Reliable or Resilient: Recovery from the Unanticipated

JOHN A. STOOP[1][1], and ERIC A. VAN KLEEF[2]

[1] *Kindunos Veiligheidskundig Adviesbureau, Gorinchem, THE NETHERLANDS*

[2] *Van Kleef Consultancy, Leusden, THE NETHERLANDS*

Abstract: The increased complexity of infrastructural and transportation systems makes those systems less tractable, requiring new notions for reliability, control over operational performance and safety assessment. To this purpose, the contribution elaborates on the principles offered by the Cynefin notion as a guide in landscaping system complexity and dynamics. Beyond the normal and predictable behavior of operators by mathematical assessment of their reliability and procedural control over safe performance of the operator, this contribution emphasizes two new approaches. The scope of this study is to reconsider the notion of human error as an adequate operator response to system failure under a variety of operating conditions. It introduces operator variance, resilience and transitions across system states and mental modes as an operationalization of the notion of Good Airmanship and Good Seamanship. On one hand a design oriented expansion of the safety envelope with respect to resilience is argued, while during operations at the performance level of the operator, the conventional Skill-Rule-Knowledge based model of Rasmussen is adapted, adding a intrapersonal reflex level and a interpersonal crew coordination level. Such an augmented ability to recover from the unanticipated is demonstrated for the aviation sector.

Keywords: *resilience; safety; complexity; operating envelope; adaptive systems; human performance*

1. Introduction

In cognitive psychology, the Skill, Rules, Knowledge (SRK) framework of the Rasmussen taxonomy defines three types of behavior in operator information processing. This SRK framework supports designers and investigators to combine information requirements for a system and aspects of human cognition. By supporting skill- and rule-based behaviors in familiar tasks, more cognitive resources may be devoted to knowledge-based behaviors, which are important for managing unanticipated events. Three categories essentially describe which information is extracted and understood:

- *Skill-based* behavior represents a type of response that requires very little or no conscious control to perform or execute an action once an intention is formed. Skill-based behavior requires very little attention once a skill is acquired.
- *Rule-based* behavior is characterized by the use of rules and procedures to select a course of action in a familiar work situation. The operator can acquire these rules can be acquired through instruction and familiarization with current operations.

---

[1] Communicating author's email: stoop@kindunos.nl

- *Knowledge-based* behavior represents a more advanced level of reasoning that must be employed when the situation is novel and unexpected. Operators are required to know the fundamental principles and laws by which the system is governed. Since operators are forced to analyze the system, cognitive workload is typically greater then when using skill- or rule-based behaviors.

Human behavior in operator task performance has been the subject of research in the scientific community. The cognitive mental models for the rational reasoning process as developed by Reason and Rasmussen have received wide recognition and application in various sectors and industries. In aviation, flight modes are defined in three basically different forms of man-machine interactions. Each flight mode represents a specific interaction of the flight crew with the Flight Management System and requires a specific mental mode and flying skills:

- a *normal* mode, where the crew performs its tasks according to planned situations and expectations in accordance with the Flight Management System under flight envelope protection.
- *degraded* modes, where disruptions of plans and expectations may occur that are unfamiliar, but anticipated and recoverable through training. Such modes can be handled under conditions of a degraded flight envelope and partial loss of envelope protection.
- a *manual* mode, where the Flight Management System is disconnected from the flight controls and the aircraft is flown without envelope protection. In such a manual mode, the crew falls back on basic flying skills, individual experiences and expertise and intuitive responses.

Such modeling of rational decision-making and man-machine interactions, however, has seen limitations in explaining human performance in specific contexts and outside the operating envelope of normal performance.

Two case studies in aviation accident investigations show limitations of this rational decision making model. On 1 June 2009, an Airbus A330 (AF447) crashed into the Atlantic Ocean near the coast of Brazil, killing all 228 persons aboard. The aircraft's black boxes were not recovered from the bottom of the ocean until May 2011, nearly two years later. The French investigation agency BEA's final report concluded, that the aircraft crashed after temporary inconsistencies between the airspeed measurements due to obstruction of the pitot tubes by ice crystals, causing the autopilot to disconnect, after which the crew reacted incorrectly and ultimately led the aircraft to an aerodynamic stall from which they did not recover.

