Investigating the Safety-Relevance of Limited Distinctive Features on a Multi Remote Tower-Working Position

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***Abstract*—The novel concept of controlling multiple airports remotely by just one tower controller at a time promises clear benefits of cost-efficiency and working conditions for aerodrome control services particularly at airports with low traffic density. The increasing amount of information and functionality of input devices places on the other hand new demands on the attention and memory of the tower controller. Helping the controller to distinguish information and to compensate for similarities in the information cues of different sources is of increased importance on a working position with independent operations. Possible confusion and forgetting of safety-relevant information is identified as a possible consequence if the implemented design of the working position offers too little distinctiveness. An experimental study was conducted, using stress test reactions and interviews for verifying the relevance of distinctive features on a multi remote tower-working position. The results reveal that the probability of confusing safety-relevant information cues might increase. In contrast, the test persons demonstrated that the working position does not offer any additional potential of lapses in memory. The final discussion addresses specific means of mitigating the risk involving design issues.**

Keywords- Multi Remote Tower; Safety; Experimental Stress Testing; Confusion; Forgetting.

I. INTRODUCTION

Design of tower controller working positions are currently well impacted by activities of ANSPs of putting Remote Tower into initial operations. First experience could already be gained for a European airport operating at low traffic density. The procedure to be applied for aerodrome control and the elementary working pattern, i.e. the perception of information, are assumed as sufficiently preserved for these operations. For this reason, potential negative impacts of Remote Tower procedures on the capability of the ATCO, to grant a safe, orderly and expeditious flow of air traffic, are considered as staying within the tolerable margins.

Because of the independence from its physical location, the Remote Tower shall pave the way to controlling multiple airports by one ATCO at a time while using novel operational concepts. This concept is called *Multi Remote Tower* and shall join several airports with low density to one tower control unit and thus support air traffic control services on demand. The benefits include the attention of the ATCO, which can be optimized considering economic efficiency as well as ergonomic criteria of work load. In this scope, SESAR WP 6.9.3 delivered key insights into possible human implications [1] and work load as well as subjective acceptance by ATCOs [2].

The conventional and proven working pattern of ATCOs will probably be impacted by such a fundamental change of his service role. This can be explained by the new function of the concept that allows for changing or alternating the working environment, in which any of the involved airports might bear an independent operational situation. The alternating environment consequently forces the ATCO to mentally associate perceived information to a specific airport, such as actual and planned traffic movements or already released clearances. The demanded capacity of memory is assumingly higher compared to a Single Remote Tower as information on wind heading, speed, cloud ceiling, precipitation, pressure and airport specific agreements or procedures are available multiple times. This is expressed by 69 possible human performance issues that highlight implications of handling multiple airports at a time [1], referring also to possible confusions. The naming convention of ICAO-standardized airports, whose taxiway designators and VFR-reporting points comply with an equal or at least similar scheme, provide only little specific distinctiveness.

Distinctiveness is generally needed to avoid so called misattribution of the human memory that causes confusion about the origins of retrieved information [3]. Hence, distinctive features are a crucial determinant for satisfying the need of the human to distinguish the tasks of independent operations and to encode task-related information to the memory. Endsley describes a relation of confusion to Situational Awareness, in which a "lack of detectability or discriminability of the physical characteristics of the signal in question" might cause errors in the "perception of the elements" (SA Level 1) [4].

The consequences of confusion-related human errors are still a persistent and major concern on the flight-deck [5]. A current example of confusion is the accident of TransAsia Airways

[1] The research activities that are related to the experiment were carried out by Lothar Meyer under contract of TU Dresden in 2011.

flight GE235 from Taipei to Kinmen Island in 2015. Beside other errors, the aircrew falsely shut down the left engine of the ATR72 during an engine flame out on the right. Accident investigators concluded that the “misinterpretation of the pattern of data (cues) available” might be caused by “similarity of cue patterns between malfunctions with very different sources” [6]. Another well-known type of confusion is referred as “mode confusion” and is specifically related to the autopilot and automation in the cockpit. This type received increasing attention, in particular, as automation of the glass cockpit and fly-by-wire rose up during the last three decades. Confusion deteriorates the current level of safety due to insufficient remaining human capabilities of screening cockpit instruments and managing attention while coping with the complexity of aircraft systems. Generally, confusion-related accidents reveal that the cockpit design offers insufficient features to the operator for distinguishing and controlling system inputs adequately. This is in particular the case during irregular situations with increased stress conditions. For that reason, design-induced errors are a major contributor to safety occurrences.

