EDUCATIONAL BENEFITS OF 3D DISPLAYS IN EARLY CONTROLLER TRAINING

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Abstract

There have been many attempts to exploit three-dimensional displays in Air Traffic Control where it has long been suspected that the 3D display may help to reduce the cognitive load on the controller by removing the need to construct an elaborate mental model of the air space and the traffic contained within it. 3D displays could allow the controller to simply re-interpret the presented information in real time without the need for them to construct this internal model and without the need to remember large amounts of complex information. This should result in controllers being able to manage larger numbers of aircraft without loss of safety, as well as reducing the pressure on controllers allowing for longer work sessions with less problems of mental fatigue.

The purpose of this study has been to explore the use of 3D in controller training and, in this initial study, to examine the basic reaction of the controllers to 3D representations and the effects, if any, which the introduction of 3D has on their work.

1 Introduction

The work of an air traffic controller is centred around the interpretation of complex four-dimensional data displayed through a two-dimensional representation, the radar display, supplemented by additional information in the form of the flight tag which provides details including the flight's identity, speed, altitude, and any navigational changes in progress. From this information the controller is required to understand the situation in terms of a four-dimensional scenario with aircraft moving in a complex three dimensional space. The process by which controllers learn to interpret the '2.5D' information with which they are presented, and form the 3D understanding of the airspace which they need to conduct their work is a complex process which is generally not well understood.

In recent work [11] a study has been conducted with student controllers and trainers to examine the nature of the 3D understanding which the students develop, the way in which the information is presented to them, and the means by which they are trained to interpret the data. The conclusions from that study are that the training is based around scenarios which enable them to learn to manage the 3D aircraft but they are not explicitly trained in the interpretation of the 3D data from the 2.5D display. This is left as a skill which they acquire in a unique and personal way, leaving each with a possibly very different way of understanding the 3D structure of the airspace.

In the work described in this paper we conduct a pilot study which attempts to examine the effect of the 3D display on the way in which trainee controllers react to the flight information, interpret it, and plan their interventions.

2 Related Work

3D displays is an area which has long been thought might have benefit for Air Traffic Control with studies going back at least to the 1980s but few conclusive results have been found where 3D is shown to be superior due, primarily, to the complexity of the problem under study. One of the first studies performed was a survey [4] which indicated that ATCOs tended to prefer 3D perspective displays for “extracting immediate spatial situational and directional information”. Two contemporary studies, however, comparing 2D and 3D displays across tasks involving terrain scenarios [16] and tasks based on weather avoidance [15], found that 2D displays had several benefits in terms of speed. Two other similar studies [12, 14] found few differences between three display formats (2D planar, 3D perspective, and 3D stereo-perspective) across different ATC tasks. Specifically they found a higher error rate in the perspective display for speed estimation, slower heading judgments for the stereo display while the planar view was fastest, but no differences between them for the task of conflict detection. As might be expected, tasks involving purely planar features, such as judgement of the azimuth angle and lateral distances, have been found [3] to be more quickly resolved using 2D displays than 3D. Another study of ATC related tasks [13] discovered that, while performance with 2D was as good as or better than with 3D, that 3D displays seemed particularly well-suited to tasks involving “perceiving complex, dynamic information relationships in a confined 3D space”. Focussing on tasks of this nature, a comparison between 2D and 3D stereoscopic display across an altitude judgment task [10] showed that both controllers and ATC connoisseurs performed quicker with the 3D display, but no differences were found for accuracy.

One feature of many of the studies which are carried out is that the test subjects are experienced ATCOs, a group who are known to have developed techniques to assist them in the interpretation of 2D representations of 3D flight information. Hence they may not form the ideal test candidates for such experiments. Indeed, in the few studies involving both air traffic controllers and pilots, the latter group having plenty of experience in the 3D realm but less of the 2D, it has been noted that the relatively slow speeds associated with 3D were more likely to emerge with experienced ATCOs than with pilots [14].

3D does, however, possess some inherent problems for the ATC task such as the fact that ATC tasks may require precise distance judgments which can be affected by perceptual bias due to perspective effects as seen in [2]. This effect is seen in several of the studies mentioned above and is explored further in [5] which considers tasks that exploit information over several dimensions and those requiring focused attention on a single source, with the conclusion that 3D perspective displays may be effective “whenever the tasks to be performed using the display are integrated three-dimensionally”. Similarly the study conducted in [6] concludes that 3D views are most useful “for tasks that require understanding the general shape of 3D objects or the layout of scenes” while 2D is mostly suitable for tasks that “require judging the precise distances and angles between objects”.

