AN OVERVIEW OF AGILITY AND RESILIENCE: FROM CRISIS MANAGEMENT TO AVIATION

Rogier Woltjer [1], Björn J.E. Johansson [2], and Peter Berggren [3]

Department of Information and Aeronautical Systems, Swedish Defence Research Agency FOI, P.O. Box 1165, SE-581 11 Linköping, Sweden

[1] rogier.woltjer@foi.se, [2] bjorn.j.e.johansson@foi.se, [3] peter.berggren@foi.se

Abstract

The concepts of agility and resilience both focus on the management of complex safety- and security-critical operations in terms of adaptability of operations in the face of change and unforeseen circumstances. After providing an overview of key concepts associated to resilience and agility from Resilience Engineering (RE), disaster management, crisis management and military command and control (C2) perspectives, this paper identifies research tensions, opportunities for cross-over of research foci, and challenges for the successful practical application of both agility and resilience. Resilience from the military C2 agility perspective seems to be mostly related to rebound or recovery, and is thus a distinctly different from how resilience is used in RE and disaster management. The other enablers (responsiveness, versatility, flexibility, innovativeness, adaptability) of agility and C2 agility, and the resilience perspectives of graceful extensibility and sustained adaptability, seem promising for innovation in aviation, pointing research to organizational and design principles to support adaptation and cope with surprise. Associated research questions applied to aviation are exemplified.

1 INTRODUCTION

The concepts of agility and resilience have a similar bearing on the management of complex safety- and security-critical operations in terms of adaptability of operations in the face of change and unforeseen circumstances that are not fully avoidable. Both fields have emerged as a reaction to earlier, mechanistic/tayloristic attempts to safeguard against failure. Agility is a term used in the literature on organizational theory (Holsapple & Li 2008; Spaans, Spoelstra, Douze, Pieneman & Grisogono, 2009) military command and control (Alberts, 2007, 2011; NATO STO SAS-085, 2013) and crisis management (Farrell, Baisini, Belanger, Henshaw, Mitchell & Norlander, 2013). Resilience has been applied in a number of social and physical sciences, such as ecology, clinical psychology, materials science, and engineering. Resilience as used in Resilience Engineering (RE; Hollnagel, Pariès, Woods, & Wreathall, 2011; Hollnagel, Woods, & Leveson, 2006) has its basis in cognitive systems engineering (Hollnagel & Woods, 1983, 2005), human factors, and safety science. Disaster management literature has also used the concept of resilience for some time (Boin, Comfort, & Demchak, 2010; Manyena, 2006). Several common definitions of the two concepts are at least partially overlapping, yet they stem from rather different conceptual backgrounds and problem areas. Both approaches do however share that they have emerged as a consequence of growing complexity and unpredictability in the type of stakeholders' activities.

In this paper, research tensions, opportunities for cross-over of research foci, and challenges for the successful practical application of both agility and resilience in relation to associated research disciplines are identified. With the help of the concepts of resilience and agility various research communities connected to different fields of practice aim to enhance socio-technical systems' adaptability and pro-activeness in coping with unpredicted events. However, these concepts are used in vastly different ways. Not addressing research tensions and opportunities for cross-over of advances between different fields and research communities might hinder the progress made towards the goal of these research endeavours, which is to improve operational management of complex systems in practice. A focused discussion of research progress of agility and resilience and its practical implications is therefore relevant and needed. This paper attempts to advance this discussion and provide implications for research on agility and resilience in aviation.

2 THE FOCI OF RESILIENCE IN RESILIENCE ENGINEERING

Resilience has been defined as "the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions." (Hollnagel, 2011a) (p. xxxvi). This definition reflects the need to not only reactively adjust after disturbances are observed but also when they are anticipated to occur. Adjusting performance with respect to disturbances but also subtle changes is essential, as fluctuations in working conditions may coincide and combine to hazardous situations due to complexity and intractability. RE emphasises the need to see the multiple goals that the core business aims to achieve, which is hardly only safety but often also productivity, security, environmental sustainability, etc. RE recognizes that not all conditions can be expected and prepared for beforehand, and that unexpected conditions will at some point occur. In order to achieve resilience, four interrelated and interacting abilities have been suggested: anticipating (knowing what to expect), monitoring (knowing what to look for), responding (knowing what to do), and learning (knowing what has happened) (Hollnagel, 2011b).

