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Ethnography of a Paper Strip: The Production of Air Safety

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Abstract

Why does air traffic control still rely on paper control strips? Is paper safer? This question has been dealt with before, and responses have pointed out that "paper has helped to shape work practices, and work practices have been designed around the use of paper" (Harper & Sellen 1995: 2). The present contribution tries to further specify these claims. At first, the use of paper as a medium of representation in the course of dealing with critical situations will be discussed. Drawing on ethnographic fieldwork carried out in two European Upper Area Control centres, practices linked to the puzzling persistence of the paper strip are then captured along with different types of critical situations. Extending the observation of practices to meso- and macro-levels, it can be shown that paper strips are multiply embedded. They help to stabilise cycles of practices, the permanent reproduction of which is critical to air safety.

1 Introduction

Air traffic control relies on local activities carried out in regional control centres. These centres are faced with a major problem of coordination: It is their mission to handle "conflicts", which may lead to the mid-air collision of aircrafts. In order to contribute to the securing of air safety, they draw on two different sorts of information. First, they are provided with anticipatory information generated by a central (European) flight planning unit on flight routes to be taken by aircraft. This information is made visible on flight strips. Second, control centres are equipped with radar screens, which display the actual movements of semi-autonomous aircraft within a circumscribed geographical sector. The situated practices of mediating between the orders of events, as prescribed and observed in real time, have been a subject of numerous ethnographic field studies. More or less rooted in the ethnomethodological tradition (Suchman 1987, 1993), air traffic control centres may even be said to be one of the seminal cases for an approach known as Workplace Studies. Starting in the late 1980s, in-depth field studies have been carried out in a number of European countries, most notably in the UK (Harper et al. 1989, Harper & Hughes 1993), in France (Gras et al. 1994), and in Sweden (Sanne 1999). Drawing on ethnographic fieldwork carried out in the Upper Area Control centres of Reims (France, March 2001) and Karlsruhe (Germany, April and October 2001), the present article contributes to this corpus of research.[1]

If the case of air traffic control has attracted attention and gained prominence beyond a highly specialised research community, this is because of the flight control strip and its unlikely persistence: Why is it that air traffic control still relies on paper strips?[2] Is paper safer (Mackay 2000)? In order to seriously address this question, a few details on the use of flight strips must be presented. Flight strips measuring 13,5 cm by 2,5 cm are printed out about 20 minutes before an aircraft enters the geographical sector a control team is in charge of. Each of them is put on a plastic support and then placed on a rack, which contains as many strips as there are aircraft already in the sector and due to arrive in the sector. A "control team" is composed of two controllers working next to each other.

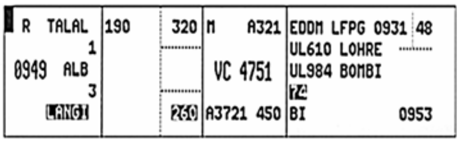

Figure 1: Flight strip as used by the Upper Area Control Centre of Karlsruhe, Germany (source: Milde 2007)[3]

Flight strips contain a wide range of information. To start from the centre, "VC 4751" indicates the flight code. It states that the aircraft is operated by "Voyageur Airlines". Directly above, the type of aircraft is identified: "A321" is for "Airbus 321". The upper line of the right column provides information on the origin (Munich, "EDDM") and the destination (Paris Charles-de-Gaulle; "LFPG") of the flight. Split up between the third row in the left column and the last row down in the right

[1] I would like to thank air traffic control staff at these centres for their reception and interviewees at various divisions of ATC (air traffic control) organisations for accepting being interviewed. Also, I am grateful for the criticisms and comments by two anonymous reviews on an earlier version of this paper.

[2] The French popular science magazine *La Recherche* has regularly covered this issue (for instance issue no. 319, April 1999, pp. 52-70). The paper strip serves as a display case of what has been called the "myth of the paperless office" (Gladwell 2002). In a more recent *Business Week* cover story, paper strips are used to illustrate the anachronistic technical infrastructure responsible for dramatic bottlenecks in a fast expanding world of air transport (Palmeri & Epstein 2007: 52).

[3] With the exception of the centre of Maastricht, all area control centres in charge of the upper part of the German airspace rely on paper strips.

column, the flight strip denotes that the aircraft will enter the sector at 9.49 am ("0949") and leave at 9.53 am ("0953"). Within the sector, flight VC 4751 will have to pass two points of intersection named "TALAL" and "ALB" (left column). There is one minute of flight between these points of intersection, and three minutes before the aircraft is handed over to the adjacent sector in charge of another German control centre situated in Langen ("LANGI"). Scheduled to reach a cruising level of 32,000 feet ("320" right half of the second column), the aircraft has entered the area covered by the Karlsruhe centre of control at an altitude of 19,000 feet ("190"). The centre of Langen expects it to be handed over at an altitude of 26, 000 feet ("260", bottom right of second column). Now, if there were a second control strip announcing a second aircraft for one of the points of intersections at the same time and same altitude, the controller would be left with some 20 minutes to "coordinate" this situation of "conflict". A possible solution might be to call the pilot of the first aircraft to change altitude. Having received confirmation by the pilot, the controller would then take a pencil to cross out "190" and write down the "coordinated" altitude on the paper strip instead.

In effect, the example on how controllers use flight strips while coordinating "conflicts" has only been provided for purposes of introduction and illustration. It serves to illustrate the approach taken by Workplace Studies. Having accumulated a larger number of observations on the many ways paper strips are used and manipulated by controllers, Richard Harper and Abigail Sellen have pointed out that paper-based control strips have physical properties difficult to replace by other media of representation. They conclude that "paper has helped to shape work practices, and work practices have been designed around the use of paper" (Harper & Sellen 1995: 2). While both claims have become commonplace within Workplace Studies and adjacent areas of research, I will argue that both claims are – still – waiting for specification. In order to explain why it is so difficult to divorce practices of air traffic control from paper strips, the present contribution suggests taking three steps of analysis. The first step (section 2) is to theorise the use of paper in terms of a medium of representation in the course of dealing with more and less critical situations. The problem of representation of both accidents and normal operation needs to be theoretically reflected; and this reflection goes beyond the habits and the present corpus of Workplace Studies. In a second step (section 3), I will turn to the empirical level of the analysis and present the issue of the paper strip in its organisational contexts, including that of the collaborative research project the present contribution draws on. This is a necessary prerequisite to specify practices, which have co-evolved with the use of paper strips (section 4). It is the analytical distinction of the "cyclical" nature of practices, which helps to identify practices of different scale and scope. This extension of the notion of practices to meso- and macro-level observations may be seen as an achievement in itself. In addition, it prepares for a return to the problem of representing normal operations, which has been theoretically reflected in a previous section. The conclusion reached in this study (section 5) is that paper strips are multiply embedded. They help to stabilise cycles of practices, the permanent reproduction of which is critical to air safety.

2 Organisational ethnography: the *active* production of safety

This section discusses a shift in the understanding of safety. If safety is identified with the absence of accidents, the representation of critical situations is (nothing but) a matter of hindsight. A perspective, which highlights the active production of safety, in contrast, requires examining the role of different media of representation and the way they are linked to specific practices. Here, I chart how the latter view has emerged from the former, which prepares the ground for subsequent empirical analyses.