An Airbus A380 coded QF32 suffered an uncontained engine failure on 4 November 2010 and made an emergency landing at Singapore Changi Airport. A turbine disc in one of the aircraft's engines disintegrated, causing damage beyond design, an uncontained fuel leak and multiple system failures. After holding a racetrack holding pattern for two hours, the aircraft returned to Changi, fifty tons over landing weight. The aircraft landed 35 knots faster than normal, blowing four tires with about one hundred meters margin at the end of the runway threshold. In addition to the normal crew, two additional check pilots were present in the cockpit. The captain concentrated on flying and managing the aircraft. The first officer monitored over 100 ECAM messages and checklist actions. Both check pilots monitored all actions and assisted when necessary. Upon landing, the crew was unable to shut down one of the engines, which had to be doused by emergency crews three hours after landing. The pilots decided not to evacuate the plane immediately after landing, as fuel was leaking from the left wing onto the brakes, which were extremely hot from maximum braking. No injuries were reported among the 440 passengers and 29 crew.

The two examples given above illustrate dynamic recovery. In the AF447 case, the crew did not successfully recover due to the ‘startle’ effect and the chaos in the cockpit. Crew coordination collapsed, while the pilots were locked in their intuitive mode by a loss of situational awareness. In the QF32 case, a successful recovery was possible by the resourceful, coincidental presence of two check pilots in the cockpit, enabling the crew to regain oversight over the situation. The QF32 crew made a successful transition through the complex state and survived.

The novelty in analyzing these two cases is the indication that performing in a complicated operating environment, a normal system state and usual mental mode are not directly accessible at the time when recovery from a chaotic system state or a panic mental mode. To regain control in a complicated system state, a recovering flight crew has to go simultaneously either through a mental mode of enhanced crew coordination or through a mental mode of training based, intuitive responses. In the QF32 case, the coordination and cooperation efforts of the crew in recovering from immanent disaster can be defined as crew coordination, while the loss of situation awareness and collapse of crew coordination in the AF447 case can be defined as deficient stress management.

2. System states and safety envelopes

Systems that rely heavily on both technology and human performance are called socio-technical systems. Socio-technical systems have a complex behavior. Most of these systems have non-linear behavior, meaning that the change in behavior is not proportional to a change in initial conditions. Such a system can be in several stable states, between which transitions occur. To grasp this behavior it is useful to identify these system states. These system states can be plotted in a system state diagram, in which boundaries can be identified that delimit the system states that are normal operating circumstances, that represent degraded operating and that represent disaster [1].

This approach enables to define the boundaries of safe operation. The operating envelope as used in aviation represents this boundary. The operational envelope can be defined as the set of conditions under which the airplane should be able to fly. Van der Top [2] has made an extension to the operating envelope by defining the viable envelope. The viable envelope delimits the set of system states that can exist without damage to the system.

In the area within the viable envelope, where the operator does not have to take any actions to keep the system within the viable envelope, the system is intrinsically safe. The operator is needed to direct the system back into the operating envelope, but not to prevent damage. Within intrinsic safe situations, the operator can control the system by doing nothing. The most important condition is, that the operator knows he has to do nothing [1].

One can state, that while the system is within the operating envelope, it will behave in the way it is designed. Within the operating envelope, the use of the system is aimed at efficiency. Within the operating envelope, the operator should have enough information and enough possibilities to control the system [3].

Holling [4] observed in a study on ecological systems, that some ecosystems vary a large amount but retain their integrity, while others break down with much less variation. He called the systems that can vary a lot without breaking, resilient systems. A resilient system can have large variation, because it has the capability of a flexible response and timely recovery due to multiple response paths, so it always returns to its old equilibrium point.

The same notion of resilience is closely related to the survival of aircrafts in trouble. Both the AF447 and QF32 were well beyond their design limits. Still one of them reached a situation in which the crew was able to land the plane. The QF32 was more resilient than the AF447.