Articulating the importance of unexpected conditions in Resilience Engineering, another definition focuses on the situations that go beyond what the organisation or system has prepared for: "the ability to recognize and adapt to handle unanticipated perturbations that call into question the model of competence, and demand a shift of processes, strategies and coordination" (Woods, 2006) (p. 22). Recently Woods outlined four uses of the concept of resilience: as rebound, as robustness, as graceful extensibility when surprise challenges boundaries, and as a network architecture that can sustain the ability to adapt to surprise (named Resilience-1 to 4) (Woods, in press).

3 THE FOCI OF RESILIENCE IN DISASTER MANAGEMENT

The emergency and disaster management literature has acknowledged the importance of the concept of resilience for some time (Manyena, 2006). Modern crises may be characterised by an increase in coupling and complexity, which makes prevention, mitigation, and preparation very challenging (Boin et al., 2010). A definition of resilience in the disaster management strand of research is: "Resilience is the capacity of a social system (e.g., an organization, city, or society) to proactively adapt to and recover from disturbances that are perceived from within the system to fall outside the range of normal and expected disturbances" (Boin, Comfort, & Demchak, 2010, p. 9). Besides similarities in proactivity, a tension can e.g. be found between the inclusion of expected events (as in Hollnagel's (2011a) definition above) and the restriction of resilience to the unexpected and not-prepared-for, as in Boin et al.'s (2010) as well as Woods' (2006) definitions of resilience.

Research tensions and challenges for the definition of resilience in disaster management in relation to related disciplines have been described in three aspects (Boin et al., 2010): (a) the moment of resilience (response/recovery after the event and/or adaptation beforehand); (b) to which event severity it applies; and (c) the state of return that resilience applies to (returning to a situation similar to before the event, make the system function again, or making it stronger than it was before).

4 THE FOCI OF (C2) AGILITY

The concept of agility is related to the concept of resilience in the sense that there is a common focus on adaptation of the management of command and control processes not only after a certain disturbance or event but also in a proactive manner. This paper focuses on agility and C2 agility as defined by and in connection to the NATO STO SAS task-groups (NATO STO SAS-065, 2010; NATO STO SAS-085, 2013) whereas other definitions and uses of the term exist.

Agility is developed from a problem space of command and control characterised by time pressure, uncertainty, and risk, in the face of complexity. Similar to the development of resilience engineering described above, military operations have become so complex that effective command and control and performance in military operations should be described as emergent properties of the behaviour of MTO-systems (Man-Technology-Organization), rather than simple cause and effect relationships. Similarly to the Resilience Engineering and Safety-II perspectives, agility is about "maintaining success in light of changed or changing circumstances" (Alberts, 2011) (p. 66). It includes both passive–active and reactive–proactive components. Alberts concludes with the following definition: "Agility is the ability to successfully effect, cope with, and/or exploit changes in circumstances" (Alberts, 2011) (p. 190) and (SAS-085, 2013) (p. 54).

Agility is a multi-faceted concept which includes the following components: responsiveness, versatility, flexibility, resilience, innovativeness, and adaptability (Alberts, 2011) (p. 204). Resilience is subsequently described as providing a system with "the ability to repair, replace, patch, or otherwise reconstitute lost capability or performance (and hence effectiveness), at least in part and over time, from misfortune, damage, or a destabilizing perturbation in the environment" (Alberts, 2011) (p. 217). Apart from the adversary as an obvious source of perturbations in a military environment, acts of nature and inevitable results of complexity are also mentioned as sources, providing overlaps with the disaster management and resilience engineering fields respectively. Resilience is in this description however more in line with resilience as described in for example physics, meaning the ability to bounce back to an earlier performance level after a disturbance, essentially a passive capacity. In contrast, some authors in the Resilience Engineering and disaster management field, see pro-active adaptability in anticipation of degradation as part of resilience. Adaptability is another overlapping theme, although here it is seen as a part of agility that is related to but separate from resilience.

The NATO SAS-085 "C2 Agility and Requisite Maturity" further develops this into a C2 Approach Space and a conceptual model of C2 agility (NATO STO SAS-085, 2013). While agility, as such, describes the ability of an entity to cope with a complex and dynamic environment, C2 agility describes the ability of the unit to adapt its way of organizing work to fit the problem at hand. To be C2 agile is thus a property describing to what extent the C2 organization can adapt its way of working to the current situation in terms of dissemination of information, allocation of decision rights and patterns of interactions (organization and structure). A fundamental hypothesis in the NATO STO SAS work has been that each type of situation/problem/mission has its own ideal point in the command and control approach space – no organization type is thus perfect for all kinds of missions/situations. Similar observations have been made in the studies of High Reliability Organizations:

> "The navy has managed to balance the lessons of the past with an openness to change and create and organization that has the stability and predictability of a tightly run hierarchy but that can be flexible when necessary…… Depending on the demands of the situation, people will organize themselves into different patterns. " (Pool, 1997, p. 42-44).