Dealing with technical failures and accidents, social studies of technology and risk have often highlighted that their representation is a matter of hindsight. It would therefore be simply erroneous to think that accident representations established post hoc provide significant information on the conditions facing the operators in a situation of crisis. The problem of hindsight persists regardless of whether technical systems have been equipped with failure-proof technologies of recording and conserving accident data. Even black boxes containing flight data and cockpit voice recorders which are designed to withstand the crash of an aircraft sometimes fail or do not contain reliable data on the course of an accident (Potthast 2006). If there is a single major achievement in the social sciences within the area of risk research, it is the way in which the idea of a perfectly neutral medium allowing for unquestionable representations of accidents has been challenged. This is why the "black box" has enjoyed particular attention in this area of research and has even become a metaphor to characterise its constructivist approach. At some point, "opening the black box" had become a standard analytical operation. While this has undeniably helped to integrate a social science approach to the study of technology and risk, its success may have caused the demise of its analytical power. According to the critical diagnosis of Langdon Winner, constructivist research on technology and risk had become irrelevant as early as the 1990s, restricting itself to a critical gesture of repeatedly "opening the black box and finding it empty" (Winner 1993).

In the past, sociological research has struggled to capture "accidents" as a legitimate object of inquiry.[4] However, social studies of technology and risk have flourished, not content to focus on a ritualised questioning of hindsight (of accident representations). In the following, I will discuss some approaches that have escaped a narrow conception of accidents and developed an alternative view on how to deal with critical situations. Among the approaches which have somehow managed to deactivate the problem of hindsight, one has to mention the work by Charles Perrow. His book on "normal accidents" (Perrow 1984) has had a major impact as it shifted from viewing accidents as single events to their inner dynamics. Having discovered that technical failures and breakdowns followed different sequential patterns, Perrow launched a comparative research program on different technologies. Once reconceived of as sequences of events rather than indivisible events, accidents can be shown to leave more or less scope and time for interpretation and intervention by users and operators. According to Perrow's conclusion, this scope for diagnosis and reaction depends on the objective characteristics of technical systems. Following this account, the problem of hindsight can no longer be generalised and may be reformulated. Hindsight is a matter of degree, depending on different types of system design. Read as a strategy to tackle the problem of hindsight and to capture accidents as an object for sociological inquiry, Perrow's study has three implications, which have become signposts for subsequent research. First, the problem of post hoc representation has been specified in terms of its recipients.

[4] According to Judith Green, "sociology has largely ignored accidents as a legitimate object of study. This (...) neglect is not mere coincidence but an inevitable outcome of the ways in which accidents have been constructed. When they have been studied, accidents have been redefined as 'non-accidental'" (Green 1997: 15).

Hindsight is not a problem to an abstract observer or the imagined general public but to the operators of technical systems. Second, the notion of hindsight is re-defined. Only if leaving no room for interventions, representations of accidents are counted as representations with hindsight. Third, the definition of accidents is extended to potential accidents or accidents which have been prevented.

Developing independently of the "normal accident approach", there has been a second stream of research originating from a North American campus, which has succeeded to by-pass the problem of hindsight. Its focus is on "highly reliable organisations", or "HRO"; that is organisations which run risky technical systems often without ever having produced an accident (La Porte & Consolini 1991, Rochlin 1993). According to the HRO approach, this outstanding performance of actively producing safety requires explanation. By implication, safety is no longer defined as the absence of severe accidents. In accordance with the adherents to HRO, who claim that this is a poor and passive understanding of safety (Rochlin 1999: 10, 2003), the central question is no longer "how do organisations prevent that accidents occur?", but rather "how do organisations deploy which modes of representation in order to anticipate accidents?"[5]

This is a tricky question if one takes into account that control room personnel relies on representations of technical failures, which are themselves exposed to technical failure. This phenomenon, referred to as second order failure (Hirschhorn 1984), calls for differentiation of the notion of breakdown and failure, which is highly relevant to the case of air traffic control. As illustrated by the subsequent sections, air traffic controllers cannot directly access first order failures. They live in a virtual environment, fully dependent on media of representation, and are therefore exposed to second order failures. Given this dependence, one has to take a closer look at how the respective representations are used to anticipate and respond to critical situations. To attribute primacy to any single medium of representation would be unfounded. This will be strikingly illustrated by the case of air traffic control (to be introduced in the following section). This empirical case emphasises that the analytical challenge consists in capturing the coexistence of different "medialities" having diverse properties. Rejecting the idea of an *a priori* convergence of media, one needs to search for an alternative way to explain why technical systems are operated reliably, despite their management being divided up between different media.

In the field of social studies of technology, many authors have argued in favour of a "difference of media" hypothesis (Latour 1991, 1996, Rammert 1998, Schüttpelz 2006, Strübing 2006). Many of these contributions, however, have failed to provide empirical analyses along with a challenging theoretical program. In order to cover this research lacuna, I have suggested focusing on breakdowns or accidents waiting to happen, thereby transforming the normal operation of technology into a more exotic species (Potthast 2007). Studying how organisations cope with breakdowns and failures, "normal" operations appear less orderly. "Accidents and their subsequent inquiries are perhaps the only passing moment when outsiders may glimpse the routinely less orderly, less rule-controlled world of technology

[5] For an overview on the HRO approach, see Roberts (1993). Air traffic control has been among the first and favourite objects of inquiry of this approach (La Porte 1988). For more recent publications taking a similar perspective, see Vaughan (2005) on air traffic control and Bourrier (1999, 2001) and Perin (2005) on controlling and maintaining nuclear power stations. A major study on air traffic control based on long term ethnography and some 180 interviews in four air traffic control centres in the US is underway and carried out by Diane Vaughan.

and science. However, because it is seen this way only around accidents, the belief is consolidated that normally practices are more orderly" (Wynne 1988: 150). Ethnographic analyses of normal operations have to keep accidents at an analytical distance. Otherwise, analysts would fall back into an explanatory scheme opposing rules (explaining normal operation) and exceptions (explaining accidents, thereby confirming the primacy of rules), which cannot be taken for granted. Technical systems are operated by highly specialised experts who have often developed remarkable skills and routines in coping with critical situations. However, in building up these routines, communities of practice contribute to shift the definition of rules (Vaughan 1996, 2002). In short: "[p]ractices do not follow rules; rather, rules follow evolving practices" (Wynne 1988: 153). By consequence, it may be deviations from the rule, tolerated by a community of practice, which contribute to reliably operating technical systems (Ortmann 2003). At the same time, tolerating deviations from the rule may lead to the emergence of practical rules. This line of argument has allowed for an alternative account of accidents and incidents. There may be accidents although everyone involved in the process has stuck to the (emergent set of practical) rules. "Working in practice but not in theory" (La Porte & Consolini 1991)? Confronted with accidents which cannot be accounted for in terms of a violation of rules? Faced with the reliability of normal operations which cannot be explained other than in terms of violating rules? Given these paradoxes, I suggest to abandon the focus on "accidents". Instead of taking rules and their exceptions for granted, I will rather speak of "critical situations" which need to be approached by means of ethnographic inquiry.

Taking the problem of hindsight as a point of departure, the present section has theorised on the status of (different) media of representation for explaining the reliable operation of complex and risky technical systems. This reflection has gone beyond the current corpus of Workplace Studies in order to prepare for a more specific explanation of a puzzling empirical phenomenon: Why is it so difficult to divorce practices of air traffic control from paper strips? I will now turn to the empirical level of analysis. The following section puts the paper strip in its broader organisational contexts and retraces a recent chapter in the long history of its failed replacement. Contrasting this story of failed research and development efforts based mainly on interviews and documentary analyses, I will then draw on in-depth ethnographic observations in order to specify practices, which have co-evolved with the use of a specific medium of representation (section 4). Both sections are based on field reports I contributed to a collaborative research project (Potthast 2002).