Non-linear systems can have several equilibrium basins. A basin can be defined as a specific set of conditions and constraints that create an optimum performance envelope. Once the boundaries of this basin are reached, the system will transpose to a different equilibrium. This new equilibrium may be as useful as the old one or be a degraded situation in which functionality is less then in the original equilibrium. A resilient system may return to its old equilibrium if large variations occur, but it may also shift to another equilibrium that is adequate for operation.

In a complex system, the operating envelope is normally well inside one basin. The system might encounter a disturbance that brings it into another equilibrium. This might be an accident, forcing the system to alter into a more safety oriented but less performing state [5]. A resilient system does not break down when exceeding its limits, but enters a new equilibrium. Performance may be less than in the operating state, but the system continues to work.

There is of course a relation between the safety envelopes. The viable envelope should include the operating envelope, or damage would occur under normal conditions of use. The resilience envelope should include the viable envelope, or the system would already be beyond repair when damage occurs. These envelopes are a formal description of the idea of graceful degradation. The damage to the system should gradually increase with the disturbance. The system should at first lose its function, then become damaged and only after that, collapse [1].

Reliability, safety and resilience can thus be considered concentric notions (figure 1) that are not conflicting but should be taken into account simultaneously. In the innermost circle in figure 1, reliability and performance are predominant, in the middle ring, safety predominates, while in the outer ring resilience and survival are the most important aims. In dynamical systems a set of limit states or envelopes exists, in which human operators have different roles. The ultimate limit is the resilience envelope beyond which the system lost and no recovery is possible.

Safety margins between safety envelopes shall be large enough to enable the operator to take correcting actions. The operator shall have the time to comprehend the situation, decide what to do and take the correcting actions. The operator shall also be in a position in order to take the necessary actions to return to a normal state.