Training is envisioned as a promising area of application for 3D where the potential users are not already trained in the use of 2D displays and have not acquired the required techniques to enable them to interpret the 2D radar display as easily. Several studies have been carried out exploring the potential of this area including [8, 17, 9, 11] which support the idea of 3D as an aid for preparing trainees for real ATC tasks. Similarly ATC trainers who have seen the 3D stereoscopic environment for ATC developed during the ongoing collaboration between Linköping University and Eurocontrol Experimental Centre [1, 7], have commented that 3D representations could enhance controllers’ training as they are similar to the constructed mental models that the trainer wishes the trainee to develop. This is the focus of this preliminary study and we hope to expand upon it with future experimental work in this area.

3 Experiment

To test the the effect that the 3D display has on the controller’s understanding and actions within the ATC problem we have performed an exper-

Fig. 1 2D view on a scenario.

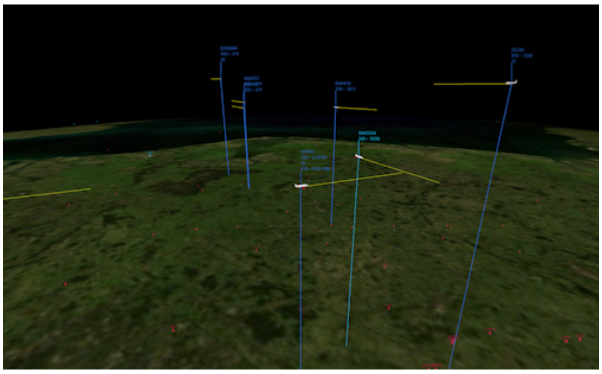

Fig. 2 3D view on a scenario.

iment to compare two versions of a 3D simulator display which we have developed. In one the view is constrained to a top down view, thereby providing a 2D display very similar to that which all ATCO's will recognise, and one where this constraint is removed allowing the controller to freely rotate the view through 360 × 90 degrees around a focal point. The focal point can be set by the user but is typically the centre of a sector (which was the initial position for our experiment) though sometimes the user may change it to focus upon a particular flight which is of interest, or to a particular part of a sector where interesting events are occurring. Example views of the 2D and 3D display are shown in figures 1 and 2.

The software system was designed to display the data in a manner quite similar to that used in the simulator with which the trainee controllers who were our test subjects, and to use as similar an interface as could be managed considering the requirement that 3D display be available. Instructions to flights were entered using a mouse-based interface supplemented by a few keyboard shortcuts, allowing them to instruct flights to turn left or right onto new headings, change flight level up or down, or modify rates of climb and descent within aircraft tolerances. The mechanisms by which commands were issued to the simulated aircraft were very close to the simulator so that the test subjects would find it quite easy to transfer to this test equipment with minimal practice required and few problems were noted during the experiment. Flights would respond to the instructions with a simulated delay for pilot action which was variable and random but lay in the range of 10-30 seconds to mimic the behaviour of a real pilot. This was similar to the behaviour used in the ATC simulators used in the training programme although the flight behaviour in the test system was less accurately modelled.

The software system did have two features which were different from the simulator system which the trainees were used to, however, and these were noted (and criticised) by the test subjects. The system did not permit the rotation of the flight labels (tags) around the flight so there was a slight problem of cluttering caused by the labels. Several of the trainees noted this problem but said it was not a serious impediment. The second feature was the way in which the measurement tool was implemented which performed a similar function in the test system as the trainees simulator: to allow the user to measure the distance from a flight to an event (such as a meeting with another flight and so predict the time to arrival of the flight, helping them in predicting when to make alterations. The interface for this was slightly different in the test system, and the test subjects regarded it as less intuitive and more cumbersome. Again the subjects did not regard it as a serious impediment but both of these features will be addressed in future incarnations of the test system.

It is important to note that the system under test did not employ any stereoscopic three-dimensional representation. The system can support such display but this was not the focus of this experiment and so it was not used in this case.

3.1 Experimental Design

To test the two visual representations a between-groups cross-over design was used. Two training scenarios were selected from the standard set used at the Eurocontrol training centre (IANS) in Luxembourg. The scenarios were based around the Maastricht area, which was a region familiar to the trainees from their prior simulator work. The scenarios were slightly modified to ensure that they contained qualitatively similar situations which the trainees would be required to resolve, but with the events reordered and in different orientations to ensure that no learning of the scenarios could be carried from one trial to the next. Half of the test subjects used the 3D system first, and half the 2D system. The other half used 2D first and then 3D. The participants were assigned randomly to the two orders.

