Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013)

# Which data provide the best insight? A field trial for validating a remote tower operation concept.

Maik Friedrich
Institute of Flight Guidance
German Aerospace Center
Braunschweig, Germany
Maik.Friedrich@dlr.de

Christoph Möhlenbrink
Institute of Flight Guidance
German Aerospace Center
Braunschweig, Germany
Christoph.Moehlenbrink@dlr.de

***Abstract*—This paper describes the validation of a Remote Tower Control workplace. The study shows how Air Traffic Control Officers (ATCOs) observe traffic from a Tower Control Working Position at Airport Erfurt-Weimar (ERF) in comparison to a Remote Controller Working Position. The validation exercise targets low traffic density airports. Shadow-mode trials were used to cover perceptual, operational and human factors aspects of a Remote Tower System, including a live video panorama and a German Aerospace Center (DLR) research aircraft. The aircraft was used to fly different maneuvers within the aerodrome. These maneuvers allow insights on the detectability of an aircraft within different distances from the tower and the gathering of operation information about an aircraft status. In addition, a Deutsche Flugsicherung (DFS) vehicle was used to position static objects on the airfield to determine the detectability of these objects for different distances to the Control Tower (RTO-camera system). Eight ATCOs from the DFS participated in the validation exercise. Time-synchronized questionnaires for the controller working position remote (CWP-remote) and the controller working position tower (CWP-tower) were applied, addressing operational relevant questions to the ATCOs. The results reveal that the information sources play a different role at the CWP-remote than for the CWP-tower. The results are discussed taking performance and subjective data into consideration. Further, the implications for the consolidation of functional requirements and system specifications for a future remote tower system are worked out.**

***Remote Tower Operations; Validation; Video panorama; perception, detectability; SESAR;***

## I. INTRODUCTION

Future remote control of low traffic airports (Remote Tower Operation, RTO) will rely on the replacement of the conventional Air Traffic Controller workplace (CWP-tower) by a controller working position remote (CWP-remote). For short- and midterm realization of a CWP-remote the out the window (OTW) view will be a digitally reconstructed panoramic view using high resolution video cameras. The DLR-internal project RapTOr (Remote Airport Tower Operation Research, 2005-2007) focused on remote tower control of single airports, while the project RAiCe (Remote Airport traffic control center, 2008-2012) focused on the idea to control multiple small airports from one remote center [1–6].

In parallel to these projects, remote tower operation was pushed forward by a joint venture project of the Swedish Civil Aviation Administration (LFV) and SAAB, called ROT (Remotely Operated Towers, 2006-2008) [7]. SAAB also coordinated the EU-Project ART (Advanced Remote Tower, 2007-2009) [8] focusing on single remote tower control. Further, the German Aviation Research Program iPort funded the ViCTOR project (Virtual Control Tower Research Studies, 2009-2012), which was led by DFS and addressed new concepts of remote operation, team work, as well as visualization aspects.

From an American perspective there is a strong motivation to work out operational and functional requirements (Ellis & Liston [9]), technical/ system requirements and the integration of concepts [10], to ensure the safety when applying RTO. Their concepts on staffed NextGen Tower also explore alternative surveillance systems for the OTW [11]. The same perspective applies for Europe, especially within the Single European Sky ATM Research Program (SESAR). There, Remote Tower is addressed under a separate Operational Focus Area (06.03.01) [12]. This Operational Focus Area comprises the different Remote Tower Activities assigned in the Operational Projects.

SESAR supports projects to bridge the gap between research and applicable operations. The SESAR research activities are linked to the European Operational Concept Validation Method (E-OCVM), which describes the development and validation activities as an iterative process within a seven step model [13]. Three steps (V1 to V3) within the seven step model were developed to formalize the process of concept validation for industrialization (Fig. 1).

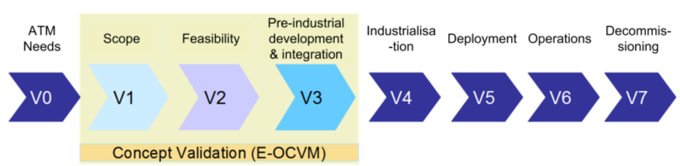



Figure 1. The Lifecycle V-Phases, validation and other ATM systems development activities [13]

To test the feasibility of the RTO concept, V2 human-in-the-loop studies have been completed addressing research questions for single remote tower [13]. To complete the

SESAR JU/D/12-446 study; DFS; DLR

analysis of feasibility in V2, research prototypes are tested also within field trials. In 2007, field trials with the first remote tower research prototype, consisting of four cameras for reconstructing a panoramic view were completed at Braunschweig Airport [14]. The data of the field trials have been used to quantify the effective resolution of that video panorama [3]. Within the ART-Project, van Schaik et al. [8] assessed the importance of visual cues for remote tower operations and suggested a formula for calculating the required resolution for either detection or recognition of each cue. While we agree that a definition of minimum resolution requirements for RTO is one important issue, it remains unclear whether the calculated minimum resolution requirement can be empirically validated by Air Traffic Control Officers' (ATCO) detection and recognition rates of such items under daylight and good visibility conditions.

This paper focuses on the empirical results of a V2 validation exercise under project 06.08.04 [15], which was completed under the scope of the OFA Remote Tower. Two Remote Tower validation exercises under this scope were already completed under project 06.09.03 [16] in Sweden. All three validation exercises contribute to the transition from V2 (feasibility) to V3 (pre-industrial development and integration) (Fig. 1). Therefore, the remote tower operations concept descriptions and the functional/operational requirements have been defined in the Operational Service and Environment Description (OSED) for Remote Provision of Air Traffic Services to Aerodromes [17]. The functional/operational requirements define what the user (here: ATCO) of the system wants the system to do. It is important to note that the functional requirements are independent from the technical solution. Complementary to the functional specification, technical system requirements define whether a specific technical system can provide specific information to the user. For the reader not as familiar with SESAR, the functional requirements for Remote Tower are defined and further developed within the Operational Threads by project 06.09.03 and 06.08.04 to end up with consolidated functional/operational requirements for V3.

Within this paper subjective and objective data from the third validation exercise (V2) are presented. We used a prototype (see section IV.B) developed by DFS and DLR in 2012. First, an extended schematic will be introduced to improve the data collection process. Second, the complete list of validation objectives is provided. Third, the method section covers the experimental setup and proceeding. Forth, the results are presented. Fifth, it will be discussed what contribution subjective and objective data can provide to develop and consolidate specifications for future Single Remote Tower Operations concepts. In addition the methods for validating a remote tower system will be discussed. Sixth, data and methods are concluded as appropriate to judge if a concept can provide the information ATCOs need.