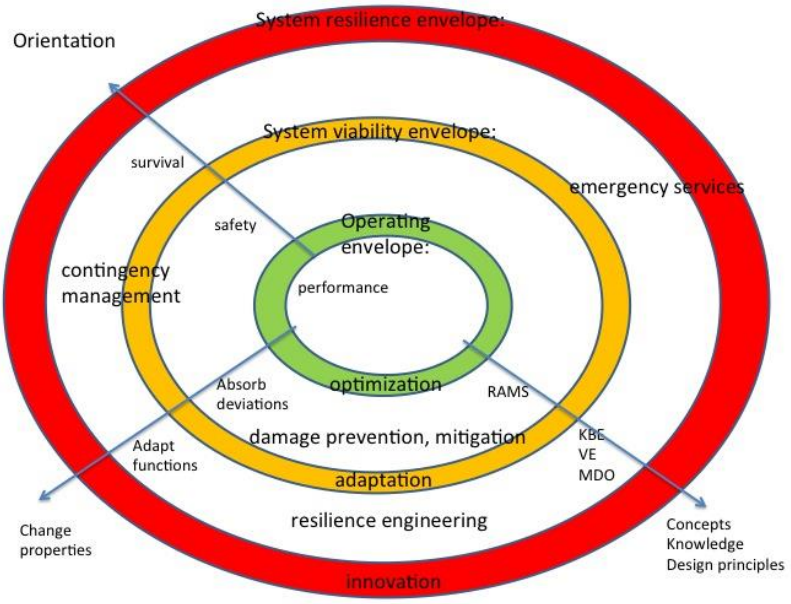

Figure 1: Safety Envelopes

3. Mental modes and decision-making

In the aftermath of the AF 447 air crash, the French investigation agency BEA concluded, that the introduction of an Angle of Attack indicator in the cockpit of commercial aircraft could improve the situation awareness for pilots. In a study into the feasibility of such a decision-making support device, the Dutch National Aerospace Laboratory NLR concluded, that full understanding of a pilot decision in unusual situations was lacking [6]. Such a control of a serviceable aircraft was presumed to happen due to incorrect actions to what pilots were thinking they saw. Understanding of how they gather information apparently was not only a matter of employing techniques, but also depends on examination of pilot behavior, how they monitor each other, what interactions were monitored and whether they were effective or not. The feasibility study encountered limitations of the logic reasoning as applied in the Skill-Rule-Knowledge based approach of the Rasmussen model in developing solution. A stall event -eventually causing the aircraft to crash in the Atlantic Ocean-, will always be an unfamiliar event. In a stall event, a Skill Based solution cannot be relied upon due to deteriorated pilot capabilities to recover from a stall, while a time consuming Knowledge Based solution is unpractical due to the emergency of the situation. The NLR concludes that therefore a recovery from a stall event can only be addressed successfully if the pilot adopts a Rule Based approach [6].

Such a conclusion, however, is questionable. According to Snowden [7], a complex system discriminates four different states of operation. The Cynefin model takes the following form:

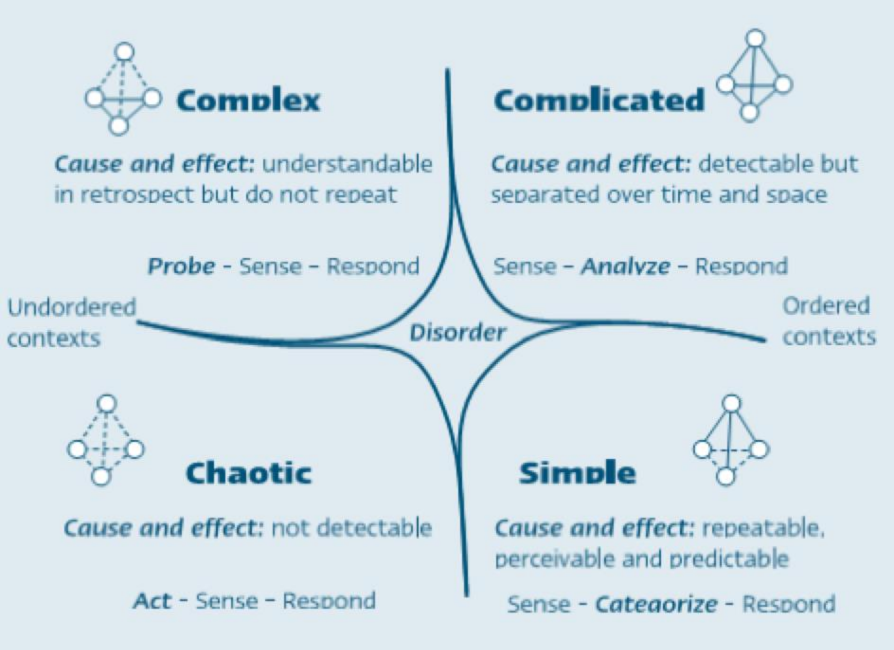

Figure 2: Cynefin Model (From [7])

In our interpretation of dynamics in the Cynefin system model, it is not possible to make a direct transition from a chaotic system state to the complicated -normal operating-system state to recover from an unfamiliar and unanticipated event. A recovery transition through intermediate states has to take place: either in a clockwise direction from the chaotic state through the complex state back to the complicated state or through the simple state back to the complicated state. Such a transition requires either understanding of the complexity of the system by crew communication and coordination and system diagnosis, or a recovery from the simple system state, coping with startle effects and panic, dealing with intuitive fight or flight responses and prevailing reflexes and best practices.

By combining the work of Kahneman [8], Slovic [9], Rochlin [10], Amalberti [5], Hollnagel, Pariès, Woods and Wreathall [11] to pilot performance, additional dimensions in safety modeling have become available. Such dimensions deal with emotion, intuition and feelings of affection, empathy and contextual framing. The identification of influences of unconscious and intuitive processes, group dynamics and environmental interferences enabled the scientific research community in the field of psychology to identify three explicit basic mental modes of operandi: rational decision making, emotional decision making and social decision making. Each mental modeling perspective has its characteristics, keywords and leading researchers as depicted as depicted in figure 3:

