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Resilience and specialization in volatile environments: evidence from the Italian Air Force Tornado crews learning practices

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ABSTRACT

The link between specialization and resilience in the organizational design literature is oftentimes characterized as a trade-off: either organizations attune their structures to a narrow class of external stimuli, or they choose the ability to manage a wide variety of inputs, thus increasing their ability to survive. Mixed behaviours are typically described in terms of compromise and lack of coherence. In this paper, we study the reliable and robust actions implemented in a volatile environment: we analysed the flying abilities and learning paths of pilots in the Italian Air Force. We show that in order to provide reliability and robustness, both high specialization and broad scope systems are required; expertise and learning are built across these areas which are traditionally described as segregated. In fact, the usefulness of such systems rests on their capability to buy time for processing and for finding appropriate or new solutions in volatile situation.

1. Introduction

Organizational studies have long focussed on the problem of understanding the interaction between the environment – and its various definitions – and organizational design, starting with the functionalist and contingency theory traditions. Recently, two streams of research have spurred a renewed interest in this interplay. The first one can be traced back to the contributions on the so-called High Reliability Organizations (HRO) (La Porte, 1996; LaPorte & Consolini, 1991; Roberts, 1990; Weick & Sutcliffe, 2001). It focussed on the analysis and design of organizations displaying robustness in the face of an extremely dangerous environment, that is an environment that can seriously endanger the very survival of the organization itself (Perrow, 1999). The main conclusions stemming from these studies include comments on the design at a structural level (e.g. units devoted to monitoring specific inputs from the environment signalling a crises, resilience) and at the individual and social attitude levels (e.g. preoccupation with failure, deference to expertise when drawing inferences). However, these studies have mostrly remained confined within a specific area of expertise and have not crossed the bridge to the broader organization studies literature (Kantur & Iseri-Say, 2012; Scott, 1994 cited in Weick, Sutcliffe, & Obstfeld, 1999: 82). The second stream referring to the generality of organizations mainly modelled the interaction of environment and structure.. On the one hand, these models have enhanced our understanding of the relationship in terms of cost efficiency of organizational solutions for different conditions in environmental complexity (Cohen & Levinthal, 1994; Winter, 2004). On the other, (J. H. Holland, Holyoak, Nisbett, & Thagard, 1989; J. H. Holland, 1995; Winter, 2004) organizational structure has been conceived as a set of “sensors”, tasked with monitoring the environment, and “reactors”, devoted to producing a response to the stimuli thus perceived. Associated sensors and reactors reflect the same level of specialization in seizing external signals and in providing specific actions to deal with them, and overall there are two set of systems, one more general purpose and a second set with more specialized sensors and reactors.

Notwithstanding these interesting results, we believe that these analyses share some important misconceptions on how they interpret the environment that undermine the scope of their explanatory power. The first concerns the relationship between features of the environment and organizational reaction structures in static terms. That is, organizations produce structures aimed at solving specific characteristics of the environment and then are unable (or mostly unable) to let them evolve. The second one derives from the mechanistic connection shaped between monitoring and (re-) acting structures that does not contemplate the possibility of interaction between the whole sensor-reactor structures, or between the single sensors and reactors composing the structures.

In this paper we explore these limitations by analysing a case in which the environment is typically volatile and as a result, where specialized efficient behaviours have to be combined with resilience. The purpose is to investigate the deployment and the role of mixed (cost-efficient and resilient) behaviours, or in other words, the interaction of sensor-reactor structures. We chose a peculiar context as our privileged field of research, namely the activities of crews flying fighter-bomber aircraft of the Italian National Air Force. More specifically we focussed on the Tornado crew members flying on the same plane with the complementary roles of pilot and navigator. We conducted a case study with the purpose of inspiring a theory (Siggelkow, 2007). Our dataset consists of archival data, interviews, the observation of real and simulated flights.

Our paper allows to highlight some critical points that have remained unexplored in the organizational literature. Our contribution is twofold. First, we offer an integrated view of sensing and acting capabilities of organizations. Second, this view represents an enrichment of the traditional approaches to organizational learning. Namely, we consider a richer set of feedback loops to be incorporated into problem representation and solution at the organizational level.

The rest of the paper is structured as follows. The next paragraph presents the literature we build on. The third paragraph is devoted to the description of the research method and the empirical setting we employed to investigate the relationship between the sensing and the acting dimensions in complex organizations. Paragraph four illustrates the main empirical evidence we collected in the form of a case study. Then, we move to an analysis of the case, identifying our main theoretical contributions and underlying some managerial implications of our understanding of the case. Last come the conclusions.

2. Our research question in the literature

In his evolutionary view on the variety of organizational structures and on their vulnerability to environmental challenges, Winter (2004) stylized some basic components and dynamic mechanisms of the environment-organization interaction that may help clarifying our contribution.

