Human-Centred Innovation: Developing 3D-in-2D Displays for ATC

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***Abstract*—User-Centred Design is extremely useful for improving existing tasks and technologies, however it is less useful for innovation. This paper documents User-Centred Innovation and how it was implemented in the Air Traffic Control domain.**

Keywords-User-Centred Innovation, Air Traffic Control, Augmented Reality

I. INTRODUCTION

Human operators will continue to be a major component of air traffic control (ATC) for the foreseeable future. As such, the efficiency and safety of any future ATC system will depend on both the technology developed and the ability of humans to harness that technology. The 3D-in-2D Displays for ATC project is intended to create visualisation tools for air traffic controllers as they face new challenges presented by future ATM programs such as SESAR (Single European Sky ATM Research). The time frame for the realization of these new technologies is 20 to 25 years in the future.

It is difficult to predict work and operational requirements so far into the future with a high degree of certainty. At the time of writing, even the operational concept for SESAR is less than well articulated, although it is clear that the basic ideas underlying SESAR will be fundamentally different from current practice. For example, concepts such as the Reference Business Trajectories and Controlled Time of Arrival within the context of the SWIM (System-Wide Information Management) system network, together with advance on-board avionics, will be integrated to implement the ideas of 4D trajectories. The underlying principles and practices for controlling future flights using such 4D trajectories will be very different from current practice. Also, while some very high level ideas of the system architecture is available, e.g. the SWIM architecture, it is difficult to make estimates about which technologies will be used and the nature of that use. Consequently, the nature of the operational concept, the likely work practices in these yet-to-be-determined work environments and the tools needed to support the work are equally hard to predict.

Our approach to this is to take a Human-Centred Innovation process to invent a number of tools that are intended to facilitate different aspects of airspace and traffic visualisation. By combining these tools in novel ways, we hope to greatly improve the acquisition and comprehension of information in ATC in these anticipated work environments.

In contrast, a common approach to designing user oriented systems is known as User Centred Design [1]. This approach prescribes an examination of the task being performed, understanding the nature of the demands that the task places on the user, and then to design of the best possible interfaces to improve the performance of the task. User Centred Design assumes that the task exists, but in our dealings with the future ATC system we cannot be certain what the necessary tasks will be, and at this stage, neither can we reliably predict what the technology will be. Indeed it is likely that the capacity of users to deal with the expected increases in air traffic will be a major factor in the design of tasks and technology. This is a "wicked problem" [2], since the process of solving the original problem is likely to reveal other problems, some of which may be more complex than the problem's original form.

To this end, we engaged in a Human-Centred Innovation process as there are no SESAR ATC tasks or work environments to study work practices and human factors needs. Rather than build on existing operating paradigms of ATC, it is necessary that we take what is known of the abilities of users and attempt to predict which tasks they will best be able to perform and with what technology, and extrapolate that within the context of SESAR. This process of extrapolation will be discussed later in our paper. During our review of the literature we found a limited amount of information on techniques for theory-driven user-focused innovation and exploration of the design space [3]. This paper is partly an attempt to fill this gap in an ATC context.

Despite the uncertainty of what SESAR will demand from the controllers, we are reasonably confident that controllers will need to visualise the airspace they control. In previous visualisation systems for ATC the view of the airspace is often completely 2D, such as the systems in use today, or completely 3D. Three-dimensional rendering of a scene eases integrated attention tasks, in which information is integrated across three or more dimensions. Such tasks may include guiding an aircraft that is making a simultaneous descent and turn. 3D

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rendering is also useful for appreciating the positions of aircraft in relation to each other in 3D space. However, well known drawbacks of 3D representations include fore-shortening of distances due to distortions arising from perspective. This makes it difficult to correctly estimate distances and hence aircraft separations. Two-dimensional information is superior for focused attention tasks, such as estimating the horizontal separation of converging aircraft. However, it requires a high degree of experience to re-construct and maintain a dynamic mental picture of the spatial relationships between aircraft in 3D space. An extensive review of the advantages and disadvantages between 3D and 2D has been reported elsewhere [4] and is summarised in Table 1.