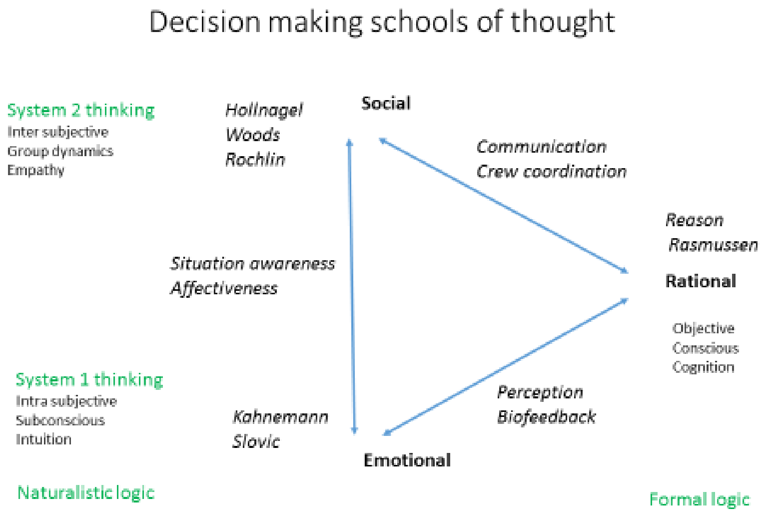

Figure 3: Decision Making Schools of Thought

Expansion of the human performance model into the domains of emotional and social interference with rational decision making processes is advocated, identifying three modes of operandi and their consecutive scientific theoretical understanding. Such a change in perspective abandons the notion of ‘human error’, where compliance with rules and regulations is required, superimposed by management with a Tayloristic perspective on labor division, separation of responsibilities and cost-efficiency considerations. Instead, an integral functioning is considered from a human centered design perspective.

The majority of the interest of the scientific research community has traditionally focused on rational decision-making processes. Only recently the social decision making dimension has gained interest, exploring interrelations with rational decision making, focusing on communication and coordination aspects for flight crews and flight operations as a social construct [10]. Interrelations between rational decision making and the emotional decision making dimension have been far less prominent, apart from an incidental interest in autogenic feedback and biofeedback issues [12, 13]. Interrelations between emotional and social decision making have drawn attention only recently due to an increasing understanding that the mind is regulated through emotions, moderating thought processes of operators and their ability to cooperate under a variety of conditions and environmental constraints [13-15]. Such overemphasis on rational decision-making has created imbalance with respect to a focus on integral functioning.

Transitions between mental modes are not arbitrary. Only a few transitions are possible. Figure 4 illustrates this.

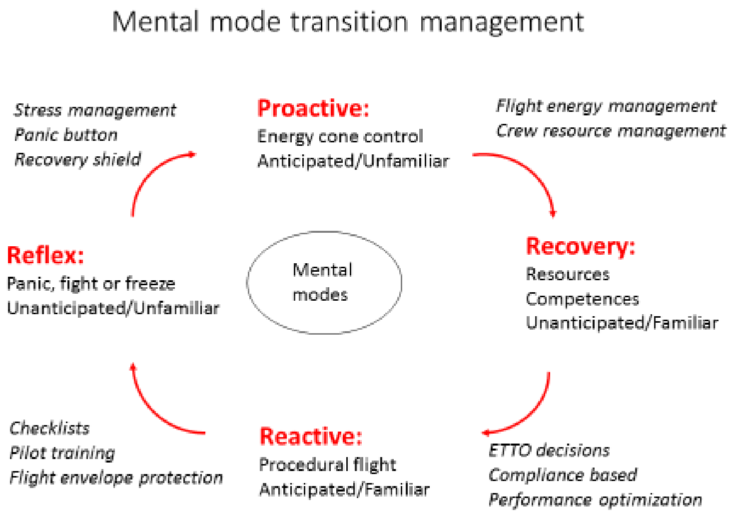

Figure 4: Mental Mode Transition Management

This implies that the mental mode of the operators contributes to the system state as much as the technical system state. A technical state of the system that is well within the safety envelopes while the pilots are in the correct mental mode may be outside the envelope with operators in a different mental mode.