He claims that organizations like organisms are endowed with a sensor-reactor system which serves for seizing environmental signals and for responding to them. Over time, they have evolved according to i) the frequency and the variety of stimuli organizations were exposed to, ii) the impact (in terms of win/loss) of facing such situations, through a cost-benefit analysis based on the assessment of risk (combining frequency and impact). As newborn and inexperienced, sensor-reactor systems were generic, addressing a broad range of stimuli and providing general, not always effective responses. Evolution through experience, then, brought to specialization thus efficiency, when relevant environmental signals were repetitive and associated solutions had become clear, stable and secure. Variety of structures is due to the fact that: evolution is still incomplete or ongoing in many cases, or environments are volatile and changing so that specialization has not been possible. Moreover, in complex systems such organizations, specialized and generic systems may coexist, and be directed towards different subsets of stimuli.

Winter offered an interesting though metaphorical exemplar for specialization. Some species of moths have developed a very sophisticated detector, which is similar to a sonar, for perceiving the shaking of bats' wings, that are their major predators, and can play a peculiar evasive dive maneuver to escape from them: this is an example of highly integrated sensor reactor systems (Figure 1 a). From the same natural context, Heiner's (1983) representation of prey behavior may be a good metaphor for general sensor-reactor system (Figure 1, b). For any signal coming from the environment which is not immediately recognized as a mate or food (sounds, sights, smells), preys activate the same reaction: they flee. Specialized systems are more efficient and are extremely effective for the kind of stimuli they were designed for. They are much more cost effective, yet, they are extremely vulnerable in any other condition: moths cannot hear anything but bats and are likely to die from a rolled paper in our houses. Conversely, generic systems are less precise and their reaction may be not necessary in many cases, e.g. when unusual noises are not revealing threats. Nevertheless, they have a higher chance to capture unknown risks and they always provide *some kind* of answer, thus increasing the resiliency of the system.

Figure 1 about here

In the traditional view of complex adaptive systems (Cohen & Levinthal, 1990; Denrell & March, 2001; Levinthal & March, 1993; March, 1991; March, 2006; Winter, 2004), the two systems typically coexist in organizations as they address different and separate sets of stimuli (Figure 1, c). For environmental conditions that have been faced more frequently and that imply a big impact, organizations tend to develop specialized sensors by means of learning. For new challenges or unusual ones, generic sensors are in place. Organizational action has been conceived as a vertical ordinated activity of reaction with some feed-back only within the concerned sensor-reactor which can be either specialized or generic.

While the coexistence of such diverse systems in the organizational population has been acknowledged, the rationale for their coexistence within the same organization still needs to be understood. For the sake of simplicity, either specialization or generic action have been studied leaving a deep gap in a grounded understanding of how stimuli are perceived and processed and how solutions are found. However, admitting the existence of both specialized and generic systems within the same context brings to the forefront the problem of the interaction of the two kinds of systems the literature has not consistently addressed.

We specify here for reference that throughout the paper we will refer to the association of sensor and reactor at the same level of specialization, that is mainstream in the literature, with the expression “vertical dimension” of the sensor-reactor system. Conversely, we will refer to the interaction of sensors or reactors of different levels of specialization with the expression “horizontal dimension” of the sensor-reactor system, and to the interaction of sensors with reactors of different levels of specialization as the “interplay between dimensions” (Figure 2). The exploration of the horizontal dimension and the interplay of sensors and reactors are the focus of this paper. We ask: aside from the vertical integration of sensor-reactor systems is there any horizontal relationship between general and specific sensors and general and specific reactors? Is a significant part of we define as learning take place also due to such horizontal loops? More generally, such questions allow us to closely investigate the forms of signal processing and its effects on the establishment of the dual system of sensors and reactors (i.e. the co-presence of generic and specific structures). Then, are the systems typically integrated through parallel or sequential functioning? Such questions bring into the picture the time dimension which is typically a neglected element in problem-solving and decision-making models.

Figure 2 about here

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3. Research Method

We conducted an in-depth case study of the relationship between environmental stimuli and organizational design solutions in order to inductively generate a new theoretical interpretation (B. G. Glaser & Strauss, 1967; B. G. Glaser, 1992; Siggelkow, 2007) of this interplay. As research method, we chose a single-case empirical analysis (Yin, 1994): 40) as suitable to gain a consistent understanding of the phenomenon (Le Coze, 2008; Suddaby, 2006; Vaughan, 2004), and more broadly, to contribute to the advancement of its theoretical framework. The analysis followed the grounded theory procedure as originally formulated by Glaser and Strauss (1967) and partially reinterpreted by Glaser (1978), and employed by several authors for investigating this class of phenomena.