The ATCO’s mental ‘picture’ or situation awareness are hosting an equivalent hazard known as “errors in memory”. They show up i.e. in confusion on whether or not a clearance had already been given [7]. Additionally, misreading, misspelling and misidentifying information tend to occur when information such as callsigns looks alike (perceptual confusion), or where information is close together, such as adjacent flight strips (spatial confusion) [8]. Forgetting and confusion are in this scope close relatives due to the common origin in human memory and the nature of interacting causally. The usual approach of ATCOs to deal with memory error is to rely heavily on transactional Situational Awareness, to pick up the correct information from the environment just-in-time [9]. Well known and investigated since long time, both confusion and forgetting of operational information need to be considered as relevant causal factors to safety occurrences.

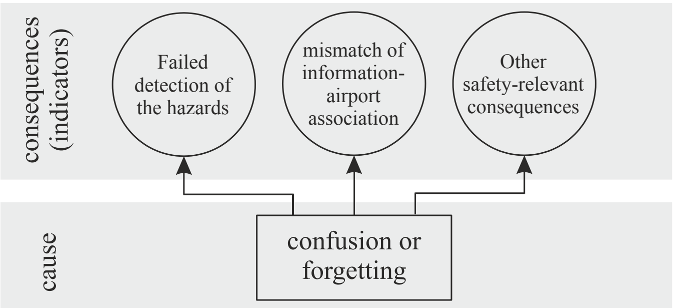

Figure 1. Investigated indicators of confusion and forgetting

Current implementations of remote tower turn the working position of the tower ATCO into a highly integrated and technical environment. The increased technical functionality and automation are inevitable features of this continuing development. In such an environment, ATCOs are forced to handle technical failures as i.e. a sudden monitor cut off while 2 aircrafts are operating in his/her area of responsibility. As such, similarities to design-induced errors on the flight-deck are becoming obvious.

To summarize, the new functionalities in a Multi Remote Tower-working position may increase the probability of confusion and forgetting significantly. Thus, adding sufficient distinctive features is an imperative support to mitigate risks and to discriminate tasks. Conversely, confusion in a Multi Remote Tower-environment is a probable consequence of insufficient distinctive features of the implemented design. For that reason, we investigate the potential of deteriorated safety with an experimental in the scope of a proof-of-concept study.

II. Method

A. The Approach

For the investigation of design-induced confusion and forgetting, the experiment consists of an experimental Multi Remote Tower-working position with three pseudo pilot working positions. Two methods are considered for measuring “confusion” and “forgetting”:

- The occurrence of confusion and forgetting is supposed to be significantly stimulated by forcing the test person to detect operational hazardous situations (stress testing procedure). The encounter of the test person with irregular situations shall promote stress and the occurrence of confusions. The association of the test person to the respective airport ex post is considered as a crucial indicator.

- The effect of confusion and forgetting on the association between operational information and the respective airport shall be investigated. This involves in particular the management of information and the activities of monitoring the airports.

Additionally, observations may reveal alternative consequences that can be found as safety-relevant in retrospect. The relationship between confusion and forgetting and its indicators are illustrated in Figure 1. The data acquisition rely on the following means:

- The rate of hazard detection along the experiment.

- Post-analysis of video and audio (voice communication) recordings - The analysis consists of a reconstruction of decision situations. This shall allow for reasoning the test person’s behavior that is observable during increased stress and potential violations of the procedures. An identification of Multi Remote Tower-related behavior becomes possible. The recordings are enhanced by key stroke-log files that provide the time of switching of the selected airport.

- Collection of subjective statements from the test persons through ex-post interviews - The interview shall gather possible causes of not detecting or recovering hazards successfully. An additional open interview shall identify concerns and complaints from the test persons that are concluded from the simulated operations and have not been considered in advance.