Managing the stress responses of airline pilots in emergency situations requires additional approaches and mental mode specific solutions [13, 15]. Such approaches may be a combination of an engineering design solution such as a recovery shield or panic button device [16] in combination with behavioral approaches such as crew coordination and stress management [13, 15].

Providing crews solely with decision support appropriate for a rule-based performance will not support them to recover directly from the chaotic state. In order to recover from a chaotic system state, a crew has to make a conscious switch from a mental mode of startle to a mode of consciously regaining coordinated control.

4. Transitions

Time is a decisive factor is safety of dynamical systems. Time should also be considered when analyzing human performance. The human brain can also be in several modes and it takes time to change modes.

A distinction should be made between life cycle time scale and the mission cycle time scale. A mission has a mission profile, being a time-phased description of the events and environments a system experiences from initiation to completion of a specified mission, to include the criteria of mission success or critical failures [17]. The life cycle of a system contains one or more mission cycles, associated with a specific operational usage of a system [18].

Resilience literature seems to focus on the life cycle time scale rather than on the mission time scale. Incentives as economics and workload cause systems to become more brittle over time [19]. Safety and resilience considerations are not encountered in daily operation and it is difficult to maintain enough sense of urgency on these. Making the resilience margin more explicit may help to stress the importance of resilience to a system's behavior.

A trade-off exists between safety, economy and workload. During operation, the system has a working point that is a result of counteracting forces, like productivity, workload and safety [20, 21]. Working procedures are explicitly or implicitly adapted with best intentions. These changes affect the safety envelopes. On the next mission the operator may be confronted with a system that has a different behavior than he expects. System behavior that was within safety limits during the latest mission is now outside the safety limit. This represents drift into failure [22].

During a mission, a dynamic system goes through transient states, sometimes reaching a steady state that can be maintained during a longer time. Between missions the system is typically in a steady or dormant state.

On a mission scale, humans also have mental modes that cannot be changed immediately and in an arbitrary sequence. The practical outcomes and the consequences are also influenced by automation actions, crew expectations and either a high or low workload. The phenomenon of 'human error' is replaced by identifying an 'undesirable mental mode', that does not comply with a required system state. Such a mismatch can be labeled as 'cognitive dissonance'.

In modeling cognitive resistance to change, De Boer [14] identified two modes of operandi in the interference between emotional and social decision-making: unconscious resistance to change and conscious stubbornness. These phenomena represent a switch between two cognitive systems of thinking -a 'system 1' of rapid intuitive interferences and a 'system 2' of slower deliberate interferences- resenting a change in the mental model and type of reasoning of an operator [8]. Such a resistance may create a cognitive lockup in supervisory control tasks and eventually can create disruptions in the performance, causing accidents. Such a resistance to change is related to an individual's beliefs, persistence, change blindness, cognitive mismatch, fixation and mental lockup when dealing with contradicting signals [14]. Resistance to change may block sharing of mental models in a team, hindering a common understanding of a situation. It may have either a positive or negative effect on performance, depending on the situation. As such, this phenomenon bears no normative judgment on the correctness of an outcome or qualification by labeling the decision and subsequent action as 'human error' if the consequences do not comply with the normative expected outcome. Acknowledging the existence of system states and mental modes under a variety of operating conditions and safety envelopes urges to develop transition strategies to facilitate a timely, consistent and adequate transition.

Cognitive resistance to change is not identical with neuroticism although it is frequently labeled as such. As a behavioral component, its indecisive positive or negative consequence, situation dependency as additional properties such as extraversion and agreeableness. Resistance to change may have advantages as well: vigilance, danger avoidance, stimuli detection, achievement and rapid reflection may induce less automatic, intuitive behavior and enhance analytic competences. The interaction between emotion and reflection may improve the overall performance and the sensitivity to types and intensities of contradicting stimuli [14].