The empirical setting selected for the purpose of the study has been offered by the Italian Air Force in which we focused on a particular wing (6° Stormo), which flies Panavia Tornado fighter-bombers. This choice follows a twofold set of motivations. On the one hand, the Air Force is a transparent organization along several dimensions that are particularly meaningful for the purpose of the study while others are simplified. This offers an ideal empirical field in which there is a methodological and theoretical justification for isolating some dimensions and focusing almost exclusively on them. In fact, consider that the “core business” of this organization is to fly a limited subset of possible missions. Namely these are attack missions, that is missions consisting in bombing ground-based targets while defending from possible hostile interceptors or ground-based weapons-systems. The missions can be carried out solo or in complex formations. We will focus on solo training missions and these make up a vast majority of the training and practice missions and thus are also more clearly and frequently observable. Furthermore, both hierarchical and incentive structures are clear and taken for granted by all the participants to the organization. One should note, also, that, there is a homogeneity of the technical domain managed by the flying crews, so that a community of practice can be identified, and there is a strong interaction between human decision makers and artefacts. On the other hand, we directed our analysis to a wing within the Italian Air Force in which only Tornados are flown. The rationale is that such kind of airplanes devoted to reconnaissance and combat require a crew of two people whose roles – pilot and navigator – are structured around a strict division of interactive labour. As such, they can be considered the simplest possible team structure in which there are still coordination dynamics, as well as more complex interactions with external actors and organizations such as the control tower.

The case study is based both on primary and secondary source data, collected at the various levels of the organizational structure, that include archival records, interviews, and direct observations of simulated and effective flights procedures as well as other activities (Table 1 details our data collection process). The systematic triangulation of such data sources (archival documents, interviews and observations) provided internal validation and reliability to the analysis and the findings (Yin, 1994): 98-99).

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Table 1 about here

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4. "The flight"

4.1 The tornado crew (pilot and navigator interactions) and its division of labour

The major source of difficulty in flying Tornados can be attributed to the fact that it is driven by a flight crew composed of two persons, a pilot and a navigator. In Tornados, the information flux is only partially overlapped between the crew members: pilot and navigator are endowed with a common set of indicators (alarms) that signal serious problems occurring to the aircraft. Other indicators are devoted to the exclusive attention of the one or the other, even it is often necessary to consider them together in order to build a complete understanding of the problem. In this way, the flight benefits from a highly specialized monitoring of some information sources which avoids information overload, and introduces interdependence also in the phase of information gathering thus stimulating reciprocal attention. This design has also the purpose of introducing a form of continuous control as activities are always interactive, as well as a form of support and confrontation in the face of serious alarms or ambiguous signals. The same interdependence and the same benefits and difficulties concern the domain of action. In fact, tasks are divided between pilot and navigator so that the completion of one activity is the necessary condition for its prosecution by the other crew member.

4.2 How to fly: the concept of situational awareness / the basic rules

The first aim of any mission is “to bring the target home”, expression which underlies a variety of aims that a flight might have, which range from the simple execution of a series of flight procedures, with the purpose of refreshing them as know how and knowledge, to the precise release of weapons in war times. Nevertheless, the completion of any mission depends on the ability of the crew to keep control of the aircraft as further activities (reconnaissance or attack) are inevitably grafted into this primary one.

“To lead” a Tornado is a complex activity which requires the consideration of a large set of information related to the condition of the aircraft, the course, the proximity to the target, meteorological conditions and air traffic conditions, and deriving from the “look out” of the crew, the flight instruments and warning lights, communications between crew members and radio transmissions (see Figure 3 below). The capability of handling comprehensively all of these information sources is functionally connected to the so called “S.A.” i.e. Situational Awareness, which represents the ability to correctly allocate attention and to prioritize incoming information.

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Figure 3 about here

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All our interviewees found it very difficult to describe what S.A. is, and specific documental material could not be more exhaustive, displaying the tacit nature of this competence. S.A. is referred to as an ability to combine environmental signals and intuitions into an ordered “mental film” of the present, past and future states. For this purpose, the visualization of the situation, which is created in parallel during the unfolding of events in the mind of the crew, allows to acquire awareness of potential threats, to simulate a reaction and to anticipate consequences and reaction. This is an imaginative activity which does not neglect any dimension of experience as it aims at “building a picture” of the situation, with sounds and sensations of the real, but before it actually takes place, before the aircraft arrives to it and before its instruments may be able to map it. Crews call this activity “to stay ahead of the aircraft”.

S.A. is a basic competence which is meant to be present while performing other activities. The main source of S.A. is experience, and there are no precise indications on how to acquire it. In fact, when a drop of S.A. takes place, in order to restore it, crews refer to general and simple principles, known as “basic rules”, that are designed to increase available time for problem solving, rather than to define a procedure for solving problems in complex situations (see Table 2). This problem solving ability is in fact meant to be there, as an endowment, it may be temporarily soothed by some conditions, and just needs to be waken up. The implicit idea is that if S.A. is maintained at a certain level, gathering and interpreting information becomes simple. There would not be ambiguous or unexpected situations which required a complex problem solving. Complexity emerges only when S.A. is low. As a matter of fact, when S.A. is adequate, “perceptions correspond to what is actually taking place” and response is simply selected in a rich repertoire of consolidated solutions linked to a set of expected problems.

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Table 2 about here

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Such a design of the perceptual system has the advantage of reassuring crews as there are no unknown situations and they can rely on all the solutions that they may need. This sense of security is acknowledged to be an essential requirement for engaging in combat missions. On the other hand, it provides the crew with no complex set of procedures on what to do, which would always be inadequate to unforeseen and unknown situations. In fact, it endows them with simple and general level principles which leave them the responsibility to find solutions but provide the contextual conditions for this to happen (increase available time, as well as reassurance, minimizing the chances of panicking).