In order to maximise performance, it would appear desirable to allow controllers to shift between 2D and 3D views [5]. However, most current rendering systems require the user to switch their attention to a new spatial context, either by shifting their view from a 2D planar radar display to a 3D rendering of it, or re-configuring the 3D display by moving the camera position, to access a top down plan view of traffic. Based on our previous cognitive task analysis and field studies of air traffic controllers' work, we do not believe that interfaces requiring such shifts in spatial context and visual attention will confer a major advantage. Other techniques such as displaying a smaller window with 3D information overlaying parts of a 2D planar view display may obscure critical information. Such a display design is potentially hazardous and therefore, also not desirable.

We hope to invent novel visualisations that combine 3D and 2D in a way that compensates for the shortcomings of these display techniques, whilst exploiting their complementary potential. We also hope that these new visualisations will increase the controllers information handling capacity, and hence their scope for control.

We will next discuss the human-centred innovation process and describe the designs that emerged from the process, their design rationale and how the concepts developed. This will be followed by a discussion of the findings from an exploratory evaluation of the designs. Then we close with a discussion about our experiences with the human-centred innovation process.

Display type	Advantages (+)	Drawbacks (-)
2D Display	Global traffic picture always available Supports correct distance estimation, focused attention tasks [6-8]; Supports improved performances for visual search tasks [9] Easy to orient. User maintain easily orientation awareness Navigation and Selection are easy to achieve	Does not spatially represent altitude information, and requires the controller to read and interpret alphanumerical altitude data to produce and maintain 3D picture Suffers from cluttering. Overlapping labels and blips difficult to read
3D Display	Supports Superior performance for integrated - shape understanding – tasks [6-8]; Supports development of accurate mental model of traffic and terrain, effective training tool [10]; Supports effective decision making for a/c maneuvering on the vertical plane [11]; Supports at glace assessment of consistency of implemented maneuver with the original one as intended by controller [12]	Hampered distance estimation performances due to perspective distortion effects [10]; Not possible to oversee global traffic/global sector out of camera view [13]; Traffics at the far end of the scene difficult to locate, due to decrease in resolution [14]; Navigation and selection difficult, user can get lost when moving the camera

Table 1. Relative advantages and drawbacks of 2D and 3D display (Rozzi et al., 2007)

II. The Human-Centred Innovation Process

The Human-Centred Innovation Process combines a focus on the needs of the user with the search for technological advances that can create opportunities for creating innovations in the way people work and in the design of tools to support the work. Focusing purely on the user and their task can be limiting as it is primarily retrospective in nature, investigating work practices that current exist. This could potentially lead us to 'designing for the last war', instead of designing for a scenario of what could be. On the other hand, focusing mainly on technological advances can lead to problems of 'a hammer looking for nails'. While each approach has benefits and shortcomings, we prefer to leverage both, drawing on the notion of the Task-Artefact Cycle [15]. We accept that new technologies will afford new capabilities that create or enable opportunities for new ways of working and even new forms of work. Taking our case as an example, the future technologies (e.g. the SWIM network) can create opportunities to change the controllers' work from directing and controlling aircraft, to supervising a larger volume of self-managing, self-separating aircraft. Once such opportunities are envisaged, it will place new demands on the future work of the controller, requiring new designs and solutions to support the new tasks.

The Human-Centred Innovation Process we adopted comprised several sub-processes: a review of the literature, and an iterative invention process involving creativity workshops, scenario development, and design exploration [15]. Then in subsequent cycles, the emphasis shifts from creation to the

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combination of existing concepts to provide hybrids that compensated for shortcomings in the original concepts.

The innovation process was firstly informed by a review of about 100 papers describing innovative visualisations in ATC, Command and Control, Medical, Geographic, Engineering and Flow imaging. This gave rise to the Combination Display Framework (Table 2). This framework allowed us to hypothesise which types of innovations were likely to be successful and focus our energy accordingly.