## II. EXTENDED FIELD TRIAL INFRASTRUCTURE

The goal of this paper is to elaborate and discuss validation methods for a single RTO concept. Previous validation exercises concerning remote towers mainly focused on analyses of subjective data such as questionnaires, interviews, observations and ATCOs' feedback [5], [16]. However, an extended infrastructure for field trials can provide additional objective data to support the development and consolidation of specifications for future RTO.

Fig. 2 shows the field trial schematics extended with objective data validation methods (red). This schematic description shows the stepwise validation within the project 06.08.04. For (1) Providing Air Traffic Service (ATS) (from tower or remote) the (2) functional requirements have been elaborated [17]. For setting up field trials, a validation plan is written and it is defined, whether the (3) experimental design includes a control condition beside the experimental condition(s). The control condition is important to have a baseline or reference, to evaluate the results of the experimental condition(s). Within field trials a baseline cannot always be provided for several reasons. However, RTO allows a comparison between CWP-tower and CWP-remote. In addition, the (4) controllability within field trial is usually limited: The amount of traffic and flight manoeuvers is not under the experimenters control and the accessibility of operational data thereby limited. Such limitation can be overcome by using a research aircraft which is under the control of the experimenter. Thereby, the experimenter can define the traffic patterns and number of iterations for certain flight manoeuvers for a systematic analysis.

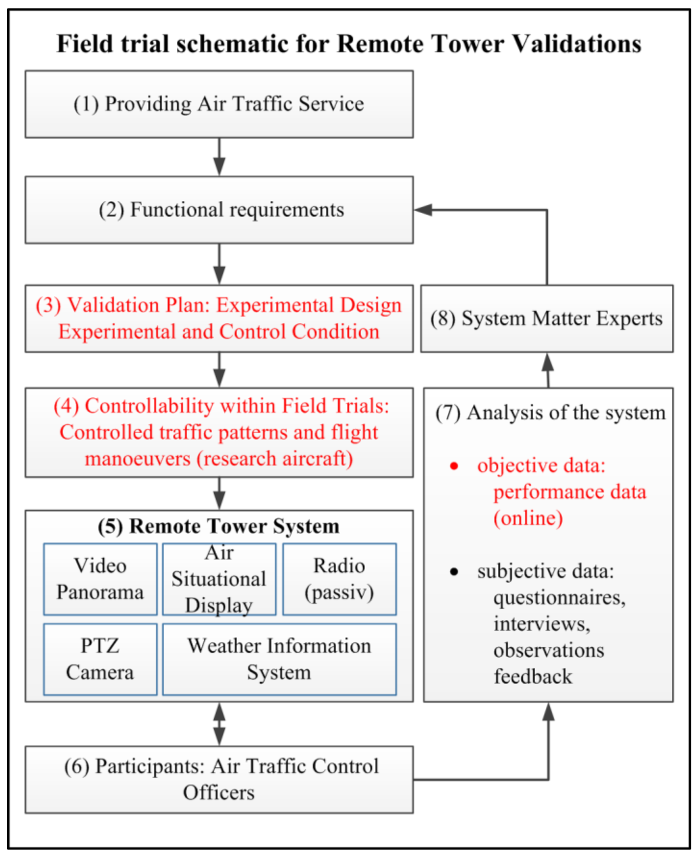



Figure 2. Field trial schematics for development and consolidation of specifications for future Remote Tower Operations.

Then, the (5) Remote Tower System is tested within field trials and data are collected from (6) ATCOs'. For the (7) analysis of the system, or to be more precise, for the analysis whether the system provides the functional requirements, different kind of data can be analyzed.

## III. Validation Objectiv

The validation objectives are identified by refinement and consolidation of the functional requirements specified in the OSED. This step is in accordance with E-OCVM and has to be applied as a preparation for field trials. The following validation objectives have been identified and therefore provide the base for the validation exercise introduced in this paper. The validation objectives are subdivided into success criteria (hypotheses) to account for several aspects of the same objective. The success criteria are used later on to judge if a validation objective is reached or not reached.

The complete validation exercise contained the following eight objectives separated into 21 success criteria:

- Human Performance Task (7 Success Criteria)
- Safety during shadow-mode trials (3 Success Criteria)
- Workload with respect to shadow-mode (1 Success Criterion)
- ATCO Tasks, Roles and Responsibilities (5 Success Criteria)
- Accessibility (2 Success Criteria)
- Perception (1 Success Criterion)
- ATC Procedures (1 Success Criterion)
- Usefulness (1 Success Criterion)

To be consistent with the infrastructure proclaimed in Fig. 2 the success criteria structure allows for covering several aspects of a validation objective with performance and subjective data. For more details on all validation objectives and success criteria see [15]. For the purpose of this paper two validation objectives were selected that contain of success criteria concerning subjective and performance data (TABLE I).

TABLE I. Objectives and success criteria that are covered by performance and subjective data

| **Validation Objectives** | **Performance Success Criteria** | **Subjective Success Criteria** |
|---|---|---|
| Human performance task | Detection of static objects | Perceived visibility at the apron |
| Safety during shadow-mode trials | Detection of safety related manoeuvers | Perceived safety during shadow mode trial |

The Human performance task assesses if basic ATC functions / tasks can be performed using the initial CWP-remote, and identify any additional issues that may contribute to the Human Performance Task Analysis. The safety during shadow-mode trials assess whether the level of safety is maintained or improved under all normal conditions when ATS are remotely provided to a single airport.

## IV. Method

### A. Participants

Eight Air Traffic Control Officers (ATCOs) employed by the DFS, participated in the validation exercise. The average participants' age was 30 years with a SD of 11.5. The average work experience was 10 years with a SD of 9. All participants worked at local or regional sized airports. 50 percent of the participants claimed that they had known the project in advance of the validation exercise. The participants received no additional payment and participated during typical working hours.

### B. Experimental Setup

The experimental setup consists of the technical setup (CWP-remote and the survey software) and the experimental vehicles (car and aircraft) used for the validation exercise. Preplanning including resource assignment for use of an aircraft started in 2008 within RAiCe [1].