B. The Experimental Setup

The experimental setup was realized in cooperation with TU Berlin and TU Darmstadt. The tower simulator consisted of three secondary surveillance radar screens, a planning tool, a ground surveillance screen and a visual presentation (Figure 2). The 180° horizontal view of the visual presentation covered the operational surfaces and the approach airspaces as well as the outbound sector. The only additional distinctive means that were provided to the test persons consisted of labels with the name and ICAO-code of the allocated airport, highlighted in the upper-left corner of each of the displays. The pseudo pilot working position consisted of a Cessna C172SP software cockpit environment, including a joystick-controller, voice communication and a set of keys to elementary control the aircraft systems. All working positions were realized using the Microsoft Flight Simulator X (FSX).

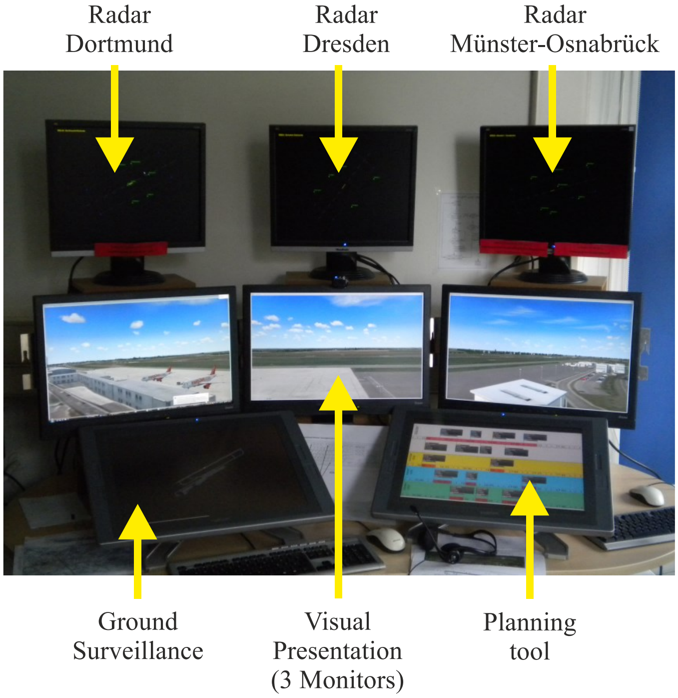

Figure 2. Experimental Multi Remote Tower-working position

The scenario consisted of basically non-coordinated VFR movements (type Cessna C172SP) with starting, landing and crossing traffic pattern at the airports Dresden, Münster-Osnabrück and Dortmund. A short summary of the script is as following:

- *D-EGRP (Dresden)* – Start 4:20 pm local time at position 8. Start-up, taxiing and lineup on RWY 04. Leaving the control zone and the tower frequency. Crossing the control zone. Entering the control zone for final approach. Vacating and taxiing to position 8.

- *D-EBNY (Münster-Osnabrück)* – Start 4:10 pm local time at position 8. Start-up, taxiing and lineup on RWY 07. Leaving the control zone and the tower frequency. Crossing the control zone. Entering the control zone for final approach. Vacating and taxiing to position 8.

- *D-EDCW (Dortmund)* – Start 4 pm local time at position 8. Start-up, taxiing and lineup on RWY 06. Leaving the control zone and the tower frequency. Crossing the control zone. Entering the control zone for final approach. Vacating and taxiing to position 8.

The ATCO was allowed to switch the visual presentation to any of these airports anytime. The tower frequencies were fused to one common frequency, allowing the ATCO to communicate with all aircrafts on all airports while using only one microphone. The principle tasks consisted of providing standard aerodrome control services according to *ICAO manual doc. 4444 PANS-ATM* and apron control services. There were five trials with each trial consisting of a scenario of 1 hour and 20 minutes execution time. The relatively short exercise time was chosen to prevent the operator and so the performance measured impacted by fatigue.

TABLE I. HAZARD EVENTS

	Hazard description	Severity Class
1.	Animal appearance	Accident
2.	Unauthorized entry of runway by ground vehicle	Accident
3.	Sever weather	Accident
4.	Unauthorized entry of control zone by aircraft (intruder)	Major Incident

Five ATCOs from the Deutsche Flugsicherung GmbH and pilots holding a Private Pilot License were invited as test persons. The pilot test persons had to pass a qualification test that shows their ability to handle the simulated aircraft correctly.