The Combination Display Framework is a two-way classification scheme for helping us understand the patterns in existing combinations of 3D and 2D representations, and the basis for their combination. Since the various display formats are largely orthogonal to their display techniques we can use this framework to identify places in the literature where current gaps exist and we can use related research to predict how successful we are likely to be in filling those gaps.

The Display Format, on the horizontal axis of the Combination Display Framework, classifies various ways of combining 2D and 3D visualisations. The broad categories of display format are the Side-by-side, Multiview, Exo-vis and In Place views. In the vertical axis we see different display techniques which implement the principle of Focus and Context, i.e. the need to see information within the context of its data sets or of the task situation. These techniques include rapid zooming, distortion, multiple coordinated views.

In this version of the Combination Display Framework (table 2), we have included some examples of visualisations found in the ATC literature. The Framework also suggests that there are many other possible combinations where exploration may bear fruit. Airspace may be rendered in strict 3D, or combined using differing methodologies.

During the invention cycles, it was necessary to force our participants who were experienced controllers, to break with their traditions and well-established work practices. We used creativity workshops to identify existing assumptions, to discuss and break them, and to consider the technologies likely to be in place in the future, to encourage the controllers to imagine scenarios that were different from the present situation and those of the near future, in order to facilitate the generation of new ideas.

As we tried not to be overly constrained by the technology (and indeed, our lack of knowledge of the what the actual future technologies might be!), we used a low fidelity, paper-based prototyping approach for the design and design space exploration for the visualization tools we were developing. Ideas could be quickly sketched and walked-through, allowing changes and refinements to be made quickly.

Since precise task analysis of the future air traffic control task is not yet possible, we have adopted a strategy for designing these tools that distinguishes between what is visualised, the *content*, and the means and devices that are used to present them, the *container*. These containers allow the combination of various content, such as the magnification of 2D, 3D views of a selected area, integration of 3D in 2D information, or 4D (spatial-temporal) information in numerous ways with different types of containers. These containers can include "lenses" which can distort or magnify the underlying 2D information; or "scoops" that would allow a controller to scoop out a segment of the airspace. These containers with the content, could then be manipulated and interacted with in various ways. For example, using gestural and touch techniques would allow one to "reach in and grab" or "scoop" segments of the airspace of interest; or using alternative display interaction technologies, we can use point of view tracking with off-axis projection to create "fish tank VR"[16] where what a person sees changes as that person's point of view changes. The idea in the innovation process is to explore a series of tools that allow us to guide the development of future tasks and technologies.

We will next describe several of the visualisation technologies we have developed. The technologies should be regarded as tools that will contribute to a solution, not solutions in their own right.

III. THE VISUALISATION TOOLS

We used the Combination Display Framework together with our human-centred innovation approach to create new ideas for the visualization tools. 10 readily identifiable novel concepts were developed and were then distilled to the six key tools reported here. It should be noted again that these tools are intended to be extended and used in further combination to form possible future solutions. They should not be seen as stand-alone controller's tools or systems.

Many of the prototypes described here were developed using the ARToolkit [17], an open source library for developing Augmented Reality (AR) applications. The toolkit uses a camera to detect markers and then augments these markers with additional information. The additional information may be displayed on a screen, via a head mounted display (HMD) or in the environment itself [18]. This is really two separate technologies – registration and display. Registration is the task of finding interesting information in the environment – this is the camera finding the marker. Display is the addition of information in the appropriate place. It should be remembered that the focus is not the registration technique (which could instead be based on magnetic tracking, infra-red tracking, or some new technology) or the display technology (which is also changeable). The only area of concern here is how the container helps controllers visualise the airspace. In many cases the flexible nature of the registration in the ARToolkit has allowed us to create cheap prototypes for technologies that do not need to use the AR Toolkit.

In the following descriptions of the visualization tools, we hope to explain their design rationale, and how these ideas developed. These ideas were based on four considerations: (i) the ability for a controller to reach into a display and select by touch or other means an area of interest for closer examination, (ii) the integration of needed 3D information into 2D to create in-place representations, (iii) the need to support accurate measurement of pertinent information such as distances and altitude differences, and (iv) the need for global awareness of the traffic situation while enabling localized spatial awareness. We will now present these concepts.