In this line, problem solving lies in the correct execution of a set of responses to the set of possible and relevant states of the world. These couples are codified in standard procedures and need to be recalled with a different degree of precision and rapidity. Some are acquired on reference manuals before actually learning to fly this particular aircraft, others are learnt by heart as they need to be recalled quickly; a third set is reported in Check lists (avionic and emergency check list) that are directly consulted and followed step after step during the flight because of their complexity and of the required precision of execution.

Overall, the ability of experts of flying the aircraft is called Airmanship. From direct observation of the performance of expert and rookie crews and anecdotal evidence presented in the interviews, differences in performance can be characterized essentially along two dimensions: the higher S.A. exhibited by experts and their better ability to select between procedure-based and basic-response behaviour and to combine the two. Ability to recall the procedures correctly and to execute them properly is, basically, the same for both veterans and rookies.

4.3 How to fly when emergencies occur: the sensor-reactor systems and their interactions

The states of the world that a complex system like the aircraft can assume are captured and synthetically represented by the flight instruments and alarm system of the airplane. In relation to every combination of them, a codified solution has been identified. Every pilot and navigator can refer to the Emergency Check List, which reports a series of actions to undertake in order to react to single or combined alarms or anomalous flight instruments values. The first part of these highly specified contingencies is called "bold face" and is learnt by heart by the crew. What follows, on the other hand, needs to be read in the case of need, is implemented by the crew members, and requires a high level of interaction.

In order to activate the correct response, there are two critical steps: the recognition of the codified category to be recalled and the response implementation.

On Tornados, the system of instruments and alarms selects and interprets signals for the crew, who can concentrate mainly on the second step, although this is complemented, at least to some extent but at all times, by the ability of the crew to "look out": literally, through the windshield for the pilot, and by means of the radar for the navigator.

5. Theoretical interpretation: an organizational solution to the problem of flying

5.1 Vertical and horizontal dimensions in the sensor-reactor systems

We can interpret the actions undertaken by the flight crews as the result of two strategies for conducting the plane, working at two different levels. On the one hand, we have an extremely generic strategy from a declarative point of view, the "stay aloft", which is however almost totally based on a highly contextual and implicit understanding of those apparently simple principles. In fact, we observe that expertise emerges almost exclusively as a differential in performance when following these principles. On the other hand, we have a detailed set of principles which we can call the "fly-by-book" strategy that relates to a corpus of practices that is both ingrained in the practice by means of formal lectures and training and embodied in the flight manual. These two strategies assign different weight and roles to two systems of actions. The first one, following the suggestion of Winter (2004), we can call the "sensor" layer. Within this layer we can find all the actions aimed at monitoring the environment. Specifically, sensing is about understanding the interaction between the plane and the environment. The second one, that according to the same tradition we can name reactor system, includes the actions taking place to restore the desired state of affairs in case something goes awry.

5.2 The vertical dimension

The relationship between the sensor and the reactor systems has been the focus of some contributions, among others, in general systems theory (J. H. Holland, 1995), economics (Heiner, 1983) and in the organizational tradition (Simon, 1996). The main idea, borrowed from biology, is that there are two "parts" in a complex system. The first is devoted to scanning the environment, the second one, connected to the first, acts according to stimuli coming from the sensors. In a simplistic version of this model – where the biological metaphor is almost literal – we might think of this relationship as physical and bi-univocal. In more sophisticated versions the relationship is represented as a condition-action system of rules linked by Bayesian mechanisms. In most organizational systems the two dimensions are disjointed and composite. In fact, the "sensor" component, in our case is properly organizational and presents an extreme heterogeneity. At the first layer, we have the perceptual (human) components of the crew. At a second layer, we have a set of mechanical sensors embodied in the plane that communicates with the perceptual sensors of the pilots. The third sensing layer is represented by the monitoring network managed from outside the plane[1], which is able to transfer information to the crew and to the plane system. To complicate

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[1] To be more precise, as a first step, we should further distinguish between the monitoring system proper, structured around the ground based radar and communication systems of both military and civilian air authorities, and the monitoring system afforded to the individual crew by other crews belonging to the same flight. For the sake of the

matters further, information can be communicated and "sensing" shared by the between the members of the crew. An apparently obvious consideration we can draw from the case is that sensors come in a wide variety, but they can be classified as "general" or wide systems of detection (case in point the eyes of the crew members) or specific sensors (e.g. a particular combination of alarm lights on the control panel). An individual stimulus coming from the environment, typically, hits both kinds of sensors at the same time. This last point is central for understanding the organizational capability of responding to stimuli: the same signal is received, manipulated and re-transmitted by the two sets of detection systems in parallel.

Coming to the set of actions we call "reacting", we can include in it the piloting tasks and the actions implemented in order to conform to the contingency plans detailed by the procedure manual in correspondence with each failure signal emitted by the plane. Essentially, we can talk about a general purpose vs. a very specific set of answers to environmental signals. The striking feature at the reaction level is that there is a direct link between strategy implemented and reaction system, whereas the link between sensor and reactor is way more problematic.