5 IMPLICATIONS FOR AGILITY AND RESILIENCE RESEARCH IN AVIATION

This section discusses some of the components of the definitions outlined above from military and crisis management to identify research questions for aviation. First, the need for aspects of agility and resilience may be identified as part of the International Civil Aviation Organization (ICAO) definition of Air Navigation Service (ANS) expectations, which are highlighted to make the point that the concepts seem to suit well to the ANS operational environment. Second, examples of research questions are derived from some of the highlighted definitions as a research agenda.

As an example of how central and important the presented concepts are to Air Traffic Management (ATM), the expectations of ANS flexibility, and capacity have bearing on agility and resilience. *"Flexibility* addresses the ability of all airspace users to modify flight trajectories dynamically and adjust departure and arrival times, thereby permitting them to exploit operational opportunities as they occur." (ICAO, 2005, p. D-2). The expectation of flexibility thus includes exploiting opportunities, a central concept in agility. The expectation of *Capacity* expectations address resilience explicitly and links several high-level expectations to each other: "The ATM system must be resilient to service disruption and the resulting temporary loss of capacity" (ICAO, 2005, p. D-1). Improving the ability to exploit opportunities and be resilient to service disruption are thus in the interest of the aviation system, and theoretical frameworks that enhance these abilities may be employed to do so.

As a step in this direction, Table 1 includes a number of the concepts as part of the agility and resilience literature and their definitions, and identifies applied aviation research questions for further research.

***Table 1**. Agility (A) and resilience concepts, with example research questions applied to aviation*

Concept	Definition	Aviation agility/resilience research question examples
Responsiveness (A)	The ability to react to a change in the environment in a timely manner (NATO STO SAS-085, p. 204)	How can a change be detected by different stakeholders and roles at different levels? What response is required? What are the *criteria* for a successful response (e.g. separation maintained, safe landing, minimize economic loss), and *how* (indicators) and *when* (immediate, delayed) can these be assessed?

		How does response at the *sharp* (pilots, controllers (ATCOs), maintenance engineers) and *blunt* ends (safety/crisis managers, middle/top management) interact and how are they interdependent? Is a collective response by stakeholders (several ANSPs, several airlines, ANS Provider-airport-airline, etc.) expected/beneficial?
Versatility (A)	The ability to maintain effectiveness across a range of tasks, situations, and conditions (NATO STO SAS-085, p. 205)	How are competencies and tasks distributed among operators (e.g., controllers being certified on various clusters of area control sectors, or both tower/terminal control; pilots with multiple type ratings; engineers with crisis management roles)? How can resources be made available and shared so that stakeholders' task coordination is facilitated (e.g., airline and manufacturer sharing crisis facilities)?
Flexibility (A)	The ability to employ multiple ways to succeed and the capacity to move seamlessly between them (NATO STO SAS-085, p. 203)	Which alternative courses of action can be taken to achieve goals (e.g., are several procedures available so that the choice of procedure is not obvious)? How do alternative courses of action intertwine? How do operators know when to switch strategy (e.g., how can ATCOs and pilots be prepared generally to identify when a procedure in an unusual situation is taking too much time to complete)?
Resilience (A)	The ability to recover from or adjust to misfortune, damage, or a destabilizing perturbation in the environment (NATO STO SAS-085, p. 204)	What strategies and resources are necessary and available to recover to a normal state? What is the normal state to recover to (e.g., in terms of flight delays, re-routings, ANS capacity levels)? Similar to Rebound (R-1), below.
Innovativeness (A)	The ability to do new things or the ability to do old things in new ways (NATO STO SAS-085, p. 204)	How can operators be encouraged to come up with new ways to achieve goals? Are alternative resources available to use in innovation of ways of working (e.g., particular expertise, maps, break-out rooms, simulation resources)? When are new approaches necessary and how do operators identify this?
Adaptability (A)	The ability to change the organization and/or work processes. (NATO STO SAS-085, p. 199)	What mechanisms are in place for changing organization and/or processes (e.g. prepared crisis-mode organization responsibilities and communication channels)? How can different levels of the organization be prepared for unexpected and new changes in work processes?
Resilience cornerstones	Monitor, respond, learn, anticipate	See Resilience Analysis Grid (RAG; Hollnagel, 2011b)
Rebound (R-1)	Rebound (Woods, in press)	See Resilience (A) above, as resilience from the agility perspective is defined as recovery from perturbation.
Robustness (R-2)	"increased ability to absorb perturbations" (Woods, in press, p. 2)	Woods (in press) argues that robust control works for well-modeled and well-understood situations, but that increasing robustness may decrease resilience (R-3/4). Thus it is relevant to ask which situations are modeled and handled using the processes and system designs in place.