The technical setup presents an overview of the CWP-remote and available information systems. The most important change to the CWP-tower is the visual reproduction of the OTW view [3]. A cameras house with five High Definition cameras equipped with a 2/3" - sensor and f = 8mm lens were used. The sensor can be described by using the fundamental relationship

$$\frac{G}{B} = \left(\frac{g}{f} - 1\right) \approx \frac{g}{f}$$

with f = focal length = 8 mm, g = object distance, G = object size, B = image size, and CCD pixel size of p= 5.5 µm. This leads to a vertical object size by g = 1000m distance corresponding to 1 Pixel is

$$\frac{G}{B} \approx \frac{1000m}{0.008m} => \frac{0.68\,m}{5.5\mu m} => \frac{0.68\,m}{1\,Pixel}$$

vertical, or ca. 2 arcmin angular resolution.

In addition to the camera house, a pan-tilt zoom (PTZ) camera was mounted on the top, to allow a detailed look into participant guided areas. The PTZ camera was moveable within a 360° view and had 12 pre-sets (fixed positions and zoom values) for fast responses. The optical specifications of the PTZ camera is given by

$$\alpha_Z = \frac{p_H}{Z} f_0$$

yielding $\alpha_Z$ = 1 arcmin (with a zoom factor Z = 4, viewing angle 2θ = 15°). The PTZ control and video stream was presented via a separate monitor within the CWP-remote.

The visual reproduction from the five cameras, situated on top of the Erfurt-Weimar tower (Fig. 3), was displayed on five 40" LCD monitors arranged in a "brocken circle" around the CWP-remote (Fig. 4), providing a 200-degree field of view.

Figure 3. Camera on the top of Erfurt-Weimar Tower.

The participants were placed about 1.8m from the monitors. Beside the visual reproduced OTW view the participants were provided with the following sources of information:

- Weather Information System
- PTZ Camera (Controlled via pen-input)
- Air Situation Display
- Flight Plan Data

The survey software "Controlsurvey" was used to question the participants during the trials. Controlsurvey was developed by the DLR for the purpose of synchronized questioning at two workplaces and with the flexibility of reacting to minor deviations from planned scenarios.

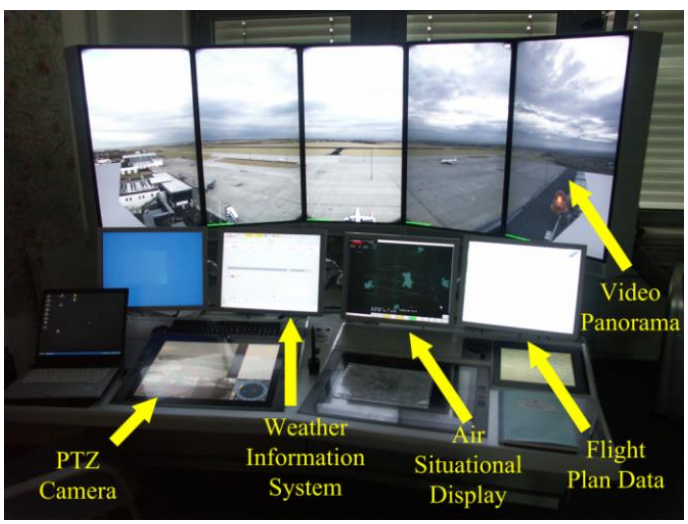



Figure 4. CWP-remote at the airport Erfurt.

The questions used during the validation exercise can be subdivided into three major question types presented in TABLE II. The different question types concern different aspects of monitoring tasks that ATCOs have to perform while providing ATS. Each question under the category aircraft manoeuvers is connected to a point or position within the traffic pattern (Fig. 7).

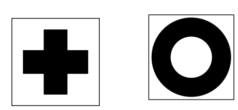
TABLE II. QUESTIONS CONCERNING TOPICS AND DETAILED DESCRIPTION

| **Questions type** | **Questions description (if available point on the traffic pattern, Fig. 7)** |
|---|---|
| Aircraft manoeuvers | • Wagging with the wings (A)<br>• Declining (D)<br>• Landing light (G)<br>• Position on the flight path ($G_{1,2,3}$)<br>• Gear down (H1 – H3)<br>• Status of the landing gear up (I)<br>• Turning of the aircraft into base leg (T)<br>• Route variations (BC and EF)<br>• Southern traffic circuit (flying south of the tower, see Fig. 6) |
| Object detection | • Searching an aircraft within the aerodrome<br>• Static objects<br>• Runway status lights |
| Weather Status | • Windsock status<br>• Holding points<br>• Range of sight<br>• Speed of wind<br>• Intensity of rainfall<br>• Percentage of clouds<br>• Type of clouds |

### C. *Experimental Design*

The validation exercise was completed as a passive shadow-mode close loop field trial. The experimental design is based on the direct comparison between the CWP-tower and CWP-remote. The workplace of the participating ATCO within a trial is the independent variable. Through the comparison of both workplaces and the synchronized questioning (Fig. 6), the effect of the confounding variables: unforeseen traffic events, meteorological conditions and time of day were reduced.

A transporter (VW bus T4) and an the DLR aircraft (Dornier Do 228-101 twin turboprop engine test aircraft; call-sign: D-CODE, length 15.03 m, body height x width 1.8 x 1.6 m, wing span 16.97 m, wheel diam. 0.65 m) were used as research vehicles. The transporter was used to position static objects in predefined distances (250m, 500m and 1000m) on the apron (Fig. 5). The static objects had a diameter of 0.6m and could be a circle or a cross mounted in the center of a square signage with an edge length of 0.7m. Within each run every distance was questioned once.



The target object cross and circle used in the validation excercise.

Figure 5. Static objects were presented in distances of 250m, 500m and 1000m to the camera system

The research aircraft flew predefined scenarios within the aerodrome to create authentic monitoring situations. Two mirrored scenarios were defined and switched between the runs. Each scenario was varied by the order of events that the aircraft should perform while flying the traffic pattern (Fig. 7) 14 times. The aircraft was also equipped with an additional sender to communicate with the experimenter remotely via a research frequency (Fig. 6), to account for unforeseen situations. Besides the research aircraft traffic, additional unplanned traffic could arrive throughout each validation run. This allowed a mixture of scheduled and unscheduled traffic and increases the external validity of the validation exercise.