5.3 The horizontal dimension

We can characterize the relationship between the two systems of sensors and reactors as horizontal, in that actions activated within the cognitive framework of each strategy are not mutually exclusive, rather, they are integrated. Again, this idea is not new in the literature. In fact, Nelson (2004) gives an account on how the two kinds of sensors might co-exist and be developed in an organizational setting when the system can generate the necessary amount of resources . He claims that scarcity of resources is what inhibits organizations to choose to implement both strategies, concentrating on just one. By the same reasoning, Holland (1995) and Heiner (1983; 1990) provide modelling mechanisms that make it more costly to upkeep a complex system of sensors, reactor, or a combination of both. In all this models (with the noticeable exception of Heiner), the organizational

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present argument we can safely simplify the description of the situation between "inner" (on board) and "outer" (off the plane) layers.

design problem is deliberately geared towards achieving results in cost effective fashion. One dimension that is often neglected in these studies is the relationship between the two systems. Looking at the case again, we can observe how the crews do not develop one of the two sensor-reactor systems alternatively, rather, they devote (training and cognitive) resources to both. Essentially this is meant to allow the pilots to select dynamically a combination of the "fly-by-book" and of the "stay aloft" strategy. Once again, this does not mean that the two strategies are univocally linked with a sensor system on the one side and a reactor system on the other and activated alternatively, rather crews act combining the two strategies differently in accordance with their perception of the situation. Time plays a crucial role in this interplay, this is why we call this interaction "dynamic": the individual actions implemented by the crew and their effects become gradually part of the situation modifying environmental conditions.

5.4 The interplay between the two dimensions

The possible combinations of the two dimensions we outlined allow us to understand the implications of allowing for a more complex interaction between the sensing and the reacting systems than the one which is usually modelled in the literature. In Figure 4 we have represented the typical situation in terms of combinations of strategic choices and expected outcomes linked to those choices faced by the decision makers.

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Figure 4 about here

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If we recall the situations described in the case, experts and rookies are on almost a level ground when it comes to the ability of recognizing a stimulus coming from the aircraft's alarm system and implement a rule-based reaction. Differences become obvious at the level of ability to buy time by employing what we called previously the "stay aloft" strategy and, even more importantly, by combining the two strategies and the corresponding combinations of sensors-reactors. Our interpretation relies on the different relationship that the two strategies take in the two kinds of crews.

In principle, the old organizational tenet that rule-based behaviour works better than any heuristic approach in well-defined situation still holds. However, as ambiguity in the signals coming from the environment increases, "experts" encounter the grey area where a problem can be solved with a similar degree of success using one of the two strategies way before rookies do. The main reason for this – and once again, this is an obvious observation in most organizational literature at least from the sixties – is that procedure-based behaviour is a lot simpler to learn, whereas, developing the right heuristics takes longer. This is represented by the relatively small distance of the two lines representing the implementation of the "follow-the-rules" strategy in Figure 4 when compared to the ones representing the "stay aloft" strategies for the two groups. Experts, moreover, can face many more situations mixing and merging the two strategies, simply because experimenting with novel solutions in the grey area becomes possible a lot more frequently due to their relative ability to handle the "stay aloft" strategy[2]. Again, from the case, we should keep in mind that the acquisition of the "stay aloft" strategy is strongly connected with the highly tacit idea of Situational Awareness. However, dynamically, we can expect learning to take place for all crews that do not suffer dramatic failures, so that the heuristic ability will become available to rookies as well. It should be noted that the peculiar mix of environmental stimuli affecting the behaviour of the crew makes it a hybrid situation. Environmental stimuli present, at the same time, a varying degree of ambiguity (from standard, very clear) and a varying degree of severity in case of failure (from no risk to almost certain physical destruction[3]). On the one hand, the crew shares with more typical examples of HROs the preoccupation for the extreme consequences that mistakes can provoke on

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[2] Expert crew members repeatedly referred to the tendency of experts to experiment with new solutions to old problems merging "book" solutions and their "feeling" for the situation. This kind of behavior emerged more frequently when the crew has an adequate ability in handling the heuristic, so that they can fall back to it if the experiment does not work, which is a rather common occurrence.

[3] This topic is outside the scope of this paper, but one should keep in mind that terminal accidents with loss of human life and/or extremely expensive machinery are not uncommon.

the ability of the organization to survive. On the other, day-by-day activities are pretty standard and need to be carried out keeping economy of forces (and costs) into account.

5.5 A few organizational consequences of the model

In organizational terms, the implications of this simple model are manifold. First, the idea that specific, rule-based behaviour and its associated sensor-reactor systems, and more general, heuristic strategies are generated statically is simplistic. The two systems and the strategies they support have different cognitive cost structures. In general, then, we can expect a low level of redundancy only in the extreme cases where a) the environment presents very simple/static sets of stimuli (heuristics would become a redundant cost); b) severity of consequences for mistakes is low or nil (it becomes affordable to develop just a rule-based scheme with low variance of stimuli or just a heuristic-based system with high variance). Observation of any real-life situation make these two cases remote, at best. Specifically, in cases where uncertain situations abound and the severity of the consequences mistakes/failures is large, we can expect most organizations to invest in redundant, dual systems of the kind we described.

