overall purpose is to provide the flight crew with mission essential information packages at the time that they are most needed. The term *information packages* used in this context is that which is required to accomplish an activity set. These mission essential information packages are derived from a comprehensive analysis of an operational environment. The overall objective of this packaging and timely delivery of mission essential information is to achieve the dual goals of mission success and excellence in flight operations.

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