3 The organisational context of the paper strip and of the empirical fieldwork

The large technical system of air transport has a remarkable record of availability. Air traffic has experienced local shut-downs due to bad weather conditions, war or terrorist attacks, but it has never come to a global standstill.[6] How to account for the safety record of air traffic control? How to explain the small number of plane crashes air traf-

[6] In 1981, a strike of air traffic control brought the North-American airspace close to a complete halt (Nordlund 1998). Twenty years later, on 11 September 2001, the same continent came to its first standstill of civil air transport in history. Air traffic controllers were ordered to land about 4,500 planes in a few hours (9/11 Commission 2004: 46). According to the 9/11 report, among the authorities involved in responding to these terrorist attacks, air traffic control was the only agency that deserves praise for its performance. Carrying out the unprecedented task of safely landing an enormous number of aircraft, "[t]hey have been superb" (ibid.: xvii).

fic control has been made responsible for? Although offering some insights to the organisational contexts of air traffic control in Europe, the present section does not yet provide an answer to this question but adds many aspects, which make the achievement of safety in air traffic look very unlikely. Presupposing that readers are not familiar with the processes of air traffic control, the section is set up as a guided tour of this world, arranged in a conventional mode of ethnographic accounts. Its story-line is the biography of a research and development project in which I have been involved, thus including reflexive elements.

The present contribution is based on ethnographic fieldwork and interviews carried out in the context of a larger international collaborative research project (named "LOOK"). Commissioned by the Eurocontrol Experimental Centre, which long ago adopted the view that paper strips must be substituted, a large research consortium was established to prepare for a multidimensional testing procedure. Supposed to prepare grounds for a systematic comparison of different working positions in terms of safety, the project was expected to support the development of *digital* control strips as a medium of representation.[7] Constructing a comparative simulation that delivers legitimate proof turns out to be a demanding task. It calls for a more thorough investigation of the role of media of representation in critical situations (outlined in the previous section and carried out in section 4).

3.1 First stop: Eurocontrol Experimental Centre

The Eurocontrol Experimental Centre is located next to a former military airport at Brétigny. South of Paris, but badly connected to public transport, we are picked up at a local train station by an employee of Eurocontrol. It is the first time I have been in a car assigned diplomatic status. I am once more impressed with my first view of the research facilities of Eurocontrol. Having been the last to arrive at the research facilities, we are seated in a bright and modern conference room. Some twenty persons present themselves as experts in such fields as cognitive sciences, ergonomics, information sciences, human-machine interaction. Their affiliations range from Paris-based university labs to university hospitals, civil and military governmental research organisations. The session is coordinated by two Eurocontrol researchers who start off with a surprisingly tight schedule for what they call a "multi-dimensionally validated simulation of different alternatives of controller environment (paper strip, Digistrip and stripless)".[8] Later in the discussion, the official project

[7] I was contacted by CETCOPRA (Centre de Recherche des Techniques, des Connaissances et des Pratiques), a Paris-based research group, to take part in this project. Firmly rooted in more than a decade of extensive fieldwork, CETCOPRA has established an unusual blend of sociological and anthropological approaches to technology (cf. Bowker 1996). Ethnographic fieldwork has been carried out in the cockpits of civil and military aircraft (Moricot 1997, 2004); it has covered the development of new aircraft (Scardigli et al. 2000), aircraft maintenance (Moricot 2001), the innovation of air traffic control systems (Poirot-Delpech 1995) and their maintenance (Martin 2000). Sites of ethnographic inquiry further include air traffic control rooms (Vongmany 1998) and training facilities for pilots and air traffic control staff (Dubey 2001a, b). There is even an ethnographic study devoted to working conditions of cabin personnel accompanying long-haul travel (Dubey et al. 2000). Bringing together some of these different professional and organisational perspectives on the operation of air transport, a first synthesis study was published in 1994: "Faced with automation: The pilot, the controller and the engineer" (Gras et al. 1994, cf. Gras 1989). About the same time, extending towards more theoretical and historical ambitions, "Grandeur et dependence" (Gras 1993, cf. Gras 1997) became *the* French contribution to the then emergent approach on "Large Technical Systems" (Joerges 1988).

[8] See Eurocontrol Experimental Centre Annual Reports (2000: 33, 2001, 2002) and Grau et al. (2003).

title is shortened and referred to simply as "the simulation".

During a break, I meet Mr H. who is closely familiar with the Digistrip development project. Thanks to his initiative, I have an opportunity to be introduced to the then current version of Digistrip. It is basically a large touch screen modelled after the rack conventional paper strips are placed on. In terms of flight data displayed, digital flight strips do not differ from the conventions explained in the introductory section. Each digital strip contains information on a single flight. Placed in two rows on the rack (which is now a screen), digital strips can be sorted and re-sorted by slightly moving fingers on the surface of the screen. According to Mr H., the Digistrip and its screen conserve working routines that have developed around the paper strip. This includes registration of inscriptions written on the screen. What is more, Digistrip is equipped with a recognition program which identifies a number of symbols (numerals and characters). This is why Digistrip promises to close the information loop left open by paper strips as illustrated earlier.[9]

3.2 Second stop: European skies as a political arena

If successful, the simulation would take Eurocontrol's interest in replacing paper strips by digital flight strips a step further. Undeniably, the supporters of the digital strip have a salient argument. Provided that it comes with a reliable technology of script recognition (for instance of notations regarding flight altitude, see introduction), digital flight strips would allow for a feedback of information into the system in real-time. This, in turn, is seen as a considerable improvement in the level of interoperability within air traffic control, a key mission for Eurocontrol.[10] Table 1, comparing the organisation of European and North-American air traffic control services, is often used to illustrate the European challenge of ensuring interoperability.

While being of comparable size and counting a comparable number of hub airports, the structure of European airspace is much more compartmentalised than its US counterpart. As shown by table 1, Europe has 47 organisations responsible for air traffic control (while the US have only one); 58 Upper Area

	US	Europe
Airspace [million km^2]	9,8	10,5
Hubs	31	27
Civil and military air traffic control organisations	1	47
Upper Area Control centres	21	58
Operating systems	1	22
Program languages	1	30
Air traffic control costs per flight [US-$]	380	667

Table 1: The divided European sky (source: Zetsche 2004)

[9] There is a range of developmental projects on digital strips attempting to conserve the advantages of paper-based environments (Mertz et al. 2000, Guichard 2001, Durso et al 2005). Digistrip has been developed by CENA (Centre d'Etudes de la Navigation Aérienne), a research centre of the French Ministry of Transports, and has been rebranded "Vigiestrip" (Pavet et al. 2006).

[10] At an early stage, Eurocontrol had to abandon its initial mission to create a single European sky. Having reframed its mission since then, it now cares for the interoperability of a European airspace which continues to be divided. Both, the history of divided skies (Bremer 1976), and the interrelated history of Eurocontrol (Eurocontrol 1993-2003), are still waiting to be analysed in detail.

Control centres in Europe compare with only 21 in the US. European control centres employ 22 different operating systems and 30 different program languages. In the US, there is only one operating system and one programming language. Reportedly, these differences are reflected by the respective costs. Air traffic control costs in Europe amount to 667 US-Dollars per flight. In the US, the price of a safe flight is 380 Dollars. This difference in costs is very significant considering that the German airspace alone accounts for three million flights per year.