Figure 3. Unauthorized entry of runway by ground vehicle (hazard no. 2)

The experimental stress testing procedure consisted of the introduction of hazardous situations. The simulation's implementation is capable of introducing a set of hazards from a previous study to the simulated operations (Table 1), which were to be detected adequately [10]. The severity classes correspond to the scheme defined in *Regulation (EU) No 1035/2011*. The moment of introduction was event-triggered to a point of provoking a worst case scenario. This especially addressed the phases of runway use such as landing, flare, breaking and take-off. For instance, the ground vehicle was placed on the runway during the final approach of the aircraft on the respective airport (Figure 3). The test persons were instructed to visually recognize any abnormal situation and to report them instantly to the experimental supervisor. The hazards were set visible for a period of 1 minute. A detection rate can thus be determined due to the possibility of missing the hazard. As the ATCO is the subject of investigation, the hazards were not visible for the pseudo pilots. This avoided additional disturbances of the testing procedure by possible early notifications from the pilots. In avoidance of recognizing and expecting pattern of event sequences in the scenario, each hazard was only shown once in the scenario. Thus the test persons were not able to derive any further expectations from the hazard observations. After successful detection, the hazard disappeared and there was no additional action to be performed by the test person. The ex-post interview asked the test person for the hazard's location. The stimuli can be assigned to the respective airport and the correct association can thus be concluded. Open ex-post interviews were used for collecting free statements of the ATCOs concerning the new concept.

III. Results

A. Hazard Detection

Neither the unauthorized entry of runway by a ground vehicle acting as intruder (hazard no. 2, a runway incursion) nor the severe weather environmental impact (hazard no. 3) was detected correctly by one out of five cases. The intruder (hazard no. 4) was not detected in even 4 out of 5 cases. The rate of successful detection was finally 14 to 20.

The ex-post interview consisted of a structured interrogation concerning the hazards. Although ATCOs kept all hazard in mind, the hazard could not be associated to the correct airport in 3 out of 14 successfully recognized hazards (21%).

B. Video and Audio Analysis

The analysis combined video, audio and key stroke-log files for concluding on confusion and forgetting by means of objective observations. The attentional focus was manually analyzed from the current posture and the observed viewing direction. Although this method allows for obtaining only a generic overview compared to eye-tracking technologies, a conclusion of the display of interest was possible. Possible events of confusion or forgetting were detected by searching irregularities or inconsistent behavior of the ATCO when combining the different sources to a coherent plausible sequence of the actions.

Video and audio analysis revealed that waypoint designators and the airport selection on the visual presentation was confused in one case. This was confirmed by the respective ATCO during the ex-post interview. The ATCO stated also that one of the causes may be the similar appearance of the airports. In contrary, there was no confusion about any callsign.

C. Open Ex-post Interview

2 of 5 ATCOs stated that there is a high probability of confusing ATIS-information. This covers mainly weather information such as the wind and QNH. With respect to the given wind direction, it was not found to hold the risk for confusing runways in use. However, the direction of the aerodrome circuit can be affected (1 of 5). The hazard of confusing taxiway designators, landing directions and aircraft positions was seen as crucial in one case each. This tackles especially taxiways to and from the runway that most commonly have equal designators such as "alpha" or "bravo". The potential of confusing callsigns however was not confirmed.

ATCOs stated that they were not completely familiar with the working environment which can have led to degraded or at least non-typical behavior. This statement corresponds to the relatively high rate of non-detected intruders (hazard no. 4), which may be affected by insufficiencies of establishing visual scan pattern in the new working environment. This would be in line with the comments of the affected ATCOs, stating that the focus of attention was set inappropriate while the intruder entered the control zone. Exemplary quotes of explaining are: "the borders of the control zones are poorly monitored" or "I completely hided them from my perceptual area". The statement correspond to the effect of tunneling [8], that is similar to blind spots, known from enroute air traffic control [11]. According to the "Perception and Vigilance"-model of the Human Error in ATM Technique [12], the missed detection is to be attributed rather to a problem of identifying the conflict than to confusion.