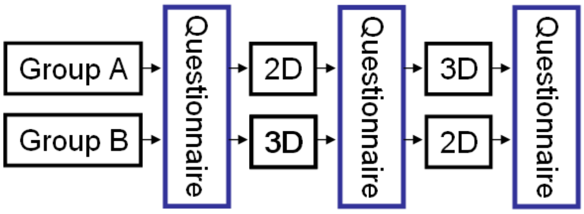

Fig. 3 The cross-over experimental design allows all subjects to trial both software platforms using different scenarios.

3.2 Participants

Our test participants were all trainee controllers in the initial stages of their training. The class available to us was quite small with just 8 subjects available, 7 men and 1 woman. They were aged between 20 and 24 years of age (median 21), and had received between 5 and 6 months of training (median 6) including approximately 100 hours of simulated practical ATC work. They were asked to participate in the experiments voluntarily, receiving no reward for participation, and were aware that participation in the experiment would not affect their training programme in any way but, since they had been asked by their trainers to participate they can be assumed to have been participating with some feeling of duty to give best performance. None of the trainers were present during any of the trials, the experimental staff being from outside the training programme and previously unknown to the test subjects.

	None	Some	A lot
3D CG training	3	3	0
3D CG programming	8	0	0
3D design packages	6	2	0
‘First Person’ 3D games	1	1	6
‘Third person’ 3D games	2	2	4

Table 1 Relative 3D computer graphics experience of the test subjects.

A consideration in the experiment was the familiarity of the test subjects with three-dimensional computer graphics systems and so a component of the pre-experiment questionnaire was designed to cover this aspect of their previous experience. These results are shown in table 1.

None of the subjects had much experience of the technical aspects of 3D computer graphics, just a small number of them having used design packages or applications and none having done any computer graphics programming. In contrast most (all but one) were at least familiar with 3D games, many of them being avid players. The most pertinent of the figures is the number of test subjects who had experience with ‘third person’ 3D games, since this is the environment which most closely mimics the software system which formed the basis for this experiment.

3.3 Experimental Conduct

Each participant arrived for the test period with a one hour slot allocated to them. They were first asked to complete the preliminary questionnaire and were asked to sign a release permitting the use of video and audio recording of the experimental trial. None of the test participants was unwilling to do this.

The experiment commenced with the subject first allowed a period of time to familiarise themselves with the tool, using a scenario unrelated to the trial scenarios. They were allowed to explore the system until they were happy that they were aware of the features system and how to use it and were permitted to ask questions freely during this phase which lasted between about five and eight minutes.

The subject then carried out the first trial using either the 2D or 3D system depending on their assignment to group. The sessions were recorded using a static video camera and table-mounted microphone. The display was a standard 20 inch LCD monitor placed about 40 centimetres from the participants eye-point and raised to be approximately level with their view. The experimenters were present in the room during the trials to observe any unexpected behaviour or incidents but the subjects were not permitted to ask questions. Some did make comments on the system to the experimenters during the trial but most worked silently, focussing on the tasks at hand.

After the first trial the subject was asked to complete a questionnaire regarding their experience with that version of the system (2D or 3D) and then asked to perform a second trial using the other representation, with a similar familiarisation period being performed first. The second trial proceeded as before and was followed by the third and final questionnaire and a general discussion to allow the subjects to express any particular features or problems they had noted with either visual representation or either scenario.

Each trial lasted approximately 22 minutes and so the total time for each experimental subject was less than 1 hour.

3.4 Data Gathered

In addition to the three questionnaires gathered from each participant and the video and audio recording of their performance the system automatically logged all events (instructions to the flights) entered by the participants during the trials, as well as the trajectories followed by the flights themselves. Thus the system is capable of playing back all of the trials precisely as they were conducted by the participants. This has allowed a detailed comparison between the two visual representations comparing specific flights and how they were handled, as well as identifying some features which are different in the way in which specific participants resolved specific problems when using the 2D and 3D representations. In this way we have attempted to resolve whether there were any substantial differences in the way in which 2D and 3D information is being perceived and whether or not the controllers were better able to identify and resolve problems within one or other of the representations.

The small sample size, with just eight participants, four per group, means that the statistical results have not proven to be significant, unfortunately, but the qualitative results are most interesting and do indicate differences between the two representations.