Second, the vertical (sensor-reactor) and horizontal (rule-based and heuristic-based) structural dimensions are intertwined in non-linear ways. More specifically, sensors developed in order to activate rule-specific behaviour might feed – at the same time – also heuristic-based behaviour and vice-versa. The design consequence of this observation is that investments in one kind of system typically present positive externalities that feed into the alternative structure of sensors and reactors.

Third, while the basic idea shared by most models of organization-environment interaction that rules work for clear and simple stimuli, whereas heuristics become necessary when ambiguity is prevalent, grey areas where both strategies work successfully, at least to some extent, can exist. These areas allow for a “safer” situation in which to explore and develop new reaction capabilities.

The characteristics of this interplay, moreover, allow us to make some remarks on the relationship between costs in establishing and maintaining such a dual system and its potential benefits in terms of resilience and robustness.

Undoubtedly the organizational design we explored in this paper presents features that make it remarkably more costly than an elementary system (either specialized or general) which is, however, highly vulnerable when environmental conditions vary.

We believe that the model of reactor-sensor combinations we propose in this paper can be fruitfully employed to integrate several alternative models of organizational learning. One common trait of these conceptualizations is their focus on the process of learning (see, for instance, (Pentland & Feldman, 2005)) or on alternative taxonomies that attempt to categorize types of learning (Bateson, 1973) or combinations of learning processes and tasks (Schön, 1987; Yanow & Tsoukas, 2009) . By contrast, our model focuses on the interaction between these processes and the logically preceding phase, namely what we can call the "sensing phase." In fact including this phase enriches the explanatory power of learning cycle models, by incorporating the tentative nature of information acquisition and parsing. It is true that we can consider organizational learning as a phenomenon occurring in self-reinforcing loops integrating many possible cycles, however analytically disentangling information parsing and the actual modelling of the situation that precedes action is useful to better assess the level of proficiency that an organizational unit (the crew in our case) can attain as a result of learning. In fact, as we outlined in the previous section, the ability to activate parallel sensing-acting structures seems to be one of the main characterizations of the qualitative difference between experts and rookies.

A second point worth making is the relationship between the two strategies for flying that we identified. As outlined in the previous section, the two strategies appear to be co-evolving during the learning process for both crews and individual crew members. This co-evolution, contrary to a more traditional view of a trade-off between "exploration" and "exploitation", reflects the interdependences embedded in the learning processes. Namely, the stratification of the "stay aloft" and of the development of complex alternative sensor reactor systems, occurs by means of an enrichment of the repertoire of signal/reaction rules that are stored in operational routines. In turn, each layer of new routines serves two purposes. First, it allows the crew to concentrate on the novel elements of the situation at and, as their attention span is not preoccupied with patterns of sensing-reacting that can be taken for granted, thus permitting a further learning cycle. Second, the enrichment of the repertoire of possible actions allows for an enhanced reflectivity on the relationships between the practice and the representation of the situation occurring during the flight. In this sense the operational set of routines represent both the result of learning and the main procedural element of learning itself (Feldman & Pentland, 2003).

6. Conclusions

In this paper we presented an alternative view of the classic theme in organization studies of the connection between environmental features and organizational design. Building on existing explanations of this link, and drawing from empirical observations of practical design solutions emerged in the simple – parameters-wise – organizational environment of piloting crews, we developed a different interpretation of the phenomenon. Typical, consolidated explanations depict the organizational design choice as being between specialized, rule-based, highly tuned structures and more general, flexible, one solution fits all structures. The design process is understood as a) depending, almost mechanistically on the variety and severity of the stimuli coming from the environment; b) defining different sets of choices composing a monitoring "part" and an reacting "part" of the organization which are combined univocally; and c) clearly defining alternative strategies for survival. In the analytical perspective we proposed, we add two separate components that enrich the explanatory power of the more traditional approaches. On the one hand, we illustrate the effects of learning - and indirectly of time – on the design process, showing how investing in different strategies can generate useful synergies and allow for exploration while maintaining the ability to "fall back" to experimented solutions. On the other, we show how, introducing an analytical separation between general and specific structures on one dimension, and between sensing and (re-)acting structures on the other, allows for a more thorough understanding of the relationship between environment and structural design. Specifically, we can account, at the same time, for situations traditionally linked to different streams of literature, such as HRO studies (concentrating on severe environments) and the models developed within the evolutionary framework (concentrating on cost efficiency).