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DISPLAY TECHNIQUE	**DISPLAY FORMAT**				
	Strict 3D	**2D/3D Combination Displays**			
		Side By side	**Multiview 2D/3D**	**Exo-Vis**	**In Place**
Uncorrelated view (no technique)		St. John ('01)			
3D in 2D symbols					Smallman ('01)
Focus + Context Techniques					
Multiwindows	EC-Lin AR ('06)				PiP Display, AD4 ('06)
Rapid Zooming	Ellis ('87) Azuma ('96) Brown ('94) Eddy et. Al ('99)				
Distortion					Distortion Display, AD4 ('06)
Overview Plus detail			Alexander & Wickens ('03)		
Filtering	EC-Lin VR ('05)	Azuma ('00)	Ilog Display		Lens Display, AD4 ('06)
Multiple Coordinated Views	EC-Lin VR ('05)	Azuma ('00) Furtsenau ('06) D3, AD4 ('06)	Ilog Display		

Table 2. Combination Display Framework [19]

A. AR in Your Hand

This concept is based on the notion of using one's hand to reach into a 2D radar display and to grab a segment of the airspace and traffic within that airspace. The AR (Augmented Reality) in your hand concept allows a controller to use his or her hand to select a portion of the 2D radar screen, and then have the 3D (or any other view of the selected area) appear in the palm of his or her hand. In this prototype we use markers to facilitate the process, but in the final implementation, we envisage it would work using just a user's hand.

Figure 1 shows the implemented prototype AR in your hand using the ARToolkit. The AR in your hand display allows a controller to intuitively examine the airspace of interest by rotating their palm to change perspective, and bringing it closer for a closer inspection. As well as allowing a controller to view a volume in detail, it could be used as a collaborative tool for controllers to share information about interesting areas of the airspace or to hand over a situation to another controller.

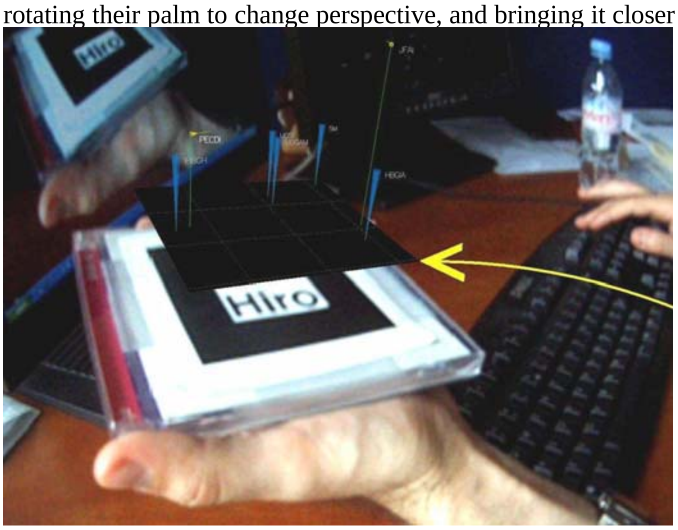

Figure 1. AR in your hand. A section of the airspace is depicted in 3D. The image is anchored to the marker, so moving the marker moves the 3D information as well. This allows views from multiple directions and collaboration between controllers.

This localised view could be placed beside a monitor for reference and dismissed at the snap of the fingers. With an HMD or future display techniques it is hoped that the 3D information can be actually viewed in the user's hand.

The key benefits of this interaction technique are that selection and viewing are simple and intuitive, the spatial context of the selection is easily perceived and there is no need for occlusion of relevant spaces. Current display technologies require either a Side-by-Side or Multi-Window format, but this may be mitigated in future.

B. The Tangible Lens

The Tangible Lens is a prototype display technique for smoothing interactions between the physical and the information space. By moving the "lens" over parts of the 2D radar screen, it will augment those parts of the screen with additional information. This information could take the form of textual, graphical or 3D information. Figure 2 shows a picture of the Tangible Lens acting as a magnifying glass, implemented in the ARToolkit.