4 Results

The results gathered are quite detailed and permit for a very precise qualitative analysis of the behaviour of the controller trainees who were our participants in the study. We first consider the complete data for the 16 trials as a display of the instructions sent by the controllers in each case. These are included in figures 6–9, at the end of this paper, which show the 2D and 3D representations for four trials of scenario A and four trials of scenario B , respectively.

Comparing first the A scenarios we can see an immediate difference between the numbers of instructions sent by the test subjects using the 2D and 3D representations. It is very clear that in three of the four trials the subject using the 3D representation was able to resolve the problems presented within the scenario using far less instructions to the flights involved. The tabulated results are shown in tables 2 and 3. There is a substantial outlier, using more than twice as many instructions to complete the scenario than any of the other three. This was partly due to a tendency to use many DCT instructions (a feature which this subject also exhibited in the 2D trial where they used more DCT's than the other subjects) but also was simply due to this subject using more flight level requests and using more than

Subj.	CFL	HDG	DCT	Speed	VRC	Total
1	13	9	6	0	4	32
3	14	7	4	0	0	25
5	9	6	6	0	0	21
7	15	10	6	0	0	31
AVG	12.75	8.00	5.50	0.00	1.00	27.25

Table 2 Instructions from subjects using the 2D representation for scenario A.

Subj.	CFL	HDG	DCT	Speed	VRC	Total
2	13	13	9	0	0	35
4	10	3	3	0	0	16
6	9	2	4	0	0	15
8	7	2	6	0	0	15
AVG	9.75	5.00	5.50	0.00	0.00	20.25

Table 3 Instructions from subjects using the 3D representation for scenario A.

Subj.	CFL	HDG	DCT	Speed	VRC	Total
2	5	4	9	0	0	18
4	4	6	7	0	0	17
6	5	1	1	0	0	7
8	7	2	6	0	0	15
AVG	5.25	3.25	5.75	0.00	0.00	14.25

Table 4 Instructions from subjects using the 2D representation for scenario B.

Subj.	CFL	HDG	DCT	Speed	VRC	Total
1	5	1	3	0	0	9
3	3	14	6	0	0	23
5	3	4	9	0	0	16
7	5	14	7	0	0	26
AVG	4.00	8.25	6.25	0.00	0.00	18.50

Table 5 Instructions from subjects using the 3D representation for scenario B.

four times as many heading changes. This indicates that this subject may not have had such a clear awareness of the flight situation as the other three subjects and may have been making repeat or contrary instructions to the flight. A similar situation is seen in the analysis of the cases in scenario B where two of the test subjects exhibit similar behaviour.

In scenario B the change between the representations is reversed, with the subjects using the 2D system sending less instructions than those with the 3D representation. This can clearly be seen from the figures shown in tables 4 and 5 where the average number of instructions used by the test subjects in the 3D case is thirty per cent higher than in the 2D case. A close examination of the tracks for these trials, as seen in figure 9, shows that the main source of the increased number of instructions is that two of the subjects, 3 and 7, became very confused with respect to one flight (KLM8644) and made repeated heading changes with respect to this flight: 10 and 11 heading changes over 6 minutes for this flight, respectively. It remains unclear why these two subjects became so confused with respect to this flight, whose potential conflict problems were resolved by the other two subjects using a total of just 4 and 5 instructions, respectively. This large, and very surprising variability underlines the need for a much larger study so that variations of this kind can be analysed more thoroughly, outlying results made more apparent, and possible sources of the problem identified.

Considering some specific cases is also interesting. Each scenario included a number of specific problems which had to be resolved. Examples included two aircraft which entered the sector separated by altitude and had to have their relative heights reversed before leaving the sector, or two aircraft which entered the sector on a collision course and who had to be made to pass safely through some separation (altitude or lateral displacement). We can examine the instructions sent to specific pairs of aircraft and examine how the subjects approaches to the problems were affected by the 2D and 3D representations.

One example is the case in Scenario A where two flights, having call-signs NWA64 and AZA662, are entering and must have their altitudes reversed, NWA664 entering above and leaving below AZA662. This problem requires heading changes to maintain lateral separation of the two flights, changes in flight level and then more heading changes to bring them back on course. The instructions for 2D and 3D scenarios are as shown in figure 4.

The instructions issued by the test subjects are clearly different, with many more instructions being given by those using the 2D representation (39 in total) than in the 3D case (26 in total). The breakdown in the types of instructions is also informative: In the 2D case 13 changes in flight level and 18 of heading are made, while only 15 and 10 are required in the 3D case. This indicates that the problem is being solved using more altitude-related thinking and less lateral but this small pilot study is not able to make any definitive statements on this matter.