Applying cognitive resistance and conscious stubbornness can be instrumental as a deliberate strategy to cope with unsubstantiated desires to change and disruptions of thought processes. These positive properties can be considered attributes of Good Airmanship or Good Seamanship. Good airmanship and good seamanship have historical roots in these transportation sectors because they originated from the nature of their global networks with distributed and delegated responsibilities. Present tendencies to replace operator responsibilities and decisions by automation and optimizing their performance by procedural flight protocols have set a development in motion towards further Taylorization, full automation and performance optimization on punctuality, fuel economy, noise abatement and environmental issues. Flight crews are facing Flight Management Systems as ‘silent crew members’, who act unanticipated and without warning. They are exposed to ‘loss of situation awareness’ and ‘automation complacency’. Introduction of Unmanned Aerial Systems in controlled airspace and automated data transmission between air traffic systems and aircraft, such as ADS-B, exclude crews further from the control loop in normal operating conditions. The capability to cope with unanticipated and unfamiliar events depends on the availability of flexibility, adaptability and resilience to recover. Synchronization of the variance in system states, mental modes and operating envelopes requires transition capabilities between the combinations of all these conditions in regaining control over the aircraft. In socio-technical systems such as aviation, Good Airmanship and human centered operations can be the alternative for further Taylorization and automation in dealing with the unanticipated and the unfamiliar.

5. Conclusions

Infrastructural and transportation systems have become more and more complex and interrelated. Modern commercial aircrafts have the characteristics of socio-technical systems. Understanding and incorporating the human performance characteristics in responding to technical events is vital in understanding the overall behavior of these systems.

Human behavior that deviates from the prescribed, rule based, behavior can be perfectly normal behavior and should therefore not be considered a human error. On the contrary, mental modes should be considered to be a part of the system state as well as the technical state of the system. The mental mode of the operators can make the difference between a safe and a catastrophic situation. In dealing with potentially catastrophic consequences, alternatives for further restrictions towards rule compliant flight performance and further automation seem to be necessary in open, globally operated networks with diverging cultures and operating conditions such as aviation. Recognition of Good Airmanship and Good Seamanship and the ability to deal with a large variance and unpredictable interrelations is a prerequisite for a safe and reliable human performance.

A transition towards a new notion on human performance also requires coping with resistance to change in other disciplines than pilots, such as researchers and designers. During research activities on biofeedback, resistance was experienced among experts in the field of aircraft design, cognitive psychology and flight training. These experts were initially skeptical about the theoretical framework and found it difficult to adhere the new approach, because it did not relate to the current analytical approach of pilot training. Such resistance is a common human property. As stated by Harris: “For psychologists, the rejection of the concept of ‘human error’ is difficult to rationalize, with the perspective of the system designer employing a formal prediction methodology to help avoid actions that will degrade the system. When considering human error, first of all pick your perspective, then choose your label” [23].

References

[1] van Kleef E.A., and J.A. Stoop. *Reliable, Resilient: Towards a Dialectic Synthesis*. 46 th ESReDA Conference, Turino, Italy, 29-30 May, 2014.

[2] van der Top J. *Modelling Risk Control Measures in Railways: Analysing How Designers and Operators Organise Safe Rail Traffic*. Ph.D. thesis, Delft University of Technology, 2010.

[3] Perrow C.B. *Normal Accidents: Living With High-Risk Technologies*. Princeton University Press, Princeton, NJ, 1999.

[4] Holling C.S. *Resilience and Stability of Ecological Systems*. Annual Review of Ecology and Systematics. 1973; 4:1-23. Available from: http://webarchive.iiasa.ac.at/Admin/PUB/Documents/RP-73-003.pdf.

[5] Amalberti R. *Optimum System Safety and Optimum System Resilience: Agonistic or Antagonistic Concepts*. In: Hollnagel E., D.D. Woods, and N. Leveson, editors. Resilience Engineering: Concepts and Precepts. Ashgate, Aldershot, England, 2006. p. 253-271.

[6] NLR. *Angle-of-Attack Information in Civil Aircraft: A Comparison of Different Display Methods*. National Aerospace Laboratory, Amsterdam, The Netherlands, 2013.

[7] Snowden D. *The Origins of Cynefin*. [internet]. 2007. Available from http://www.cognitive-edge.com.