Figure 2 shows how the German airspace is organised. Vertically, it is divided up into an upper and a lower slice; in its horizontal extension, it is split up between a number of geographical sectors. Figure 3 shows the upper area sector controlled by the centre of Karlsruhe ("Rhein Radar"). Among others, the centre of Karlsruhe was expected to send controllers to take part in the simulation to be arranged by the research consortium, commissioned by Eurocontrol. This is why I was invited to do ethnographic fieldwork at this particular centre. Furthermore, I had the opportunity to accompany Gérard, member of the CETCOPRA team, spending several days at the Upper Area Control centre of Reims.

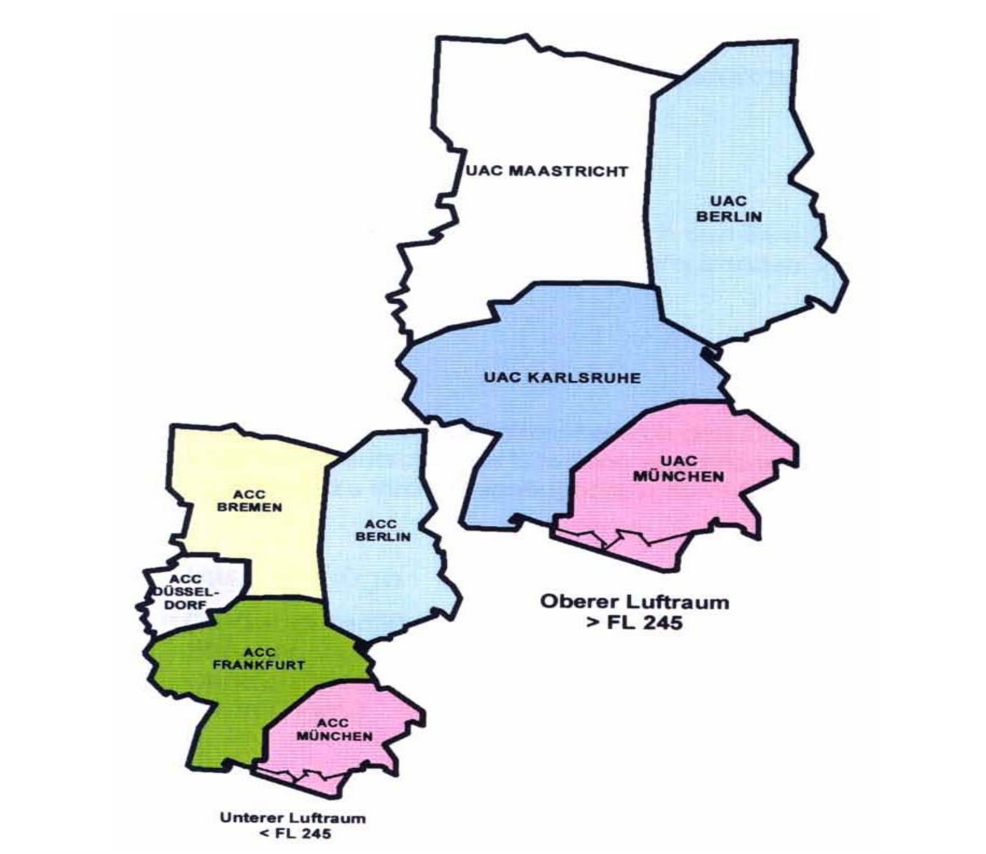

Figure 2: Horizontal and vertical organisation of Air Traffic Control in Germany (source: DFS 1997)

3.3 Third stop: The repetition of critical incidents

During this field trip, we meet an experienced controller who has recently provoked a near-miss. He takes us with him to a working position the only purpose of which is to recapitulate critical incidents. Together we are watching the short critical sequence, again and again. Unsurprisingly, we struggle to seize the severity of the

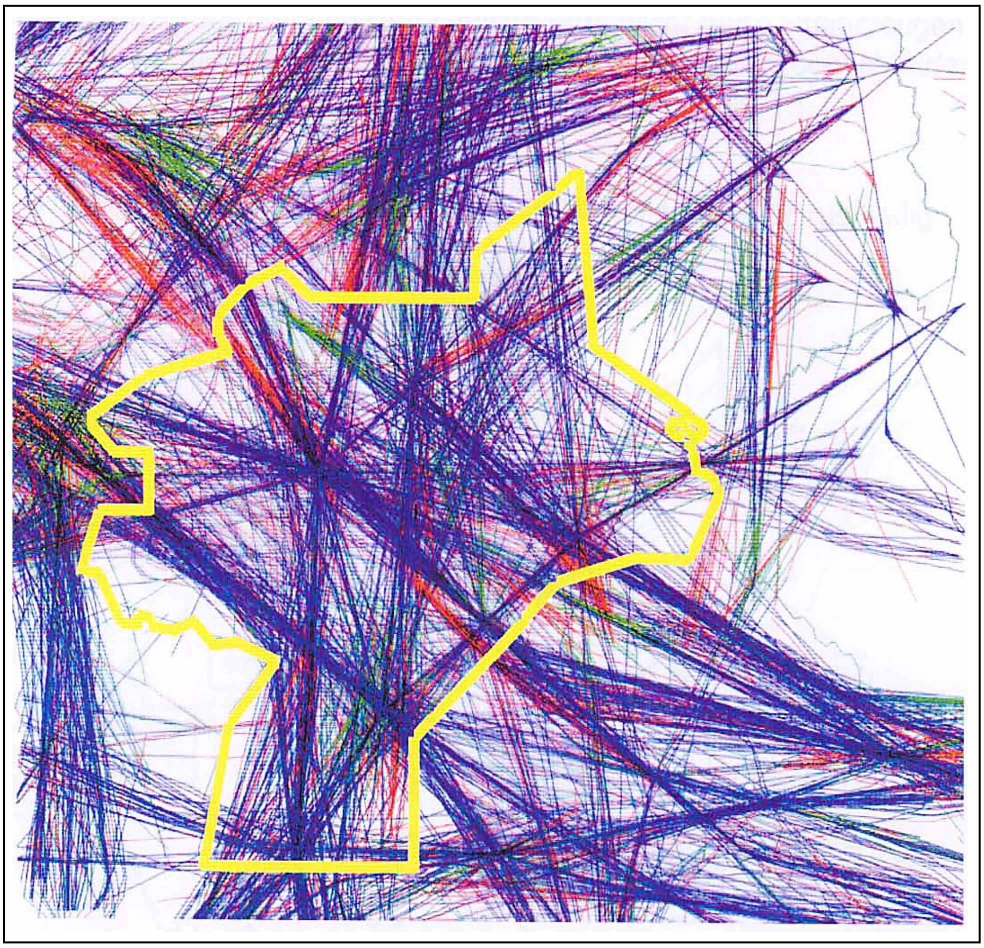

Figure 3: Flights controlled by the Upper Area Control Centre of Karlsruhe (source: DFS 1997); the charts show flight paths, colour-coded by departures (red), arrivals (green) and en route flights (blue)