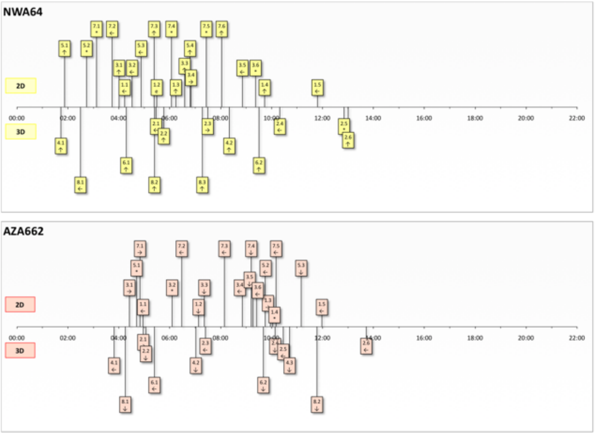

Fig. 4 Reorganization of flight levels between two flights in 2D and 3D scenarios.

4.1 Qualitative Impressions

After each trial the test subjects were asked for a number of impressions of the 2D or 3D system which they had just used to compare their various impressions. A four point Likert scale was used to compare the subjects' opinions with results as shown in figure 5. The results show, as might be expected, that the 3D representation was found to be a little more difficult to work with from two particular respects: that lateral separation of flights was more difficult to identify and that orientation was more difficult to maintain. This had a knock-on effect in that interpreting the flight information and maintaining situational awareness were seen as slightly more difficult, although the latter could be attributed to a lack of familiarity with the systems. Certainly some of the subjects seemed perfectly at ease in the 3D display while some were less so, with one subject spending the majority of the 3D trial with the viewpoint rotated to view the scene as a 2D display. One area which showed a slight improvement over the 2D was in the identification of vertical separation which received a slightly higher average score. One test subject, who gave very low scores to almost all of the questions in both the 2D and 3D cases was very unhappy with the interface since it was not identical to the one which was being used in the training programme simulators. This subject found the changes, although considered minor, between the simulator and the test 2D representation very difficult to adapt to and so graded both systems poorly.

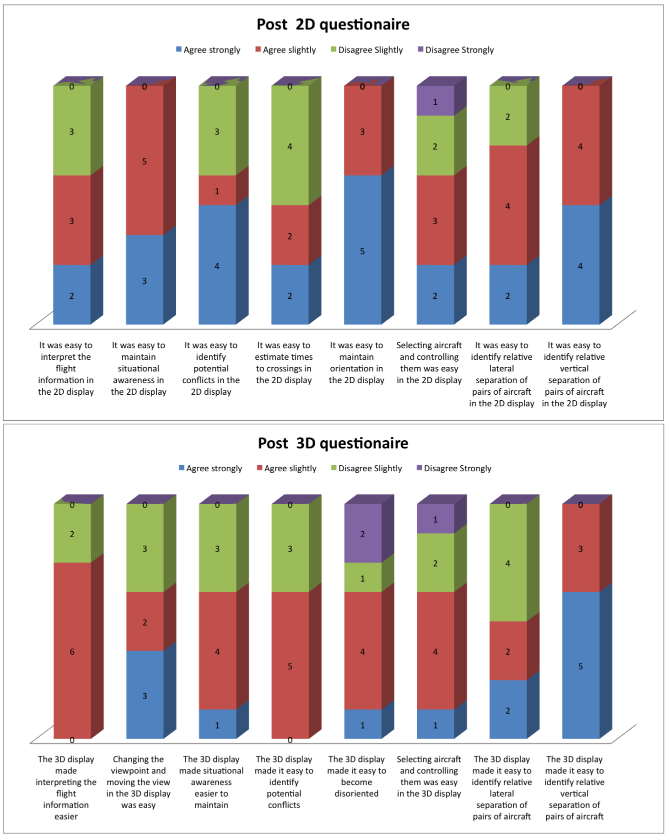

Fig. 5 Summary of post-2D (top) and post-3D (bottom) questionnaires.