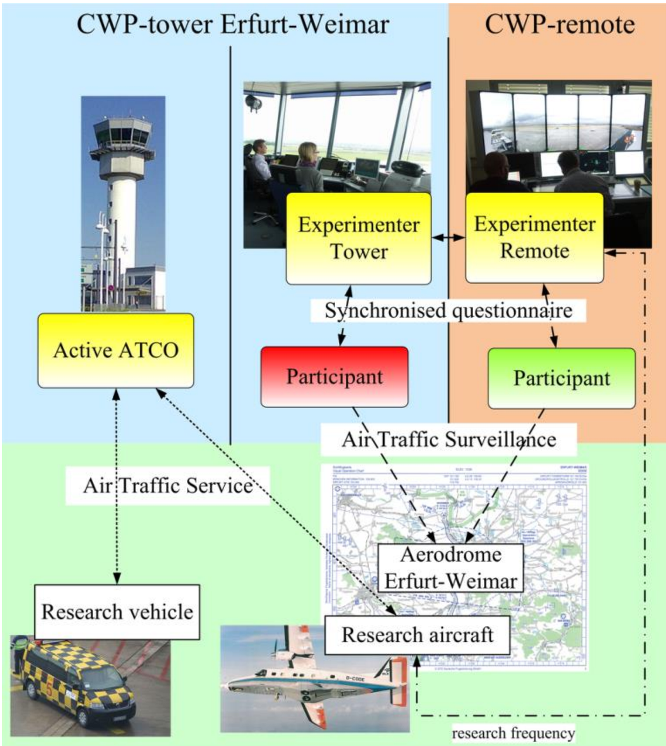



Figure 6. Experimental procedure for comparing CWP-tower and CWP-remote.

For the success criteria described above the most important maneuvers are Declining, Landing Light, and Gear Down. The Decline maneuver was performed at point D (Fig. 7). The research aircraft either declined and climbed about 300ft or not and the participants had to answer if they saw the maneuver or not. The Landing Light maneuver was performed at point G (Fig. 7). The aircraft either switched off their landing lights or not and the participants had to answer which state they could perceive. The Gear Down maneuver was performed before point H1. The aircraft either pulled down its landing gear or not. The participants were asked once per traffic pattern at one of the different distances H1, H2 or H3 (0.5 NM, 1.0 NM, and 1.5 NM before the runway) what the current state of the landing gear was.

The dependent variables within this validation exercise are divided into performance measurements (answers given, response times and sources of information used) and subjective measurements (debriefing questionnaires). The selected performance success criteria (TABLE I) are covered by the answers given and the used source of information, whereas the subjective performance success criteria are covered by questions within the debriefing questionnaire. The used sources of information were subdivided into the panorama (OTW view or Video panorama), the magnification (binoculars or PTZ-camera), the air situational display (Radar), weather information system (WIS), or any combination of these systems. The participants were instructed to name only the system that they used to make their final decision. This means e.g. if they used the video panorama to position the PTZ-camera and then used the PTZ video for their answer the used source of information was the PTZ-camera. The subjective related measurements were covered by a debriefing questionnaire. The debriefing questionnaire used a 6-point Likert Scale (1= totally disagree; 6= totally agree; average of 3.5).

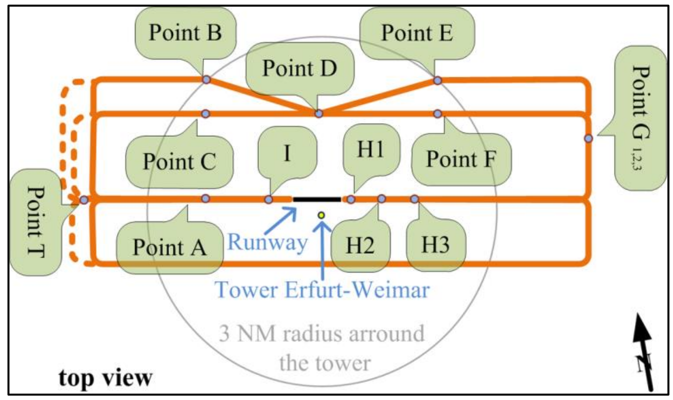



Figure 7. Traffic pattern of the reseach aircraft within the aerodrome Erfurt-Weimar

## D. Procedure

The participants were randomly divided into four groups (two per group). The validation exercise took place from 17th of July until the 20th of July 2012. Every day a different group took part in the exercise. Each group had to complete two trials. For the first trial it was randomly decided which participant worked at the CWP-tower and CWP-remote. Within the second trial the group members always switched workplaces. Besides the two participants an active ATCO was needed for every validation run to ensure the save provision of ATS (Fig. 6). This was necessary because air traffic safety regulations did not allow active control of any traffic within the aerodrome.

Within every day of the validation exercise the procedure was equal. A briefing of the new group was performed and they were instructed about the project and the validation exercise. That was followed by assigning the ATCOs to the different workplaces (Fig. 6). Afterwards a 30 minute PTZ camera training was conducted. Then the first validation run was performed with a duration of about 140 minutes. After that the participants switched workplaces and the second validation run was performed. At the end, a 60 minutes debriefing with a debriefing questionnaire was performed with both participants.

Every validation run started with the research aircraft's first movement away from its apron parking position. The aircraft followed a predefined scenario, while the participants on both workplaces had to answer the same questions addressing the question types from TABLE II. All questions, regardless of the question type, occurred synchronized to generate two comparable sets of answers that differ only in the used workplace. Every question was placed in a dialog between the participant and the particular experimenter. The experimenters read the questions to the participants. The participants used their workplace to collect the answer. Then they replied the collected answer as fast as possible to the experimenter and added their used source of information. The answers from both CWP were combined into question pairs. Question pairs were generated if both participants answered. In addition to this conservative analysis Fürstenau et al. [18] use a different analysis using the signal detection theory and also the answers that were not provided. The questions concerning the aircraft manoeuvers were asked at predefined points within a standardized traffic pattern (Fig. 7, A to T).

## V. RESULTS

This section covers the results for the success criteria presented in TABLE I. A complete list of all results from the SESAR- JU D36 Project 06.08.04 can be found in [15]. The results section is divided into the "Human performance task" and "Safety during shadow-mode trial". Each subsection covers the performance and subjective results.

Throughout the validation experiment a total number of 1326 performance related questions pairs were collected on both CWPs. 936 aircraft manoeuver related questions pairs lead to an average of 117 per trial and an average of 12 completed traffic patterns per run. Fig. 8 shows one traffic circle with the corresponding answer times from both workplaces. The letters in Fig. 8 are equivalent to Fig. 7 and show that the participants answered at different response times but are equal to certain extend. 36 debriefing questions were used to collect the subjective data, at the end of each validation day.