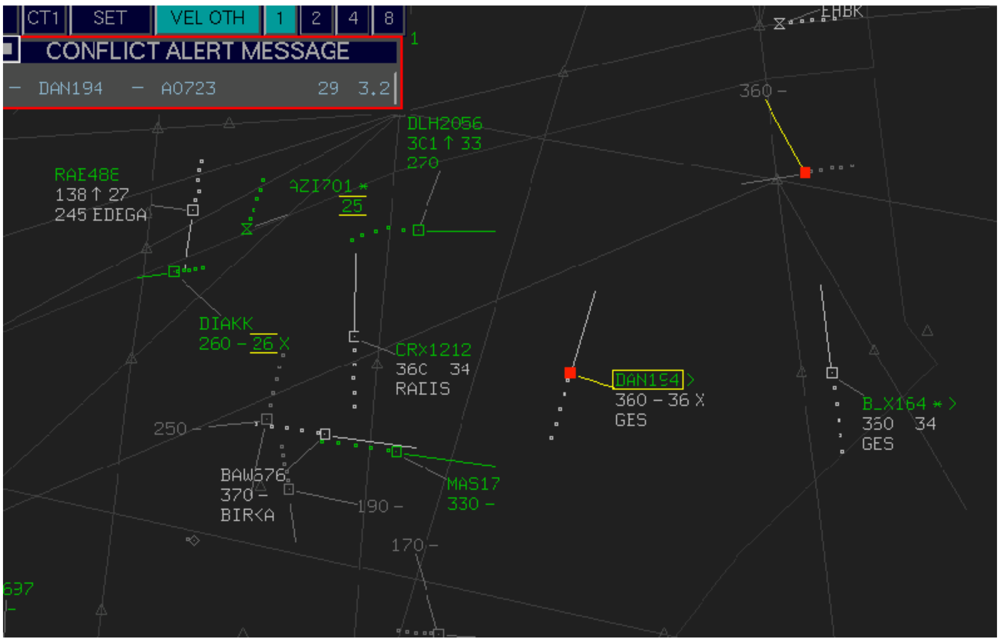

Figure 4: Conflict alert message displayed by air traffic control radar screen (http://www.eurocontrol.int/muac/public/ standard_page/PDphotoGallery.html, download-ded 20 Nov. 07); see also the Atlanta Terminal Approach Control centre which provides live monitoring online (http://atcmonitor.com/, latest view on 30 March 2008)

situation for its representation, by radar images and recorded radio calls, remains rather distant and virtual.

The two needles highlighted in red (cf. figure 4) represent two aircrafts which are flying at the same altitude (36.000 feet). As they are calculated to arrive at the same time at a point of intersection, air traffic control needs to step in and handle the potential "conflict". The emphasis on paper strips should not obscure the fact that air traffic control is also based on radar screens. Controllers are provided with a double representation of their area of responsibility. As stated before, there are always two controllers in charge of a sector. On average and during the daytime, they have to simultaneously keep an eye on about 15 flights.

On the radar screen, each flight is represented by a needle indicating the direction of the aircraft (cf. figure 5). The length of the needle correlates with the speed of the aircraft. Calling "DLH123", the controller can establish radio contact with the pilot. "330", once again, indicates the current flight level, and "<F" tells the controller that the plane has started in Frankfurt.

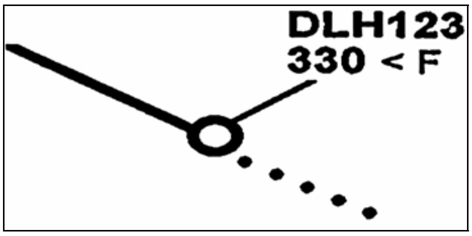

Figure 5: Representation of an aircraft by air traffic control radar screen

3.4 Fourth stop: The division of technical support

Arriving at the Karlsruhe centre, I am met by Mr. L., a former controller who is now managing the technical support division. He describes his job as a constant challenge consisting of two tasks: first, to stay close enough to everyday operations to understand its manifold requirements; and second, to carefully guide the centre through the inevitable technological improvements. Carrying out this task, he has to mediate between two spheres of activity both of which tend to be closed worlds. While many centres have been trapped in a process of divorcing "operations people" from "technical people", Mr. L. claims that Karlsruhe was lucky to escape this separatist trap: For a particular historical reason, it is the only German centre to have an in-house development team. This team is said to have "grown up" with the system and taken care of its development for decades. All interviewees confirm this view. Following the path of in-house technological development and locally adapted implementation, the Karlsruhe centre is presumed to have a long-term regional advantage.

3.5 Fifth stop: Control room

Inside the control room, I am often reminded of Mr. L.'s motto. He needs to do everything in order to prevent the controllers' sense of safety from being negatively affected. This implies adhering to high standards of transparent communication and avoiding any kind of behaviour, which could lead to barriers of communication or mutual blame. Most importantly, controversies about the right path of technological development must be kept out of the control room.

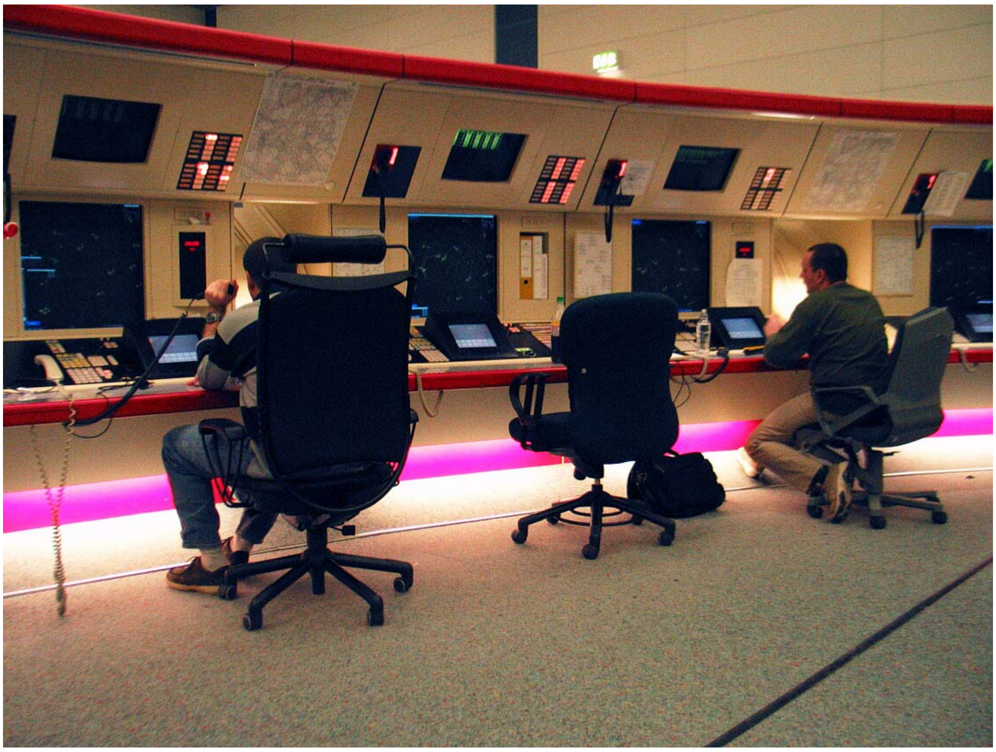

Figure 6: Air traffic control room (source: DFS 1997)

In a word, the operations room must be free of conflict – and this indeed is the case! Whenever I am in the control room, during day or night shifts, controllers behave towards each other at a strikingly high level of professional sincerity. There is no sign of ambiguity or aggression. The rules of socially competent and fair behaviour seem to be clear and undisputed. It adds to this impression of sincerity that no opportunity is missed to greet each other and to shake hands. Whoever visits the control room, for whatever purpose, is carefully introduced.