5 Conclusions and Future Work

Overall this pilot study has not generated the definite results that were anticipated for a number of reasons. First the variability in the way in which the trainee controllers dealt with the various problems included in the scenarios was quite unexpected. The scenarios included standard problems, taken straight from the training programme within which they were participating, and to which standard approaches were expected but many of the trainees responded in different ways, producing substantially different solutions (although only one, using the 2D representation, resulted in a brief loss of separation of two flights). This high level of general variability has made it very difficult to identify the variation in controller behaviour between the 2D and 3D scenarios indicating that a much larger study is called for.

Secondly we have noted that the two scenarios (A and B), which were designed with the intention of producing very similar behaviours from the test subjects, were reacted to quite differently. The majority of the subjects found the B scenario significantly simpler to resolve, except for the two test subjects who became very confused with respect to one flight producing a large increase in the total number of instructions issued during the scenario. This, again, has made it very difficult to identify variation between the 2D and 3D scenarios and, again, indicates the need for a study based on a much larger number of subjects.

The 3D representation does appear to provide some potential benefit, the more complex scenario being resolved substantially more easily by most of the test subjects. It clearly also has the power to confuse, however, with the example of two controllers becoming very confused with respect to the lateral separation of one specific flight and using huge numbers of instructions to deal with a simple situation.

Acknowledgements

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Fig. 6 The four 2D trials of scenario A.

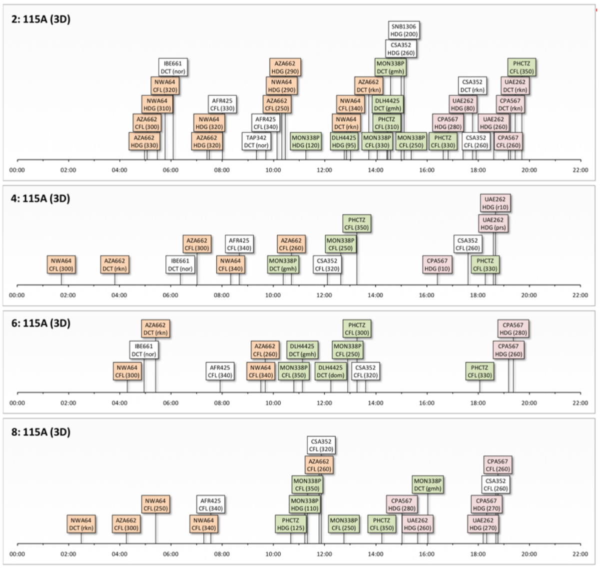

Fig. 8 The four 3D trials of scenario A.

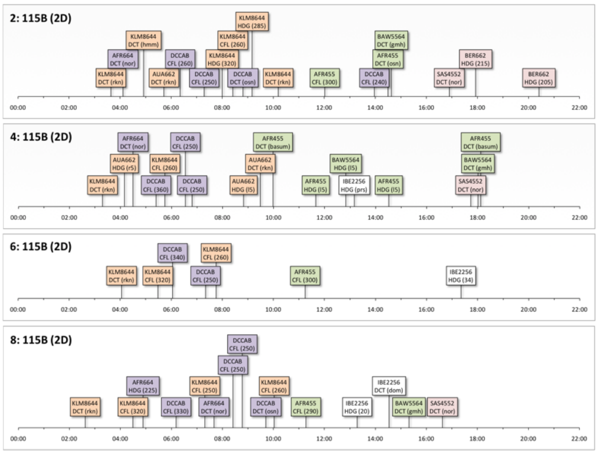

Fig. 7 The four 2D trials of scenario B.

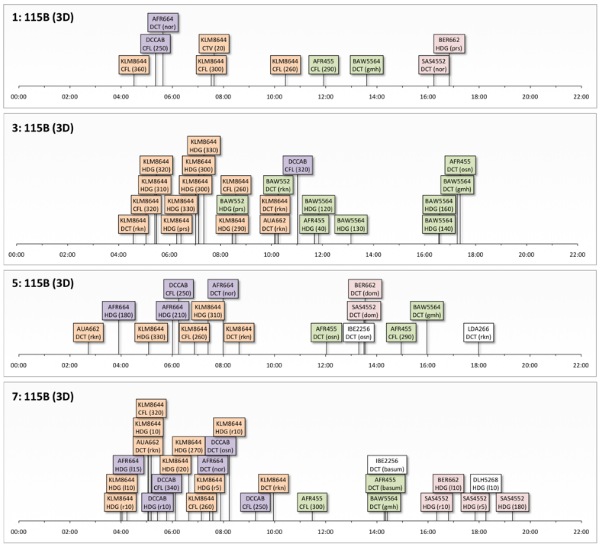

Fig. 9 The 3D trials of scenario B.