[8] Kahneman D. *Thinking Fast and Slow*. Penguin, London, England, 2012.

[9] Slovic P. *Trust, Emotion, Sex, Politics and Science: Surveying the Risk-Assessment Battlefield*. Risk Analysis. 1999; 19(4) :689-701.

[10] Rochlin G. *Safe Operation as a Social Construct*. Ergonomics. 1999; 42:1549-1560.

[11] Hollnagel E., J. Pariès, D.D. Woods, and J. Wreathall (Ed.). *Resilience Engineering in Practice: A Guidebook*. Ashgate, Farnham, 2010.

[12] Cowings P., and W. Toscano. *Autogenetic Feedback Training (AFT) as a Preventive Method for Space Motion Sickness: Background and Experimental Design*. NASA Technical memorandum 108780, 1993.

[13] Gorter D.P., and C.D. Jaeger. *Project Samurai Pilot: Exploring the Use of Heart Rate Variability Biofeedback as a Stress Management Technique for Commercial Pilots*. M.Sc. thesis, Delft University of Technology, Faculty of Aerospace Engineering, 2014.

[14] De Boer R.J. *Seneca’s Error: An Effective Model of Cognitive Resistance*. Ph.D. thesis, Delft University of Technology, 2012.

[15] Mohrmann J. *Investigating Flight Crew Recovery Capabilities From System Failures in Highly Automated Fourth Generation Aircraft*. M.Sc. thesis, Delft University of Technology, Faculty of Aerospace Engineering, 2013.

[16] Stoop J.A. *Towards a Failsafe Flight Envelope Protection: The Recovery Shield*. Advances in risk and reliability technology symposium, Nottingham, UK, 21-23 May, 2003.

[17] Department of Defense. *Definition of Terms for Reliability and Maintainability*. Department of Defense, Washington, DC, Military standard 721C, 1981.

[18] Department of Defense. *Electronic Reliability Design Handbook*. Department of Defense,

Washington, DC, Military handbook 338B, 1998.

[19] Woods D.D., J. Schenk, and T.T. Allen. *An Initial Comparison of Selected Models of System Resilience*. In: Nemeth C.P., E. Hollnagel, and S. Dekker, editors. Preparation and Restoration. Ashgate, Farnham, England, 2009. p. 73-94.

[20] Rasmussen J. *Risk Management in a Dynamic Society: A Modelling Problem*. Safety Science. 1997; 27(2/3) :183-213. Available from: http://www.ocw.nur.ac.rw/NR/rdonlyres/Aeronautics-and-Astronautics/16-358JSystem-SafetySpring2003/0E565A87-DFC1-4A54-B751-DF36BA2D6147/0/rasmussensafetyscience.pdf.

[21] Cook R.I., and J. Rasmussen. *'Going Solid': A Model of System Dynamics and Consequences for Patient Safety*. Quality & Safety in Health Care. 2005; 14(2) :130-134. doi: 10.1136/qshc.2003.009530.

[22] Dekker S. *Drift Into Failure: From Hunting Broken Components to Understanding Complex Systems*. Ashgate, Farnham, England, 2011.

[23] Harris D. *Human Performance on the Flight Deck*. Ashgate, Farnham, United Kingdom, 2011.

John A. Stoop is emeritus Professor at Lund University and owner of Kindunos Veiligheidskundig Adviesbureau, Gorinchem, The Netherlands. He has a M.Sc. in aviation engineering and a Ph.D. from Delft University of Technology. He liaised with the University of Applied Sciences of Amsterdam, department of Aviation. His expertise focuses on air safety investigations, forensic engineering, and system change. He has practical experience in accident investigations in all modes of transport.

Eric A. van Kleef holds a M.Sc. in civil engineering from Delft University of Technology. He is currently a Ph.D. candidate at Delft University of Technology and owner of van Kleef Consultancy, Leusden, The Netherlands. His expertise is in the field of safety of large infrastructural systems, contingency planning, and resilience. He is liaised to the Dutch National Operation Center.