In many respects, the control room was quite accessible for carrying out an ethnographic program which I have developed elsewhere (Potthast 2007: 87ff.). Within the flow of work practices, there are moments of increased attention. These are easily distinguishable from routine action. Signals of increased attention and nervousness multiply; lowered voices; curt phone calls ("call you back!"); requests for repeating messages. A control team facing a difficult situation is often joined by colleagues standing behind them and observing what is happening. In such cases, they stay at arm's length and act in a perfectly unobtrusive manner. If asked, they are capable of explaining what has happened.

Notwithstanding these informal gatherings, air traffic control is carried out by teams comprised of two persons. Each team is in charge of a geographical sector and provided with two different modes of representations. On the one hand, there are radar screens, on the other hand, each of the working positions ("suites") has paper strips placed on a rack. When a new paper strip comes in, it is put on the rack according to two simple basic rules.

First, it is placed next to those flights heading for the same (few) points of intersection. The second principle of the sorting order is simply chronological. Following both principles, strips are constantly re-grouped. As described earlier, some flights need to be coordinated. In this case, changes of direction, altitude or speed are written on the respective flight strip.

Finally, there are distinct job descriptions for the two positions of a control team. Placed on the left side (cf. figure

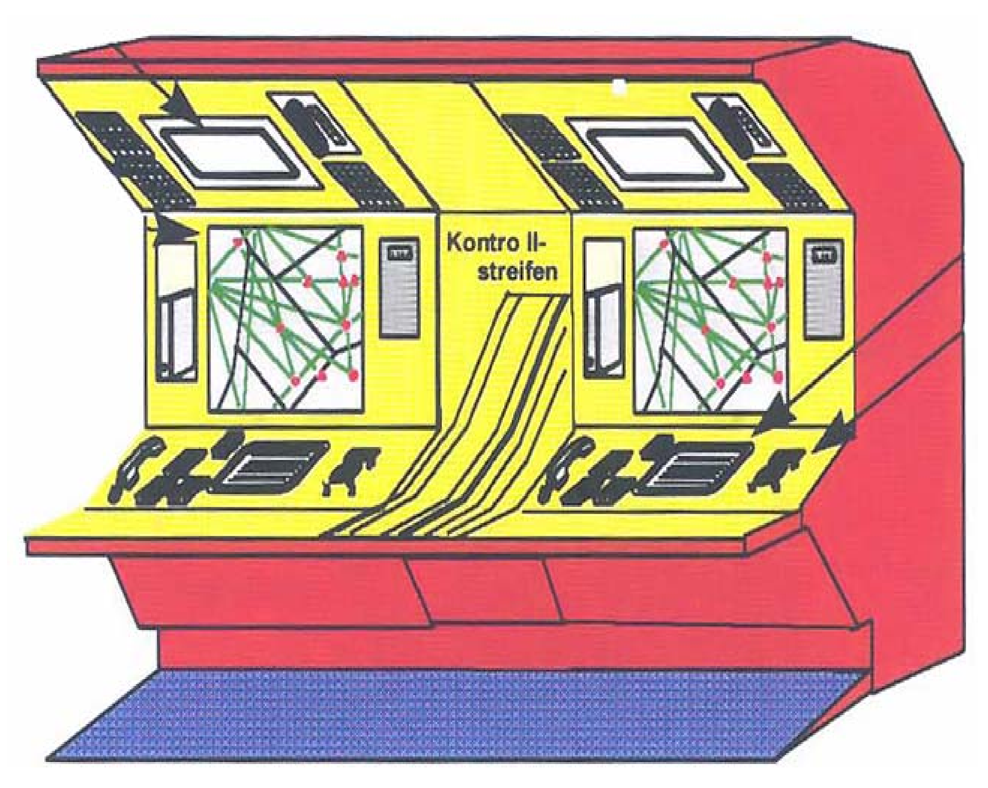

Figure 7: Air traffic control "suite" (source: DFS 1997); a typical air traffic control working position is designed for two persons and equipped with radar screens and a rack for flight progress strips ("Kontrollstreifen") in the middle; there is a controller position on the left and a coordinator position on the right

7), "The radar controller is in charge of identifying and maintaining the destination of flights. He has to (...) declare clearances and give orders to ensure that minimum separation between aircraft is respected at every time and to document these activities on the flight strips" (DFS 1997: 4; my translation). To his right, "the coordination's controller is in charge of collecting and distributing information. He approves on taking over flights from adjacent sectors and is in charge of the handing over by radar. Based on control strips, he produces and keeps an up to date image of the traffic situation. He announces potential violations to minimum separation to the radar controller (...)." (ibid.: 11; my translation).

3.6 Sixth stop: Seminar room

If there is a single space in which the worlds of operations people and technical people overlap, it is the seminar rooms. Controllers are frequently requested to attend presentations on diverse subjects related to their work, be it a future re-organisation of sector boundaries or the introduction of a new software package. Taking part in one of these seminars, actually on the introduction of "Reduced Vehicle Separation Minima" (RVSM), I am struck by the overly didactic and highly ironic style of presentation. In terms of atmosphere, it is hard to imagine a sharper contrast to the almost assiduous sincerity encountered in the control room. The presenter anticipates this, delivering a remarkable performance of self-irony. His visual presentation consists of a close sequence of well-prepared didactic elements. However, permanently interrupting himself and commenting on every single didactic clue, he makes it look ridiculous. The public clearly enjoys this performance. Participants are highly responsive, and contribute funny remarks and comments throughout the presentation.

3.7 Seventh stop: The sudden end of a research project

After its first year, the collaborative research project came to a sudden halt. Since then, only one out of three scheduled simulations did take place. The sudden end also implied that the project, conceptualized as a systematic comparison between work practices in different regional centres (i.e., the contribution by CETCOPRA), had to be abandoned at an early stage.[11]

Organised as a guided tour, the present section has told the story of an abandoned research and development project, which aimed at replacing paper strips by digital strips. Pointing to the practical circumstances of the project rather than to particular uses of the paper strip, it has been shown that there are many reasons to doubt that paper strips will soon be replaced. Provided that the everyday production of air safety is deeply embedded in regional exceptionalism and path dependency, and given the delicate nature of the relationships between operations and technical development, it is a task of extraordinary complexity to build up a simulating and testing procedure, which is consistent and considered legitimate by all parties involved. The next section will provide a more fine-grained analysis of this picture.

4 Cycles of practical activities supported by paper

How is it possible to reliably operate technical systems despite their being divided up between different media? As argued before, adjustment between different types of technology based on different types of media cannot be taken for granted. Instead, one may expect that this implies a permanent effort of mediation. "Because of their arbitrary nature, languages, bodily techniques and rituals seem to have a tightly restricted potential for accumulating refinement and integration"[12] (Schüttpelz 2006: 104). The observations analysed in the present section focus on paper strips at the interface of extra-somatic and somatic technology. This is what ethnographic studies on air traffic control workplaces have usually done. Consequently, there are well-documented and detailed observations on the uses of paper strips. This has been crucial in developing a new understanding of how air safety is actively produced. However, revealing mediating practices has often remained inconclusive. The present section will therefore go beyond the habits of Workplace Studies and be more precise about the way practices are identified. It will do so by distinguishing different sets of practices by taking their cyclical (or recursive) nature as a common trait and the length and scope of cycles as a criterion for differentiation. Interpreting the empirical material with this analytical device, I have identified four sets of practices presented here in an ascendant order. To begin with, there are observations on the role of control strips for stabilising the shortest cycle of control activity. It is this cycle, which has attracted most attention by former research – at the expense of neglecting the other three.[13]

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[11] The only reason provided for the decision to stop the project was a financial bottleneck caused indirectly by the attacks of 9/11 (Dubey et al. 2002: 2). The budget of air traffic control is calculated on the amount of air traffic control charges paid by airlines. As a result of air traffic significantly decreasing after 9/11, the revenues of air traffic control including Eurocontrol and its European Experimental Centre were also affected.