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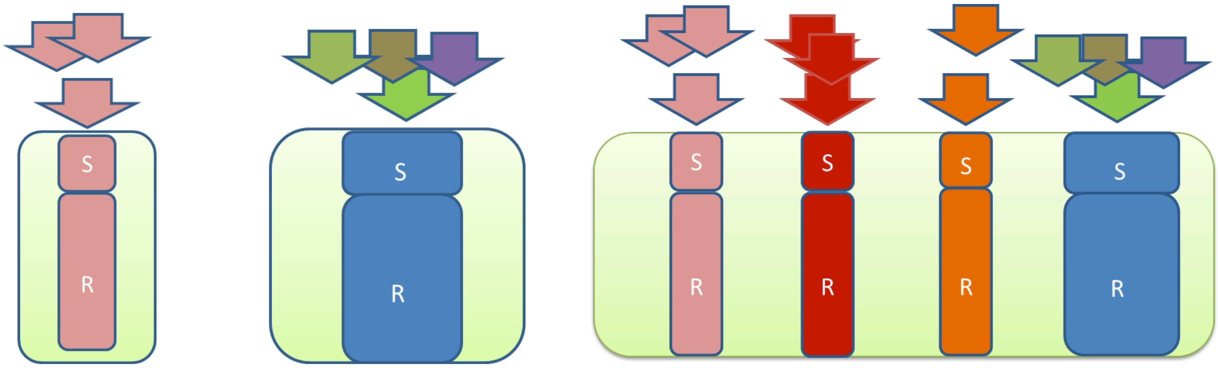
Figures



a) b) c)

Figure 1: Alternative representations of the sensor-reactor systems. Situation a) depicts a specialized sensor-reactor system. Situation b) represents the typical solution to situations where heterogeneous or ambiguous stimuli prevail and a generic sensor-reactor is adopted. Situation c) describes a mixed solution where generic sensor-reactor systems (in blue) coexist with stimulus-specialized systems (in pink, red and orange).

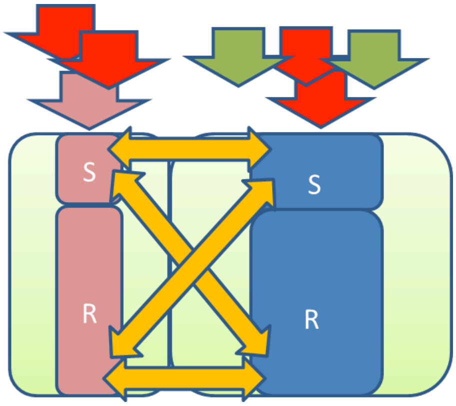


Figure 2: Vertical and horizontal dimensions of the sensor-reactor system and their interplay.