The lens is envisaged to be a physical tool that will be permanently attached to the screen. When a user needs

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additional information the tool will be grabbed, dragged to the relevant area and used to acquire the necessary information. When the information has been obtained, the tool is released and springs out of the way. This tool would greatly reduce the intrusiveness of acquiring additional information.

Figure 2. The tangible lens, implemented with the ARToolkit. The area inside the cardboard "lens" is a magnified view of that region of the airspace.

Additionally, the acquired information would have a high spatial relevance. With the development of multi-touch screens, exemplified by the iPhone, it may be possible to replace the lens with something like a "pinch" touch interface.

This is an example of the In Place display format, since the additional information is replaces part of the 2D view on the main screen. Principle benefits are the rapid acquisition of spatially relevant information, the minimal occlusion period and the intuitive simplicity of the interaction.

C. AR 3D Wall View

The 3D Wall View is an example of the notion of the scoop where a segment of the airspace may be scooped up and placed beside a controller or used for discussion with other controllers. This view uses the Exo-Vis display format implemented using the Side-by-Side display technique. It grew from two earlier concepts, the "local view" and the "precise distance estimation view." While these concepts were not useful alone, in combination they provided a promising new tool.

The 3D view (figures 3 and 4) allows a rapid comprehension of the structure of the airspace, while two 2D representations on the wall (called the 'altitude ruler') give users precise data needed to assess the traffic situation or guide aircraft accurately. Such a view can allow a controller to check whether a given aircraft is able to level off at an assigned flight level after a climb (or descent); visualise the 3D path of an aircraft close to terrains; guide an aircraft through a complex approach, monitor one or more holding stacks at the same time, or access a pilot's point of view during severe weather conditions.

All of these airspace features can be included and magnified in a sub volume such as the one described above. We have implemented this view as both a stack manager and an approach controller. The multiple uses of this view are an example of why these visualisations are regarded as tools as opposed to solutions. The key benefits of this view are the general overview combined with spatially relevant 2D information.

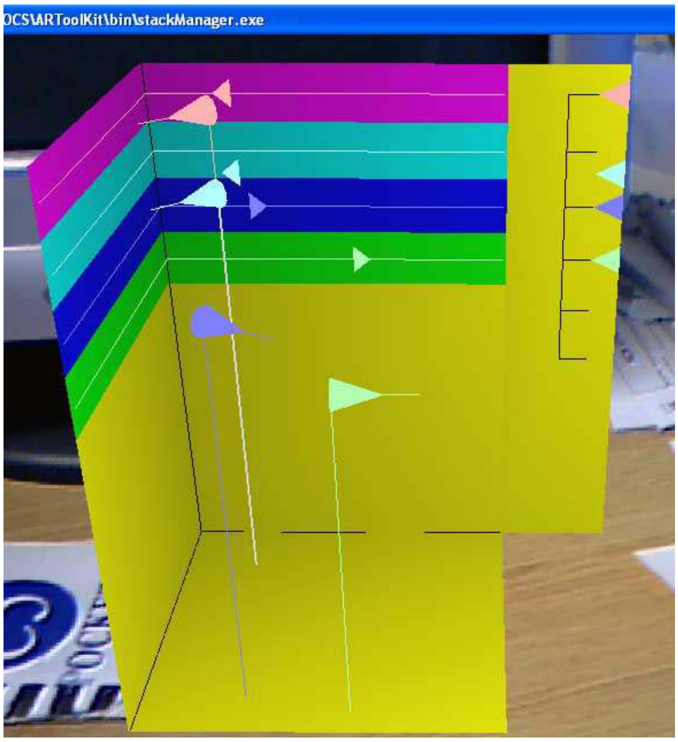

Figure 3. The 3D walls display provides a 3D overview to aid situational awareness and a 2D view to aid precise judgements

This 2D information is much more useful to a controller when making precise judgments such as separation or heading. In the stack manager, it is quite difficult to determine the vertical separation of aircraft from the local view alone. However the wall view allows the controller to rapidly and accurately determine which, if any, aircraft are deviating from assigned flight levels.