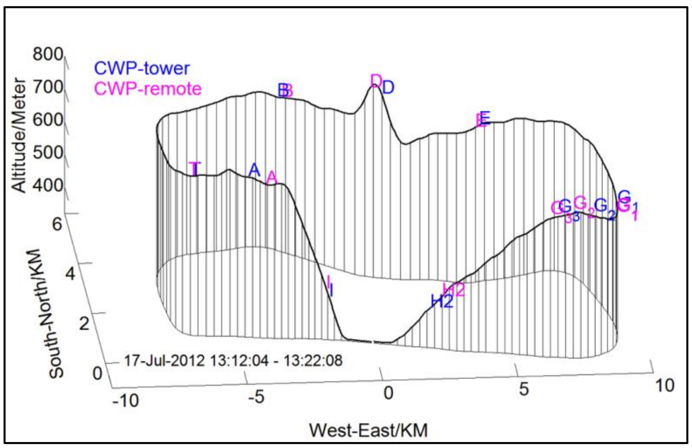



Figure 8. One traffic circuit performed by the research aircraft with Erfurt-Weimar Tower as origin.

### A. Human performance task

#### 1) Perceived visibility at the apron

For this success criterion the ATCOs' answers on the aspect of perceived visibility at the apron were selected from the debriefing questionnaire. The relevant set of items for this success criterion from the debriefing questionnaire is summarized in TABLE III.

TABLE III. ITEMS FOR PERCEIVED VISIBILITY AT THE APRON (SCALE FROM 1-TOTALLY DISAGREE TO 6-TOTALLY AGREE)

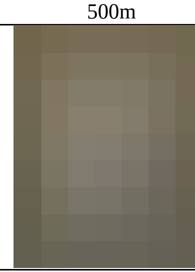
| Item key | Item | Mean | SD |
|---|---|---|---|
| Runway markers | I was able to see all runway markers sufficiently good. | 2.88 | 1.25 |
| Holding points | I was able to see all holding points sufficiently good. | 3 | 1.51 |
| Airfield traffic | The view on the airfield was sufficient to control the traffic safely and efficiently. | 3.38 | 1.60 |
| Apron area | I was able to see the apron area sufficiently good. | 4.37 | 1.06 |
| Taxiways | I was able to see the traffic on all taxiways sufficiently good. | 4.37 | 1.06 |
| | ***Summary*** | ***3.58*** | |

The summary in TABLE III shows that the mean value of the questions is in the positive range of the scale which leads to an acceptance of the success criterion.

#### 2) Detection of static objects

The video panorama data for the static objects was visually examined to specify the image quality. The number of horizontal visible pixels was determined as indicator for image quality. In a distance of 250m a black object on the white signage with an average of ca. 5 pixels could be identified (square signage ca. 10 pixels). This result is similar to the previously presented equation for the sensor optic that would result in a resolution of 3 pixels for an object with 0.5m length in a distance of g = 250m. Nevertheless, the shape of the static objects could not be identified in any case, compare TABLE IV (250m). In a distance of 500m the square signage where the static objects were mounted could be identified six times (N=8) with an average of seven pixels, but the shape (cross or circle) of the static objects could not be identified anymore. In a distance of 1000m the static object could not be identified once (N=8). Given that the participants were also placed 1.8m away from the monitors, the given resolution (video panorama) was not enough do discriminate between cross or circle in any of the three distances.

TABLE IV. EXAMPLE PICTURES OF THE STATIC OBJECTS FOR THE THREE DISTANCES.

| 250m | 500m | 1000m |
|---|---|---|
|  |  |  |

The distances 250m, 500m and 1000m were chosen as independent variables to test the detection of static objects in several steps. For every distance the correctness of the answer was analyzed. TABLE V shows the results for the correct answers. The descriptive data show a reduction of the performance depending on the distance of the static object. For the detection of static objects a nonparametric $\chi^2$ - test was conducted. The results showed no significant difference between the expected and empirical distribution for both workplaces ($\chi^2$ (2) = 0.14, n.s.). This leads to an acceptance of the success criterion.

TABLE V. ANSWERS FOR THE DETECTION OF STATIC OBJECTS

| Distance | Expected distribution of correct answers | | Empirical distribution of correct answers | |
|---|---|---|---|---|
| | ***Correct Answer CWP-tower*** | ***Correct Answer CWP-Remote*** | ***Correct Answer CWP-tower*** | ***Correct Answer CWP-Remote*** |
| 250m | 8 | 8 | 8 | 8 |
| 500m | 7 | 8 | 7 | 7 |
| 1000m | 8 | 8 | 8 | 6 |

In addition to the answers the used source of information was analyzed for both workplaces. Fig. 9 shows the used sources of information by using only the questions correctly answered for each distance. The used sources of information differ for both CWPs. The participants at the CWP-towers show a transition from the panorama for near objects to the binocular in the distance. The participants at the CWP-remote used always the PTZ camera as a source of information.

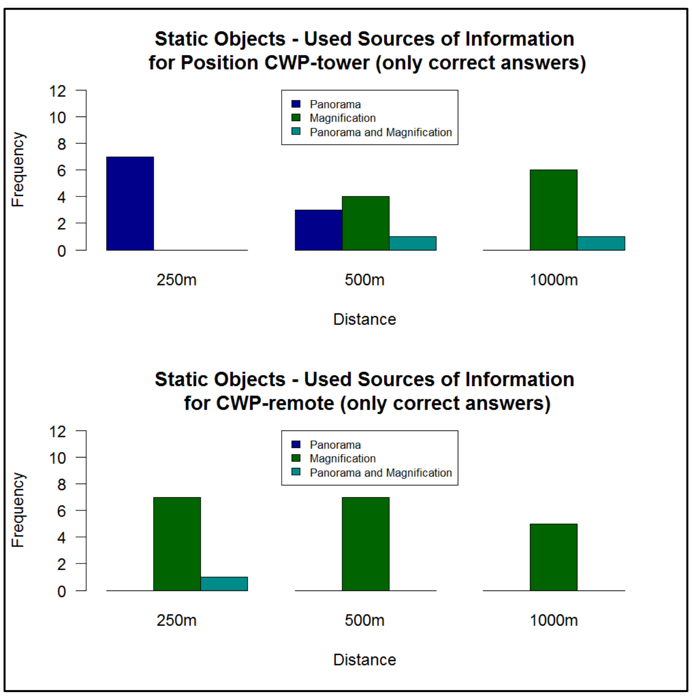



Figure 9. Used sources of information for Static Objects

## B. *Safety during shadow-mode trial*

### *1) Perceived safety during shadow-mode trial*

For this success criterion the ATCOs answers and comments on the aspect of perceived safety in comparison to the CWP-tower were selected from the debriefing questionnaire. The relevant set of items for this success criterion from the debriefing questionnaire is summarized in TABLE VI.