		For example, safety assessment techniques in both air traffic management and aircraft manufacturing model a large number of risks. R-3 and R-4 (below) would ask how to cope with the surprise situations that are not covered by these methods, rather than relying on that all these anticipatory processes fully specify all future situations.
Graceful extensibility (R-3)	"resilience as the opposite of brittleness, or, how to extend adaptive capacity in the face of surprise" (Woods, in press, p. 3)	This perspective on resilience asks "how do systems stretch to handle surprises?" (Woods, in press, p. 3). Thus it is relevant to ask what aspects of a situation are regarded as surprises, how do controllers and pilots identify surprise, and what strategies can be identified that operators and organizations use to adapt (see Rankin et al. 2013, for an attempt in describing some of these issues for flight crews).
Network architectures for sustained adaptation (R-4)	"the ability [to] manage/regulate adaptive capacities of systems that are [and are part of] layered networks […] to produce sustained adaptability" (Woods, in press, p. 4)	The air traffic system arguably develops more and more towards increased interdependency between nodes in a layered network. ATM units and aircraft become more interconnected (e.g. through trajectory management) and aviation stakeholders are more linked than ever before (e.g. through collaborative decision making). Questions from this perspective (Woods, in press) ask how architectures of these networks, and design principles and techniques (see Woltjer et al., in press, for an attempt in this direction for ATM) can support adaptation at and between layers over time, and how this property can be assessed.

6 DISCUSSION

Agility, and C2 Agility, thus shares some concepts with resilience, primarily in term of their aims. Both resilience and agility consider adaptive capacity as the primary way to cope with the kind of events that emerge from the complexity of today's challenges. They both consider learning as an important source for improving the ability to cope with challenges, but they also recognise the need to be able to cope with what cannot be anticipated. However, there are some important distinctions too. Firstly, resilience engineering, and safety in general, does not cope with an intelligent enemy and therefore does not need to "exploit changes in circumstances" in that sense – it is enough to "sustain required operations". However, an issue that is more prevalent in aviation, and that military is affected by but in a less distinct manner, is the economic pressure in the highly competitive aviation environment. The "exploit changes in circumstances" aspect of agility could provide a contribution here, linking business continuity and interactions of these aspects with crisis management and safety management aspects in aviation stakeholders. Also, the expectation of flexibility in the ATM system clearly points to the need for exploitation of operational opportunities, for example in order to provide efficiency in traffic flows.

Further, agility focuses largely on adaptive capacity in terms of C2 (by utilizing the C2 approach space and the concepts of C2 maturity and C2 maneuverer agility), which would translate to "organization" or "management" in the industrial domain. Resilience engineering is not specific in its view on organization/management and lacks a theoretical construct for discussing how management and organization can or should adapt to changing circumstances. The concept of "layered network architectures for sustained adaptation" (Woods, in press) seems a step in this direction and highlights a similar concern for organizational and design principles to support adaptation, which may be developed further for aviation translating the C2 agility approach space to aviation.

Resilience from the agility perspective described seems to be most related to "rebound" or "recovery", and is thus a distinctly different from how resilience is used in Resilience Engineering and disaster management. Robustness and recovery aspects have a longer history in aviation so that the other enablers of agility and the perspectives of graceful extensibility and sustained adaptability seem more promising for innovation. Associated research questions have been exemplified for aviation (see Table 1). Other research tensions identified include whether expected conditions should be included in the concept of resilience, and to which extent anticipation is part of resilience/agility.

Possibly due to Resilience Engineering's roots in mainly cognitive systems engineering and reactions to traditional human factors and safety, the debate of how Resilience Engineering can contribute to these operational practices often focuses on discussions as reactions to traditional safety and human factors paradigms. This paper has aimed to broaden this discussion and argues for the consideration and relevance of a number of concepts and ideas developed under the label "agility", and how these may contribute to improving operational realities in ways congruent to the ambitions of resilience engineering. In particular, these concepts may broaden the discussion of resilience from safety to business continuity concepts such as seizing opportunity and exploiting circumstances, and clarify the multifaceted concept of adaptability of organizational features.