In the approach control implementation the complex trajectory of an inbound aircraft can be quickly comprehended with the global view, but the 2D representations on the walls and floor make it easier to determine if the target is on the correct glide path and slope.

A current drawback is the separation of the walled area from its spatial context, but further combination with other displays – such as the Tangible Lens detailed above or the AR Tabletop described below should mitigate or eliminate this problem.

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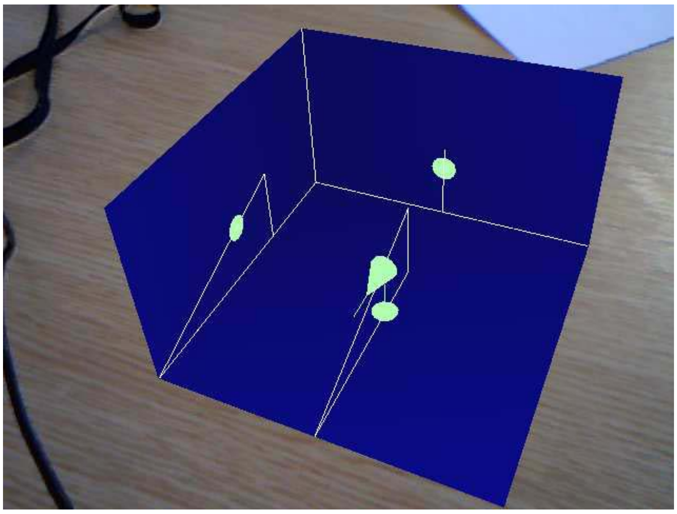

Figure 4. The same 3D walls container this time with approach control content.

D. *Skyscraper and Symbicons*

The skyscraper set of display concepts allow a controller to monitor a standard 2D plan view and to selected areas of the 2D space for 3D viewing. The user can see a 3D representation of an area of interest within a 2D overview of the entire airspace. The aircraft in our concept prototype are represented as red-cyan anaglyphs in the selected airspace. When viewed using red-cyan filters (cheap 3D glasses), the selected aircraft appear to stand out of the display, much as if one were looking down at skyscrapers from above. Aircraft at

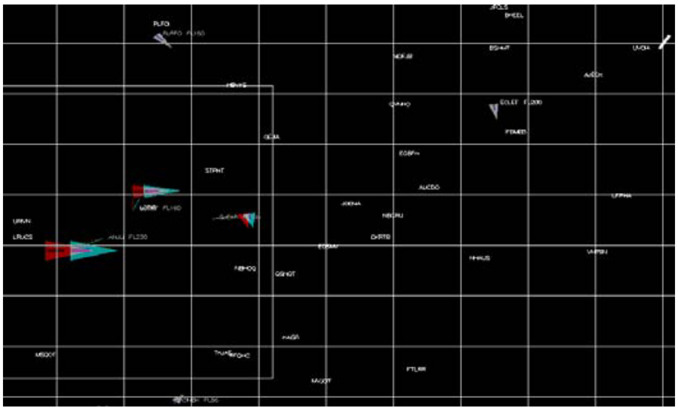

Figure 5. The skyscraper and symbicons display. The red-blue aircraft appear to pop out of the screen when viewed with 3D glasses. The lines on the aircraft indicate whether the target is climbing, descending or flying level.

higher altitudes appear closer to the viewer while aircraft at lower altitudes appear farther away from the viewer (Figure 6).

Such a 3D-in-2D view is useful for de-cluttering since the selected aircraft appear to stand out of the display, gives a controller a quick assessment of the traffic situation, and can provide clear indications of where the aircraft are in 3D space. Note that such a view can be combined in the "AR magnifying glass" lens view, and can be implemented in advanced autostereo display technology that does not require glasses or anaglyphs to simulate visual depth.

The 3D view need not represent actual altitude. For instance, instead of presenting a locality where the third dimension represents altitude, the user could choose to filter aircraft according to airspeed, with the perceived depth designating the relative velocities of the selected aircraft.