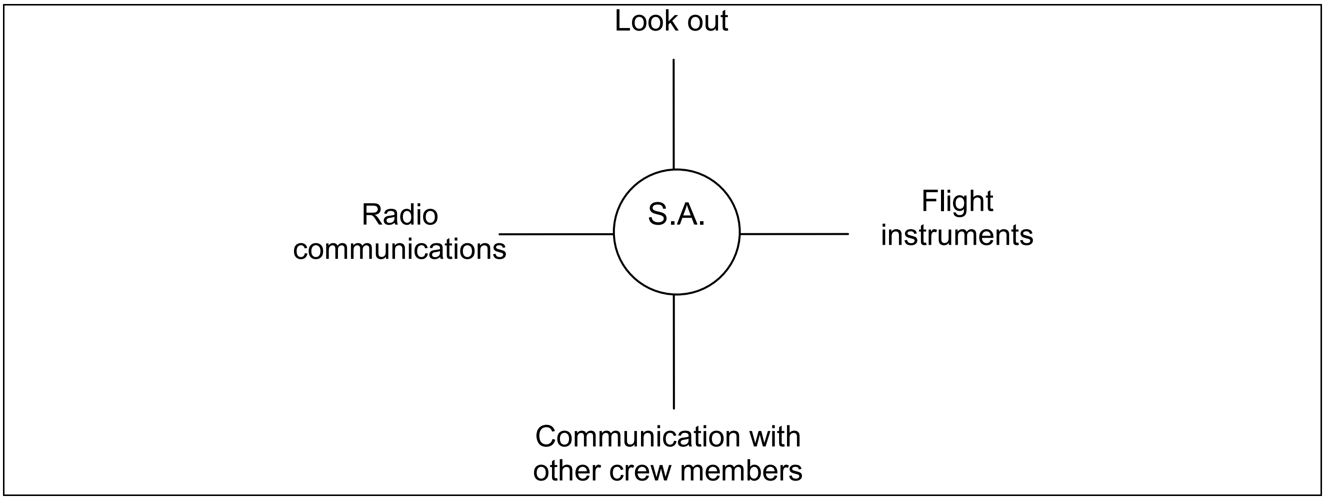


Figure 3: The components of Situational Awareness

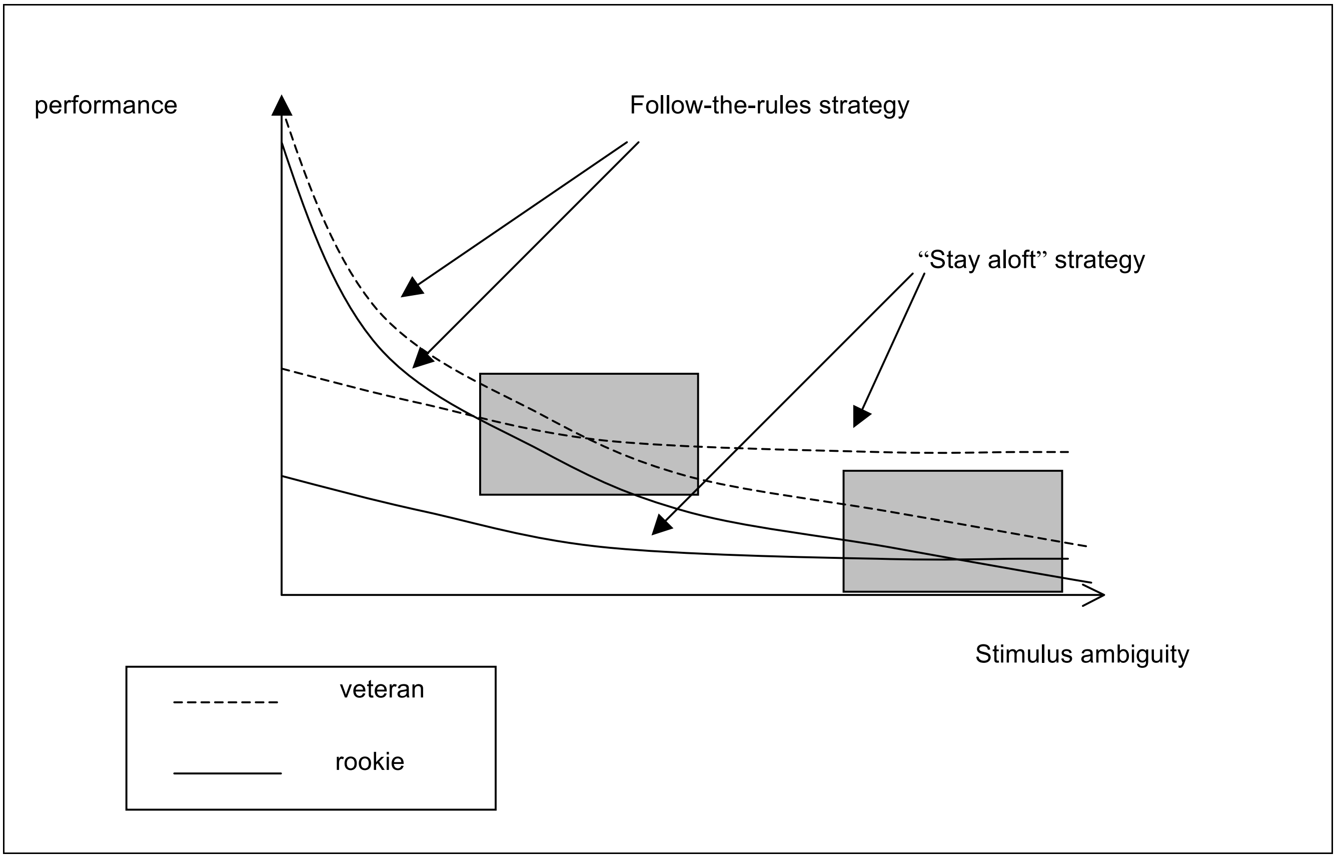


Figure 4: Relationships between strategy choice, sensor system activation and performance for veteran and rookie crews. The gray rectangles represent situations in which both alternatives offer comparable performance and thus can be activated indifferently, or almost indifferently by the crews.

Tables

Table 1: Information on fieldwork activity

Archival documents	
Material for external communication or available to a restricted public	
General information on the Italian National Airforce: www.aeronautica.difesa.it	
Official presentations of the wing	
DVD commemorating the wing's 50th anniversary	
Review "Security of the Flight"	y. 2005, 2006, 2009
Internal-only documents	
Formal repertoires of contingency plans for quick reference (avionic -, weapon check list)	
Theory and Operations Manuals of flight and weapons	
Archive of failures	
Flight plans	
Risk matrices	
Interviews	
Commanding General (Attack and reconnaissance forces)	1
Wing commander	3
Flight security Chief Officer	3
Chief Operative Officer	1
Pilots	2
Navigators	2
Trainer-pilots	3
Support personnel	2
Total	17
Field Observations	
Simulated flight activities:	
Observation of Flight and weapon Simulation by expert crew and emergency handling procedure	1
Observation of simulated debriefing by experts	1
Observation of Flight Simulation by rookies	1
Observation of simulated debriefing by rookies	1
Flight Simulation by the two researchers	1
Real flight activities	
Observation of take off and landing procedures	4
Observation of flight preparation procedures, dress up, pre-flight meetings, pilot/navigator pre-flight briefing , cartographic briefing, post-mission debriefing	1 each
Other observations:	
Observations of interactions among personnel	2 days
Observations of barracks life and procedures on base during day/night	2 days
Observations of base spaces and logistics operations	1 day

Table 2: Basic Rules for maintaining Situational Awareness

1. respect standards
2. communicate deviations from the expected/planned and intentions on what to do
3. avoid mental saturation
4. do not take anything for granted
5. act openly with no concern for roles or positions

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