TABLE VI. ITEMS FOR PERCEIVED SAFETY (SCALE FROM 1-TOTALLY DISAGREE TO 6-TOTALLY AGREE)

| Item key | Item | Mean | SD |
|---|---|---|---|
| Traffic | The CWP-remote would allow me to handle traffic at least as safe as the conventional CWP-tower. | 2.25 | 0.89 |
| PTZ | The PTZ camera enabled me to control the VFR traffic as safe as on the CWP-tower. | 2.25 | 0.89 |
| Panorama | The quality of the 200 ° panoramic view supported by the PTZ camera is sufficient to control traffic safely and efficiently conforming to current ATC procedures. | 2.5 | 0.93 |
| CWP-remote Setup | The experimental setup of the CWP-remote with all its necessary functionalities is comparable to a CWP-tower regarding air-traffic control regularities. | 3.25 | 1.39 |
| | ***Summary*** | ***2.56*** | |

The summary in TABLE VI shows that the mean value of the questions is under the average of the scale which leads to a rejection of the success criterion. The additional gathered comments from the ATCOs were categorized into those concerning the video panorama and those in regards to the PTZ camera. The main comments for the video panorama were that the quality of the video panorama was deficient and that the southern traffic circuit could not be monitored. The main comments for the PTZ camera were that the image stability and sharpness should be increased and the liability to wind decreased.

### *2) Detection of safety related manoeuvers*

For this success criterion the participants performance to identify safety related manoeuvers of the research aircraft were analyzed. The maneuvers Declining, Landing Lights, and Gear Down were identified as the most safety related. For each of the three manoeuvers an average of 12 question pairs per trial was gathered and analyzed. These values were used as a direct comparison between the CWP-tower and CWP-remote. The results are presented in TABLE VII.

TABLE VII. ANSWERS FOR THE SAFETY RELATED MANOEUVERS

| Manoeuver | Mean correct answers (SD) CWP-tower | Mean correct answers (SD) CWP-remote | Significant difference (F-test) |
|---|---|---|---|
| Decline | 86.1% (34.9) | 82.4% (38.3) | F(1, 7) = 1.62, n.s. |
| Landing Lights | 83.33% (37.0) | 44.3% (49.37) | F(1, 7) = 40.45, p<.05* |
| Gear Down | 94.32% (23.2) | 94.52% (22.2) | F(1,7) = 0.96, n.s. |

As TABLE VII shows, the participants' answers given concerning safety related manoeuvers of the research aircraft are not significant degraded for the manoeuvers Decline and Gear Down and are significant degraded for Landing Lights. Due to the fact that 2 out of 3 manoeuvers show no significant difference for the performance measures it is concluded that the success criterion is reached. Comments from both workplaces indicated that the position of the landing lights at the research aircraft wasn't easy to identify and that the double negative question lead to irritation.

In addition to the answers the used source of information was analyzed for both workplaces. Fig. 10, 11, and 12 show the frequency for the used sources of information by using only the correctly answered questions. The data in Fig. 10 and 11 is separated by both workplaces and in Fig. 12 also for the different distances (0.5 NM, 1.0 NM, and 1.5 NM before the runway).

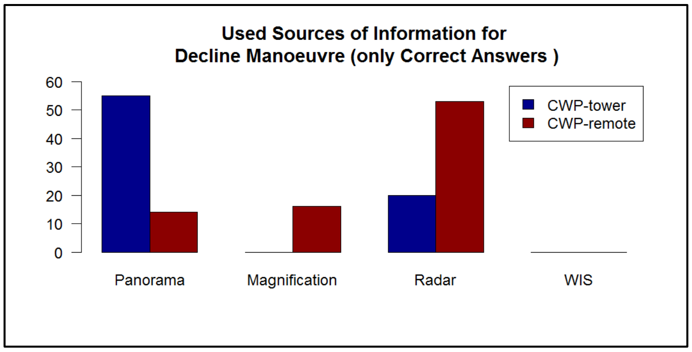



Figure 10. Used sources of information for Decline

The used sources of information for the Decline maneuver (Fig. 10) differs for both CWPs. The frequency for the panoramic view as source of information is higher on the CWP-tower than on the CWP-remote. On the contrary, the frequency for the radar as source of information is higher on the CWP-remote than on the CWP-tower.

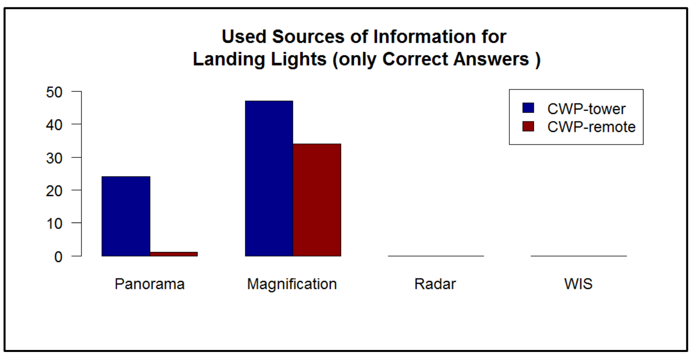



Figure 11. Used sources of information for Landing Lights

The used sources of information for the Landing Light maneuver (Fig. 11) differs for both CWPs. The panorama was only used at the CWP-tower, with only one exception.

The used sources of information for the Gear Down maneuver (Fig. 12) also differs for both CWPs. The participants at the CWP-towers show a transition from the panorama for the near questions (H1) to the binocular in the far questions (H3). The participants at the CWP-remote always used the PTZ camera as the final source of information.

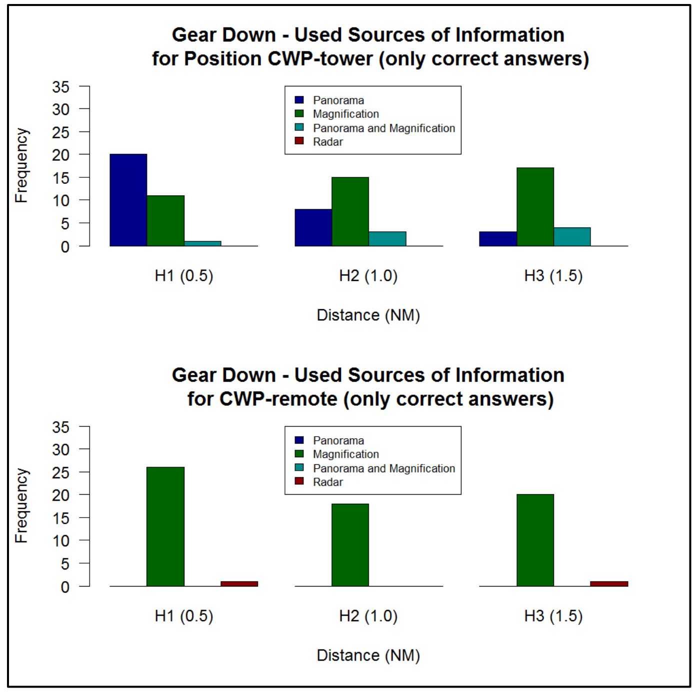



Figure 12. Used sources of information for Gear Down

## VI. DISCUSSION

In the result section, success criteria for the objectives *Human performance task* and *Safety while shadow mode trial* (TABLE I) were presented. The success criteria for both objectives were based on subjective and performance data. The results show that ATCOs' performance at the CWP-remote and CWP-tower were comparable, although the subjective ratings showed significant differences, how the ATCOs perceived the different working environments. It has to be discussed in what way the significant change in applying different information sources at the CWP-remote compared to the CWP-tower can explain these findings.