Symbicons, or icons with embed symbolic 3D-related information can be used to add information about the aircraft's behaviour, indicating if the aircraft is climbing, descending or banking (figure 6). This is an example of the integration of 3D information into a 2D space.

This symbicon concept has been implemented as a short black line on the axis of the aircraft. If the line is towards the rear of the aircraft (triangle) symbol, it indicates that the aircraft is climbing; and if it is located more forward, it indicates it is descending. If the line is to the left, it indicates that the aircraft is banking left, in a climbing left turn (if to the rear and left), or in a descending left turn (if to the left and forward). Symbicons and the 3D skyscrapers are complementary technologies (figure 5). They allow users to readily perceive information about the intentions and actions of aircraft, and rapidly determine flight levels. In this design, we can preserve the need for global awareness of the overall traffic situation provided by the 2D representation, while decluttering the display by separating the aircraft and their labels in depth and supporting analogical reasoning. Smallman et al. [6] found that symbolic 3D led to better visual identification performance.

Note that symbicon techniques could be added to other displays as well, especially the AR Tabletop described below. The combination of a 2D Display, 3D Filtering and Symbolic information are an excellent example of the utility provided by the Combination Display Framework.

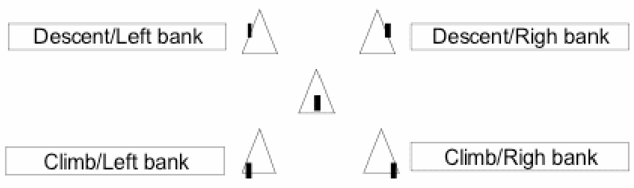

Figure 6. How the symbicons concept works to display attitude information

E. *AR Tabletop Display*

The Table Top Display (figure 7) is a collaborative workspace rendered in genuine 3D. Multiple controllers can view a single workspace from multiple directions, allowing them to share ideas and solve complex problems. The view allows examination from any angle, and can provide textual information, just like a 2D display. Note that we are able to augment the entire table top – we are not limited by the size of the marker. Practically, there are a number of display technologies to bring this about, especially spatial AR and "fish tank" VR. The display format is a pure 3D environment, but it is easy to see how symbols could augment the display, or how walls could be used to provide precise information in a spatially relevant way (see Figure 13 for an early paper mock-up of how the 3D walls could be implemented on the Tabletop display). This display benefits from a strong spatial context

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and easy collaboration, as well as the potential for combination with the other tools described above.

IV. EVALUATING THE CAPAB ILITIES OF THE VISUALISATION TOOLS

We also carried out an exploratory evaluation of the designs to identify the capabilities afforded by the new 3D/2D representation concepts and their potential uses. In particular, to identify the variety of perceptual and interaction issues that may arise, such as the new user capabilities provided by the tools. Also of interest was the identification of feature interaction effects, i.e. how some of these concepts might in combination lead to more powerful capabilities, or hinder controller performance.

It was not the intention of the evaluation to quantitatively assess the effect of the new designs on a particular set of operational tasks, since the tools were not yet intended to solve particular problems.

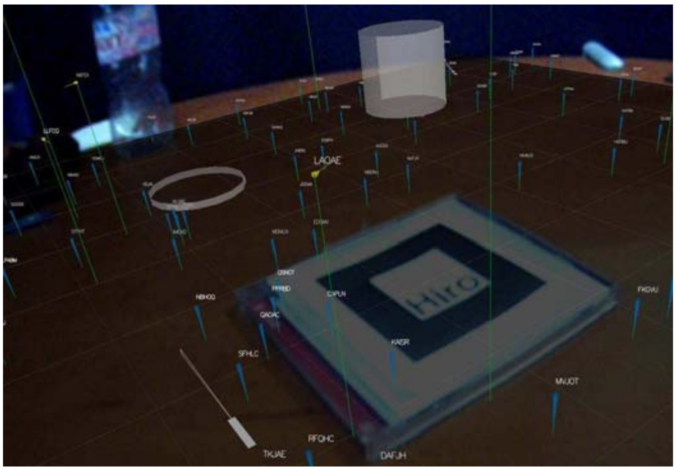

Figure 7. The tabletop AR display uses a single marker to augment an entire workspace. Users can view the display from multiple points of view, and obstacles such as clouds and restricted airspaces are clearly visible.