[12] Translated by the author from the German original.

[13] The basic material generated and explored in the following pages is about different life cycles of information. This is partly in accordance with an ethnographic convention which has been presented most comprehensively by Richard Harper (2000). It is surprising that while the author often compares different ethnographic studies on different subject areas, his "ethnographic program" seems to be built on the assumption that there is only one cycle of information per organisation.

4.1 Passage of a plane

Using paper control strips, the work of air traffic control gains a dimension of physical experience. Control strips "are materialising" flight movements; and they do so "one by one" (Gruszow 1999). Paper strips remind controllers of the trivial fact that each aircraft is a discrete entity. A paper strip put on a plastic slide and placed on the rack is a plane entering the control room. A similar observation can be made about a plane leaving the sector. To hand over a plane to an adjacent sector, the radar controller provides its pilot with the new radio frequency. Having received confirmation he simultaneously says "bye-bye" to the pilot and throws away the paper strip. These two gestures mark the beginning and the end of the shortest cycle of control practices. Within this cycle, there are various activities which involve the manipulation of control strips. As described above, the tasks of the two controllers differ and are only loosely coupled. At the same time, activities carried out by the radar controller need to be intelligible for his or her colleague and vice versa. Activities directed at moving or marking paper strips are an efficient way to maintain this level of intelligibility. This is even more obvious as there seems to be no need for oral communication. While doing their work, controllers are rarely seen talking to each other. This is how paper strips work: they stabilise an arrangement of parallel yet related activities. They bring about an element of scansion and rhythm, which contrasts with the type of balanced attention required by watching radar screens. To use a favourite quote of a number of controllers: "Thanks to paper strips, control activities are palpable" ["greifbar"]. To give an example, a controller might put a paper strip slightly on the edge of the rack. This is to signal a potential conflict without having to interrupt or to wait for his colleague who is still carrying out another task. Paper control strips stabilise passages of planes and are used as a medium of communication facilitating temporally deferred interactions between controllers.

4.2 Hand-over

Some of the partners contributing to the collaborative research project raised a fundamental criticism towards the selection of sequences decided to be relevant for a comparative simulation. They expressed concern that situations in which paper strips matter most may turn out to be impossible to simulate. They argued that limiting simulations to a closed single "suite" (of two working positions) was an unjustified design decision and a questionable limitation. Controllers in Karlsruhe would support this criticism. They report that paper strips are of particular importance when copresence (of two controllers, as described in the previous paragraph) is interrupted. There is one type of interruption which occurs on a regular – and cyclical – basis: having worked for 90 minutes, controllers are replaced for a break. A smooth hand-over presupposes that a controller who is about to take over responsibility is capable to quickly grasp an overall picture of the current situation. This is when the paper strips, sorted on a rack in a way as to anticipate potential conflicts, are often used. On several occasions, I have observed that, arriving at a control station, controllers use their fingers in order to memorise the representation of their flight sectors. Swiftly touching control strips one by one, and sometimes slightly changing their sorting order, they seem to actively apprehend the situation. Shift work brings with it a second cycle of practices, which is not defined by paper strips but stabilised by their use in hand-over situations.

4.3 Rite of passage

The collection of paper strips serves as a mode of representation, which duplicates the control system by radar. In case of emergency, it may also act as a medium of representation substituting for radar screens (cf. Hutchins 1995). This is a lesson many controllers have learned by the end of their professional training: Out of the blue, their instructors would switch off the screen. This is a hard test which is said to shortly precede the veritable rite of passage of the "first release": the first time a controller takes full responsibility of a geographical sector (Dubey 2001b: 173ff.). Members of the CETCOPRA research group reported that some instructors went on testing their former trainees by switching off the radar screens and enquiring about the location of planes on the basis of paper strips.[14] These tests are events of high significance for they recall the rite of passage and thereby contribute to reproducing a specific pattern of relationship between more and less experienced controllers. Concerning the issue of medial representation, re-enacting these tests may be regarded as a ritual of distrust. Faced with the test situation, controllers need to distance themselves from a particular medium of representation (namely radar screens) and to switch to the medium of paper strips for compensation. As a result, they might remain somewhat suspicious of the radar screen. In other words, testing is a way of exposing the mediality of a medium.

A rite of passage constitutes and is accompanied by a third set of cyclical practices. Also being stabilised by the use of paper strips, its life cycle is much longer than those identified in the previous paragraphs. By implication, first release experiences and tests are events which rarely happen. Statistically speaking, they are low-probability events. In order to understand their significance, one needs to look more closely at the social pattern in responding to situations of high uncertainty. As illustrated above, controllers may be responsible for causing a near-miss. Although this might happen only once in a controller's lifetime, controllers say they would always recall this event. More importantly, they report that to go through a troubling situation of high uncertainty is far from being a private experience. Controllers claim to be aware of their colleagues (responsible for adjacent sectors) being "in form" or struggling. This is why it does not come as a surprise when a controller, unable to cope with a complex situation, calls out "stop!" Given the current design of air traffic control, managing (or failing to manage) situations of crisis will never be left unnoticed to colleagues. What is more, the collective dimension in responding to critical situations can be expected to result in a strong social and affective cohesion. According to the analyses of the CETCOPRA group, this is why social organisation in air traffic control centres takes the particular form of "clans" (Dubey 2001b: 195). Following this interpretation, the rite of passage provides a model for how critical situations are managed. "The existence and the mediation of the collective compensates for the quasi-absence or the virtual presence of aircrafts. In other words, controllers catch up on the distance which separates them from the sky and from the reality they are acting upon (...)"[15] (Dubey 2001a: 13).

4.4 Generational change

Interviewees at the Karlsruhe centre are convinced that Digistrip, as prepared and tested by Eurocontrol, is incompatible with a future operation system all German air traffic control centres are waiting to be equipped with. This is why the Karlsruhe regional centre would not openly opt for Digistrip. In the light of this macro-political constellation, both the simulation and the future of Digistrip do not look very promising. But interviewees also let me know that they are confident to find a way to locally develop a new version of Digistrip which would be adapted to the specific requirements of that centre. If this vision was implemented, the Karlsruhe centre would

[14] Thanks to Gérard Dubey for sharing this observation.

[15] Translated by the author from the French original.

again demonstrate its commitment to always opt for fully tailored solutions and never become dependent on external expertise.

If asked whether Digistrip will be introduced or not, interviewees answer by embedding this question into a larger political framework. Without going into details, these accounts help to explain why I did not come across a single voice of dissent or a single sign of resistance against the idea of turning paper strips into digital strips. It seems to be more important and a reason of confidence that the regional centre is able to integrate the issue of Digistrip into the particular Karlsruhe success story. If there was no doubt about the centre's exceptionalism, there would be no reason to worry. Confidence, however, is paired off with a gloomy picture. The local success story might soon come to an end as the generation that has developed the system from scratch, and has been in charge of its maintenance since then, is now close to retirement. Particularly, this applies to the head of the software development team who is said to personify the generation which grew up (with) the system and who is said to "live the system".