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7 REFERENCES

Alberts, D. S. (2007). *Agility, Focus, and Convergence: The Future of Command and Control*. The International C2 Journal, 1(1). 1-30.

Alberts, D. S. (2011). *The Agility Advantage: A Survival Guide For Complex Enterprises and Endeavors*. USA: DOD CCRP. Retrieved from http://dodccrp.org/files/agility_advantage/Agility_Advantage_Book.pdf .

Boin, A., Comfort, L. K., & Demchak, C. C. (2010). The rise of resilience. In L. K. Comfort, A. Boin, & C. C. Demchak (Eds.), *Designing Resilience: Preparing for Extreme Events* (pp. 1–12). Pittsburgh, PA: University of Pittsburgh Press.

Farrell, P. S. E., Baisini, C., Belanger, M., Henshaw, M., Mitchell, W., & Norlander, A. (2013). SAS-085 C2 Agility Model Validation Using Case Studies. In *Proceedings of the 18th ICCRTS*, Alexandria, VA, June 19-21. Washington, DC: DoD CCRP.

Hollnagel, E. (2011a). Prologue: The scope of resilience engineering. In E. Hollnagel, J. Pariès, D. D. Woods, & J. Wreathall (Eds.), *Resilience Engineering in Practice: A Guidebook* (pp. xxix–xxxix). Aldershot, UK: Ashgate.

Hollnagel, E. (2011b). Epilogue: RAG – The Resilience Analysis Grid. In E. Hollnagel, J. Pariès, D. D. Woods, & J. Wreathall (Eds.), *Resilience Engineering in Practice: A Guidebook* (pp. 275–296). Aldershot, UK: Ashgate.

Hollnagel, E., Pariès, J., Woods, D. D., & Wreathall, J. (Eds.). (2011). *Resilience Engineering in Practice: A Guidebook*. Aldershot, UK: Ashgate.

Hollnagel, E., & Woods, D. D. (1983). Cognitive systems engineering: New wine in new bottles. *International Journal of Man-machine Studies, 18*(6), 583-600.

Hollnagel, E., & Woods, D. D. (2005). *Joint cognitive systems: Foundations of cognitive systems engineering*. CRC Press.

Hollnagel, E., Woods, D. D., & Leveson, N. (Eds.). (2006). *Resilience engineering: Concepts and precepts*. Aldershot, UK: Ashgate.

Holsapple, C. W., & Li, X. (2008). Understanding Organizational Agility: A Work-Design Perspective. In *Proceedings of the 13th ICCRTS*, Seattle, WA, June 17-19. Washington, DC: DoD CCRP.

ICAO. (2005). *Global Air Traffic Management Operational Concept*. International Civil Aviation Organization.

Manyena, S. B. (2006). The concept of resilience revisited. *Disasters, 30*(4), 433–450.

NATO STO SAS-065 (2010). *NATO NEC C2 Maturity Model* (CCRP Publication Series). Washington, DC: DoD CCRP.

NATO STO SAS-085 (2013). *C2 Agility – Task Group SAS-085 Final Report* (STO Technical Report STO-TR-SAS-085). Brussels, Belgium: NATO Science and Technology Organization.

Pool, R. (1997). When failure is not an option. *MIT's Technology Review, 100*(5), 38-45.

Rankin, A., Woltjer, R., Field, J., & Woods, D. (2013). "Staying ahead of the aircraft" and Managing Surprise in Modern Airliners. In *Proceedings of the 5th Resilience Engineering Association Symposium* (pp. 209–214). Soesterberg, NL: Resilience Engineering Association.

Spaans, M., Spoelstra, M., Douze, E., Pieneman, R., & Grisogono, A. (2009). Learning to be Adaptive. In *Proceedings of the 14th ICCRTS*, Washington, DC, June 15-17. Washington, DC: DoD CCRP.

Woltjer, R., Pinska-Chauvin, E., Laursen, T., & Josefsson, B. (in press). Towards understanding work-as-done in air traffic management safety assessment and design. *Reliability Engineering & System Safety*. doi:10.1016/j.ress.2015.03.010.

Woods, D. D. (2006). Essential characteristics of resilience. In E. Hollnagel, D. D. Woods, & N. Leveson (Eds.), *Resilience engineering: Concepts and precepts* (pp. 21–34). Aldershot, UK: Ashgate.

Woods, D. D. (in press). Four concepts for resilience and the implications for the future of resilience engineering. *Reliability Engineering & System Safety*. doi:10.1016/j.ress.2015.03.018.