The data of the field tests reveal that for the current performance level of the remote tower system, the PTZ camera plays a different role for ATS, compared to the binoculars at the CWP-tower. Therefore, also the implications of these results for the refinement and consolidation of functional requirements and specifications for a future Remote Tower System will be worked out.

### A. Validation Objectives and Success Criteria

*Human Performance task:* For this objective the combination of the success criteria' *Perceived visibility at the apron* (subjective data) and *Detection of static objects* (performance data) support each other. The subjective results show that the ATCOs rated the visibility of the apron area positive. The performance results show that there is no significant deviation between the CWP-tower and CWP-remote in the detection rate of static objects in different distances on the apron area. This depended mainly on the resolution of the video panorama. Even so, the sensor system would arithmetically provide the information, additional influences as contrast, image processing and lighting can only be determined by an experimental validation. To overcome the limited quality of the video panorama, the magnification was used more frequently at the CWP-remote. In some cases, the ATCOs at the CWP-tower relied only on the OTW view to answer these questions. The data support the point of view that, although ATCOs used the magnification to verify specific information within the apron area, this approach was satisfying for information within the apron area.

*Safety during shadow mode trials:* For this objective the results of the performance and subjective success criteria on *Perceived safety* and *Safety related maneuvers* are different. While the performance data show that there is no significant difference for the recognition of safety related maneuvers on both workplaces, the subjective data show that the ATCOs rated the *Perceived safety* at the CWP-remote as not sufficient to provide safe ATS, in comparison to the CWP-tower. The data indicate that the CWP-remote includes system components which enable the ATCOs to collect the information derived from the pre-defined functional requirements. However, the ATCOs' ratings on P*erceived safety* indicate that the suggested solution to get the information about flight manoeuvers is not satisfying. One explanation for these findings can be that the Remote Tower System provides the ATCO with sufficient information, but the ATCOs have to relearn, that information at the CWP-remote is gathered differently. An alternative explanation for the results is that the performance criteria do not cover the functional requirement exhaustively. For an increase of the ATCOs' *Perceived safety*, in the future a higher transparency about the information sources at the CWP-remote will be necessary, explaining which information sources are accepted to verify certain system states within the ATCO's airfield of responsibility.

### *B. Implications for the consolidation of functional requirements and specifications for Remote Tower Systems*

In the introduction it was worked out that the experimental set-up of this validation exercise can provide performance and subjective data to sharpen the requirements and to consolidate the specifications for a future Remote Tower System. The performance data provide objective data about which information was successfully provided by the CWP. In addition, the ATCOs' answers on the questionnaire items provide their subjective rating and therefore the ATCOs' perspective on the maturity of the Remote Tower System. For sharpening the functional requirements both data sources are of relevance. The performance data provide objective data which performance was possible when the ATCOs interacted with the Remote Tower System under research. Such data provide a good starting point for the further definition of quantitative system performance requirements within the validation cycle. In addition, subjective data provide ATCOs' ratings which are not only influenced by the system characteristics, but also by the users' characteristics and their background [13]. If the explanation for these poor rating is that the Remote Tower System does not provide sufficient information to the ATCOs it must be thoroughly checked whether an additional functional requirement can be defined which can address such a shortcoming.

The functional requirements ask for a definition, which information an ATCO needs, independent of the technical system. Within this field study performance data indicate that in general the Remote Tower System can provide the information defined by the functional requirements. However compared to the CWP-tower, the ATCOs working at the CWP-remote utilized different information sources to complete the field trials. This finding indicates that beside the functional requirements, system and technical requirements must define in more detail which subsystem of a future remote tower system will provide the information to fulfill the functional requirements. For example, for the subsystem live video panorama, the technical requirements must define explicit which performance is provided by a live video panorama and therefore the ATCOs know, which aircraft type (size) is visible, in which distance to the aerodrome. Van Schaik et al. [8] suggested a theoretically motivated formula to calculate the required resolution for the video panorama, however this resolution has not been validated.

Also the verification and validation of such technical/system requirements is out of the scope of this paper, the suggested methodological approach (including research aircraft, video recordings, GPS data) can provide valuable data for verification and validation of such technical requirements, but has not been accomplished or published so far.

With increasing maturity of the remote tower validation phases (V1-V3), also the technical and system requirements will be defined. A consolidation of these technical requirements will increase the transparency in what way working at a future CWP-remote will differ from working at a CWP-tower. It is expected that this transparency elicits a strong positive impact on ATCOs' *perceived safety*, when working at a CWP-remote in future field trials.

## VII. Conclusion and Outlook

In line with the results of the accomplished validation exercises [9] under the OFA Remote Tower, the results of this validation exercise provide an additional step for the remote tower concept validation, based on a live-video panorama. The paper focused on the functional requirements rather than the conventional engineering approach for system verification. The study also shows that performance data is needed to support the subjective data results or show new perspectives to evaluate the subjective data. After addressing the feasibility of the concept (V2) within this exercise, V3 validation activities center on system integration, for which the consolidation of the operational concept and the prototype system is the main goal.

## Acknowledgment

The activities developed to achieve the results presented on this paper were created by SESAR Lot 1 activity (SJU/D/12-446 study) for the SESAR Joint Undertaking within the frame of the SESAR Program co-financed by the EU and EUROCONTROL. The opinions expressed herein reflect the authors' view only. The SESAR Joint Undertaking is not liable for the use of any of the information included herein. The experimental set-up was contributed by DFS and DLR. The authors thank the ATCOs for participating in the field trial and the system matter experts from the DFS for their input on the study. We would like to express our greatest gratitude to the people who have helped and supported us throughout the validation. We are grateful to all the technicians that developed and implemented the CWP-remote. Special thanks go to Markus Schmidt, Michael Rudolph and Tristan Schindler for design and experimental setup, Anne Papenfuß and Nils Carstengerdes for their experimental input, Norbert Fürstenau for the financial vision, Monika Mittendorf for her help with data analysis, Andreas Grüttemann for his expertise in capturing flight path data and the department for flight experiments.