The preceding paragraph on the "rite of passage" has dealt with an element which is part of the training of air traffic controllers. It has to be said that in the age of simulators, this particular exercise looks as if it was part of an antiquated didactic repertoire. Observing changes in the process of training, controllers of the senior generation express a deep concern that the rise of the simulator comes with the demise of a more interactive professional training. They already feel surrounded by a new generation of controllers labelled "the Nintendo Generation". Members of this generation are said to be no longer rooted in aviation and therefore to be deprived of an appropriate cultural orientation. Among those, who claim to have enjoyed full training, it is common to criticise that current training practices fail to take into account the interface between pilots and controllers. To bring evidence to this criticism they point to the fact that training sites, which once included airports, are now situated far out in the countryside. It should not come as a surprise, therefore, that younger colleagues no longer had a "system's perspective" as they had grown up and in a synthetic world. The younger generation is supposedly condemned to act in a synthetic world, which is said to "lack depth" and will neither object to digital strips nor defend the Karlsruhe exceptionalism. Members of the older generation testify that they "cannot imagine working without paper strips". However, with a generation moving towards retirement, the paper strip will probably disappear. As opposed to the observations reported and interpreted throughout the preceding paragraphs, generational change comes with a break in practices rather than with cyclical practices stabilised by the use of a particular medium of representation.

5 Representing normal operations

As stated before, the central problem of coordination faced by centres of air traffic control is to adjust between centralised flight plans and the semi-autonomous actual movements of planes.[16] To carry out this task, air traffic control draws on two distinct sets of representation. Its contribution to the production of air safety needs to be portrayed as a performance: flight control centres actively mediate between the order of plans and the order of observed events. Far-spread activities are brought together, observed and coordinated. This performance would not be that noteworthy if air safety was produced according to a superior harmonious "logic of operation". However,

[16] Although the introduction of TCAS, a cockpit-based "Traffic Alert and Collision Avoidance System", has by-passed air traffic control, it seems to have further amplified this problem (cf. Weyer 2006, 2007: 76ff.).

according to research on the large technical system of air transport, this assumption is erroneous. It seems to be more appropriate to think of air safety in terms of heterogeneous visions. Competing models of what is considered to be the perfect order have come to overlap (Gras 1993). Adherents to different models can be identified by the way they conceive of and handle critical situations. On the one hand, one has to mention the model named after "Ikarus" (Gras et al. 1994). Claiming that the capacity for adaptation and quick reaction by pilots is crucial to air safety, its basic principle is to protect the autonomy of pilots. On the other hand, this model sharply contrasts with a second one called "mechanical bird". To opt for the "mechanical bird" is to subscribe to the idea that there would be no risk of collision if control was entirely delegated to ground-based planning and engineering (ibid.). As indicated (and despite the fact that the titles chosen may sound a little outdated), both models are internally consistent in cognitive, in normative, and in social terms. Both models need to be permanently balanced, and this is precisely the task left to air traffic control (ibid.). To state it more dramatically, air traffic is in charge of the necessary linkages between the sky and the earth. Gras and his colleagues have concluded that the heterogeneous character of air transportation must be taken seriously, whenever new technology is introduced. In line with this argument, the present contribution systemically explored the coexistence of different media of representation and their implications for critical situations.

How to explain high levels of reliability while taking into account a multiplicity of different media? Following a theoretical exposition, the analysis took two steps, drawing on ethnographic material. First, I documented a failed attempt to demonstrate the advantages of digital strips over paper strips. Second, I presented a number of observations on practices that have co-evolved with the use of the paper strip. The first part of the analysis facilitated taking the second beyond the conventions of Workplace Studies. Having placed the paper strip in its organisational contexts in the first place, the analysis could be extended to practices of larger scale and scope. Thereby, I have escaped the scheme opposing "microsociality" and "macrosociality".[17] I have captured and characterised a maximum variety of practices all of which are related to different types of critical situations. Current initiatives to replace paper strips should be aware of their contribution to stabilise critical situations by closing the loop of cyclical practices. Each cycle of practices has a critical point of transition. This has been particularly obvious in the case named "rite of passage". In this regard, I have pointed out that (older) controllers tend to shy away from medial representations provided by radar screens. As described above, they repeatedly stage the mediality of this particular medium. Deliberately switching off monitors, they point to a potential for disruption and recall the difference between first and second order failures. This useful exercise in comparing dis/advantages of different media can no longer be reproduced once paper strips have become replaced by digital strips.

The observations presented in this article do not provide evidence that paper strips are "irreplaceable". On the other hand, the analyses presented above do not support the following view. According to Digistrip proponents, paper and paperless control are

[17] Ethnographic studies on "situated action" tend to subscribe a microscopic research program. As examined by Conein and Jacopin (1994: 477), they often share two explanatory goals. On the one hand, they try to demonstrate that interaction with objects cannot be decontextualised, that is divorced from social interaction. Contrary to this, they seek to show that each form of knowledge or capacity is based on the use of resources which are part of its particular local environment.

no longer exclusive alternatives for technological development. The once declared objective of substituting the paper strip is said to have been redefined. In the meantime, all major centres for research and development have adopted a new objective and a new rhetoric, which stresses "integration" instead of "substitution". As the potentials of "integration" are constantly being emphasised, paper strips have lost part of their backward reputation. Even positive qualities - such as being palpable, durable and adaptable to extremely different situations - have been attributed to paper strips (Pavet et al. 2006: 55). However, while paper strips have undeniably been rehabilitated, all the qualities rediscovered relate to the smallest cycle of practices. What then about the remaining cycles of practices reproduced and stabilised with the help of paper strips? Controllers and engineers interviewed during the case study emphasise a "longue durée" perspective. Unremittingly, they give priority to observations, which refer to more extended cycles of practice. As stated earlier, they regard the Karlsruhe regional centre as a relict of a failed attempt to harmonise air traffic control on a European scale; a relict, which was then turned into a regional advantage. Given these macro-political framework conditions, there is no neutral space, which would allow for a purely technical simulation, comparing paper strips and other technical devices. The more this macro-political aspect is emphasised, the more unlikely it will be to find an easy path towards increased interoperability.

Based on ethnographic fieldwork and interviews in air traffic control centres, the present analysis has drawn attention to multiple sets of practices, which differ in scale and scope. However, it does not provide an answer to the fundamental questions emerging in the course of this inquiry: How do different sets of practices relate to each other? How to conceive of their relationship? For instance, how to bring together the two perspectives sketched in the previous paragraphs, stressing either short or long cycles? To deliberately leave this question open is to insist on the need for respecting differences between practices which have co-evolved with the uses of paper strips. Knowing more about the multidimensional uses of paper strips (cf. Vongmany 1998: 67) does not offer immediate practical advice. But still, there is a suggestion addressing practitioners inasmuch as that the present analysis presupposes and nourishes processes of organisational learning. In this sense, it shares the ambitions of the approach on highly reliable organisations (Hale et al. 1997, Bourrier 2002). As it is unlikely that organisations will learn from large crises and dramatic accidents, social studies of technology and risk should continue to invest in research on normal operations.

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