The open ex-post interview also revealed that all hazards were more likely to detect and recover in time under real conditions. Anyway, the ATCOs confirmed the need of paying attention to only one airport at a time (typical "single task" behavior). Attentional sharing over two airports is considered as critical especially during periods of runway use and periods immediately prior to entering the runway or prior to crossing threshold upon landing. An exemplary quote is "Inattentiveness to other control zones apart from the one I'm actually controlling is bad".

IV. Conclusion

The combination of objective experimental findings and the subjective operator statements indicate clearly that the potential of confusion is relevant and can well be measured. The safety-relevance of limited distinctive features could be verified by the confusions that were observed during the trial. In turn, forgetting of any event could not be concluded from the observations made during the trials. A reasonable explication is that ATCO most commonly take notes during the trial. This helped to plan and sequence actions as well as to keep the actual processes in mind at any time.

Concluding from the findings and the statements of the trials, a direct consequence of confusion on operations might be generally related to one of the following types:

- misleading action (to the wrong airport),

- transmission of invalid information to the flight-deck or
- a missing action of the tower controller.

They represent three proposed types of human error that affect operations in different qualities. The ultimate consequence depends strongly on the conditions of the situational context. For example, it is likely that the occurrence of confusion is most effective for a further escalation of a situation that is already critical. This case is of particular importance as confusion is itself a likely outcome of an irregular situation. Thus, confusion turns out to be a hazardous accelerator in situations with increased stress and work load such as emergency situations or seemingly daily situations with increased time pressure. Summarizing, confusion can be regarded as a *Performance Shaping Factor* that probably increases uncertainty of the ATCOs decision-making in aerodrome control services.

From a logical point of view, the moment of switching the airport raises the need for an attentional reorientation regarding the focused information. Such a moment of "refocusing" and the period immediately thereafter may be featured by a critical transition of attributing the information correctly to the respect airport. Endsley generally hypothesizes a "negative affection" on Situational Awareness by the "rate of change of the components" that increases task complexity [4]. Following this hypothesis, confusion is unlikely to occur if the ATCO switches only a few times per day between the airports. The reason for this could be that decreasing the frequency of switching of the working environment allows the ATCO working pattern to approach the equivalent of a Single Remote Tower.

On the other hand, any additional airport that is to be controlled simultaneously raises the number of possible conflicting information cues and thus offers additional opportunities for similarities. The number can thus be regarded as a primary determinant of similarities in the information offered to the ATCO.

As with most Performance Shaping Factors, a reduction of this factor to an acceptable level is more likely possible than a complete elimination. The principle mean of mitigation is to enhance the differences between the airports. Related to this, the open ex-post interview pointed out hints, which can be summarized as following:

- Avoiding similarity of the operational context such as the simultaneous control of airports that have similar runway directions, layout of operational surfaces, callsigns, and topology/appearance of the vicinity.
- Adding features to the design of the working equipment. This might involve color and form associations as well as the font types for coding the information by a characteristic feature.
- Limiting the frequency of alternating attention between the airports to a fair degree. This addresses in particular the need for harmonizing the temporal density distribution of traffic over the day on the respective airports. It also involves means for allowing the ATCO to plan the expected traffic and to cluster traffic airport-wise for establishing an operator-friendly sequence of control actions.
- Establishing a relaxation time after alternating the airport for establishing situational awareness.

Even though the population consisted of only five ATCOs, the effect of combined experience from professionals and an experimental working environment is meaningful for gaining relevant findings on the Multi Remote Tower-concept. Generally, such experimental studies should be used further to extend the human's imagination of possible accident causes and chains of escalation that are concept-related. It helps increasing ATCO's awareness with adequately adopted operational procedures as potential further outcome of this type of study tackling implications of a new function in combination with timely stress-rich situations. The experience *in situ* thus enables to identify deviations from proven working pattern. On the other hand, such experiments with small sample sizes and small periods of executional time cover by nature only a limited set of all potential safety-relevant cases that may occur. The open ex-post interview is consequently an appropriate and mandatory means to extending the objective results by expert's experience that goes beyond a functional approach to hazard identification and verification.

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