While the focus of the innovation process was centred on users the design process was, as yet, too immature to make quantitative analysis of the tools productive. Indeed, focusing on specific implementations would have instead hampered the exploration of the tools' full capabilities. The evaluation took place at EUROCONTROL with three non-operational Air Traffic Controllers, each with between 3 to 18 years of operational experience. They were requested to perform exploratory tasks in simplified scenario demos and asked to imagine how the new visualisation could help them to carry out operational tasks. We also used a set of predefined questions to stimulate thinking about alternate uses of the tools.

A. *Applications of the 3D-in-2D Concepts in ATC*

The study showed in general, that 3D visualisation can help a controller manage holding stacks, busy airspace sectors and military aircraft interception. Several potential benefits were indicated:

- 3D in combination with 2D appears to offer the potential to reveal 3D positions and trajectories relative to each other.
- Perception of dynamic and static 3D volumetric shapes of restricted airspaces is easier, reducing the cognitive load on controllers.
- Current radar displays can result in nearby aircraft overlapping aircraft on the screen, making it difficult to read call signs. 3D displays can alleviate this.
- The use of 3D might provide military controllers assistance to track high performance aircraft. This supports the finding of a previous work analysis [5]. At this stage however it seems that more operational evidence need to be collected, since none of the subjects involved in the session had military experience.
- In busy airspace sectors, 3D could be useful for disambiguating traffic arriving or departing from a given airport from those arriving and departing from another nearby airport. With the arrival of technologies such as PRNAV (Precision Navigation), this could increase the effective use of the airspace. Aircraft could be guided along 3D paths not available today due to uncertainty in navigation. For instance, in between the departure of a fast and a slow aircraft – the former departing first and climbing at higher altitude, the latter departing shortly afterwards and climbing at a lower altitude – it is not possible to put any aircraft today; but with the support of PRNAV it would. Such an improved use of the airspace would result in higher density of activities which could be better appreciated in combination with a 3D visualisation.

B. *Applications of 3D-in-2D Concepts beyond ATC*

Other application areas beyond ATC include airspace planning; procedure design, experimental scenario design, and training.

Three dimensional CAD (Computer Aided Design) applications facilitate planning and design with a combination of both 2D and 3D views. 3D viewing could enhance the planning and design of airspaces. Planners and procedure designers could use a virtual airspace to collect a qualitative understanding of different aspects of the airspace, such as ground clearances or noise distribution.

There is also potential for use in experimental scenario design and performance analysis. A researcher could accurately visualise traffic in 3D space, a task that most researchers will find considerably more difficult than trained controllers.

Trainee controllers could experiment with new airspaces using 3D-in-2D displays. They could interactively explore a localised 3D space using different features to understand its configuration, the distribution of global traffic, and assess the implications of maneuvers, e.g. lack of separation, overshoot or unnecessary travel distance.

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These areas may be more suitable for initial airspace design because they are not real-time, operational situations. This means that some limited experimentation is possible. Since airspaces and procedures are carefully designed and examined over long periods of time, the addition of 3D visualisations has the potential to give users a way to improve comprehension, collaboration and efficiency without risking passenger safety.

V. CONCLUSION

The human-centred innovation process was intended to provide new concepts that could aid human performance in the future SESAR ATC context. It was necessary because the domain under consideration consists of loosely defined tasks with new or even future technology. Indeed, this process is likely to inform the development of those tasks and future technologies.

The Combination Display Framework allowed us to reason about which combinations of display format and techniques were likely to produce good results, and focus creative energies in those directions. This aided the transfer of knowledge from the work of others while reducing the risk of duplication.

The iterative component of the Human-Centred Innovation process led to the discovery of potential tool combinations. The skyscraper-symbicons concept and the AR 3D wall view both combined existing concepts to create vastly improved visualisations.

In general, the Human-Centred Innovation process allowed us to creatively develop technology while remaining focused on the needs of users.

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