## REFERENCES

[1] N. Fürstenau, M. Schmidt, W. Halle, and M. Rudolph, "Internal Report - RAiCe Projektplan , IB 112-2008/09," 2008.

[2] M. Schmidt, M. Rudolph, B. Werther, C. Möhlenbrink, and N. Fürstenau, "Development of an augmented vision video panorama human-machine interface for remote airport tower operation," in *Human Interface and the Management of Information. Interacting in Information Environments*, 4558th ed., pp. 1119–1128, M. J. Smith and G. Salvendy, Eds. Berlin, Heidelberg: Springer, 2007.

[3] N. Fürstenau, M. Schmidt, M. Rudolph, C. Möhlenbrink, A. Papenfuß, and S. Kaltenhäuser, "Steps Towards the Virtual Tower: Remote Airport Traffic Control Center (RAiCe)," Proceedings ENRI Int. Workshop on ATM/CNS, vol. 1, no. 2, p. 14, 2009.

[4] C. Möhlenbrink, M. B. Friedrich, and A. Papenfuß, "RemoteCenter: Eine Mikrowelt zur Analyse der mentalen Repräsentation von zwei Flughäfen während einer Lotsentätigkeitsaufgabe," Tagungsband 8. Berliner Werkstatt Mensch-Maschine-Systeme, p. 6, 2009.

[5] S. R. Ellis, N. Fürstenau, and M. Mittendorf, "Determination of Frame Rate Requirements for Video-panorama- based Virtual Towers using Visual Discrimination of Deceleration during Simulated Aircraft Landing : alternative analysis," BWMMS 9, pp. 519–524, 2011.

[6] C. Möhlenbrink, A. Papenfuß, and J. Jakobi, "The Role of Workload for Work Organisation in a Remote Tower Control Center," *Air Traffic Control Quarterly*, vol. 20, no. 1, p. 5, 2012.

[7] S. Security, "Remotely Operated Tower -The Future of Being Present," 2008. .

[8] F. J. van Schaik, G. Lindqvist, and H. J. M. Rössingh, "Assessment of visual cues by tower controllers.," 11th IFAC/IFIP/IFORS/IEA Symposium on Analysis, Design, and Evaluation of Human-Machine Systems, p. 19, 2010.

[9] S. R. Ellis and D. B. Liston, "Visual features involving motion seen from airport control towers.," 11th IFAC/-IFIP/IFORS/IEA Symposium on Analysis, Design, and Evaluation of Human-Machine Systems, 2010.

[10] D. Hannon, J. Lee, M. Geyer, S. Mackey, T. Sheridan, M. Francis, S. Woods, and M. Malonson, "Feasibility Evaluation of a Staffed Virtual Tower," *Journal of the Air Traffic Control Association*, pp. 27–39, 2008.

[11] F. Friedman-Berg, "Staffed Next GenTower Human-in-the-Loop Camera Integration Evaluation," 2012.

[12] Committee sesar program, "Overview and Release 1 Plan v1.0," no. December, pp. 1–60, 2010.

[13] European Organisation for the Safety of Air Navigation, "E-OCVM v3. Volume II," 2010.

[14] C. Möhlenbrink, M. Rudolph, M. Schmidt, and N. Fürstenau, "Wahrnehmungsexperimente im RApTOr Demonstrator.," 2. RTO-Workshop, Poster presentation, 2007.

[15] M. Friedrich, C. Möhlenbrink, and N. Carstengerdes, *SESAR- JU D86 Project 06.08.04 - Single Remote TWR Ph1 V2 - Validation Report*, 00.01.00 ed., p. 65. Brussel: , 2012.

[16] C. Mullan, G. Lindqvist, and T. Svensson, "SESAR-JU Project 06.09.03 - Remote Provision of ATS to a Single Aerodrome - Validation Plan," SESAR, Brussel, 2012.

[17] C. Mullan, G. Lindqvist, T. Svensson, M. Abel, and P. Ankartun, "OSED for Remote Provision of Air Traffic Services to Aerodromes, including Functional Specification for Single & Multiple aerodromes," Brussel, 2012.

[18] N. Fürstenau, M. Friedrich, M. Mittendorf, M. Schmidt, and M. Rudolph, "Discriminability of Flight Maneuvers and Risk of False Decisions Derived from Dual Choice Decision Errors in a Videopanorama-based Remote Tower Work Position.," in *Human Computer Interaction HCI International 2013: Engineering Psychology and Cognitive Ergonomics*, Springer Lecture Notes Computer Science, Ed. Las Vegas, NV USA: Springer, Berlin, Heidelberg, New York, 2013.

## AUTHOR BIOGRAPHY

**Maik B. Friedrich** was born in Schmalkalden on the 8th of November 1981. He studied computer science at the technical college in Schmalkalden and applied computer science at the Otto-Friedrich University in Bamberg. He earned a Dipl. Inf. (FH) at the Computer Science department from the technical college in Schmalkalden, Germany in 2006. He also earned a Ma. Sc. at the Computer Science department from the Otto-Friedrich University in Bamberg, Germany in 2008. His major field of study is cognitive modeling in the area of air traffic control.
He works within the DLR research group Remote Tower and in the domain of airport airside traffic management with the focus on concept operations and validation. Since 2008, he has been running software simulations and coordinating operational exercises at diverse research projects, like RAiCe or RAiCon. Validating concepts of remote surveillance is a major part of his work, especially in the VICTOR project funded by Iport. Since 2010 he works together with the local ANSPs TTC & DFS in the field of remote Tower operations.

**Dr. Christoph Möhlenbrink** got his M.A. in psychology from the University of Konstanz, Germany in the year 2005. In 2011 he received his PhD from the mechanical engineering faculty of the Technical University of Braunschweig, addressing human-machine modeling and heuristic decision making.
Since 2006 he is a research fellow at the Human Factors Department, Institute of Flight Guidance, Braunschweig Germany.He was involved in the remote tower projects RapTOr (Remote Airport Tower research, 2005-2007) and RAiCe (Remote Airport Traffic Control Center 2008-2012). Christoph is interested in understanding controllers' and pilots' behavior at work, modeling interactive behavior, and eye-tracking research.
Christoph Möhlenbrink is member of the Human Factors and Ergonomics Society Europe.