3D IN 2D PLANAR DISPLAY PROJECT

D4-3: COCKPIT DISPLAY CONCEPTS AND SOFTWARE PROTOTYPES (LOT NO. 4, WP 4)

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Authors
William Wong
Fan Han
Stephen Gaukrodger

Organisation
Middlesex University
Middlesex University
Middlesex University

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DOCUMENT CONTROL

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<tr>
<td>Other members of the project team</td>
<td></td>
</tr>
<tr>
<td>Martin Loomes</td>
<td>Middlesex University</td>
</tr>
<tr>
<td>Ifan Shepherd</td>
<td>Middlesex University</td>
</tr>
<tr>
<td>Bob Fields</td>
<td>Middlesex University</td>
</tr>
<tr>
<td>Paola Amaldi</td>
<td>Middlesex University</td>
</tr>
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1. INTRODUCTION

In this report we describe the cockpit display concepts we have developed in Work Package 4-3, the concepts upon which the designs are based, methods for visualisation of these concepts, the technology in which to contain them, and the techniques for interacting with and controlling the visualised content. In addition, video reports of the designs and interaction will be made available through the internet on the project website, and other distribution media, such as CDs or DVDs.

We will report this work using our 4C’s framework – Concepts, Contents, Containers and Controls. Concepts are the operational concepts that have been identified as relevant to the SESAR remit of the project, such as the concept of energy management; contents present suggestions as to how the concepts can be visualised, such as the notion of pinchable and pullable trajectories which can also represent energy and other multi-dimensional data; containers refer to the technologies for holding the visualisations, such as the FishTank VR visualisation technology which uses view-point tracking to reinforce proprioception; and controls are the methods and technologies for manipulating and interacting with the visualised content within the containers, such as 3D gestural interaction using data gloves that allow spatial interactions.

An overview of the work, their paths of development, the technologies we have used to implement them, and how they enable new ways of working, is illustrated in Figure 1a which...
shows the technical and operational development process and dependencies, and Figure 1b which visually summarises how the work is classified into the 4Cs Framework of concepts, content, containers and controls.

Figure 1b. The key outcomes from Year 2: concepts, content, containers and controls

It should be noted that although this report signifies the conclusion of a work package tasked with the design of displays for cockpit use under SESAR, we acknowledge that it is not the end of this line of work. It is very likely that in subsequent work packages where we will evaluate these design concepts and their variant implementations, and develop new designs for use by air traffic controllers at the CWP, we anticipate that new designs for use by pilots and ATCOs will continue to emerge and evolve.

2. THE CONCEPTS TO BE SUPPORTED

The concepts to be supported for this study were based on a cognitive task analysis, a form of in-depth interview based on the Critical Decision Method, with four senior airline captains in D4-2. One of the key support tools for use in the flight deck under a SESAR context would be to assist pilots in flying 4D trajectories. It would be beneficial if such a future flight deck system incorporated: energy profile management support; indications of track miles; visualizations for integrating and interpreting multiple variables such as heading, speed and
altitude - to assist in energy profile management; adapting tools such as the ‘green arc’ to support reporting and visualization of energy dissipation during real-time control; awareness of the surrounding traffic situation; the representation of process lags to support energy profile planning and execution; and information about the intentions of controllers, as pilots currently use their TCAS displays to see the traffic situation ahead (e.g. around the airport), to observe how the air traffic controllers have lined up or sequenced the arriving aircraft. This provides us with an opportunity to develop concepts for tools to help communicate intention between the cockpit and the ground, which will have an impact on how pilots manage their aircraft energy profiles.

A number of concepts to address both the future pilots’ and air traffic controllers’ spatial temporal needs under SESAR, and derived through our evaluations and future design analysis, have been created. Some of these have been prototyped using a variety of interaction and visualization technologies, with some building on prototypes developed in Year 1, and others newly implemented this year.

Another concept to emerge from our analysis of what constitutes the spatial-temporal needs of pilots is the realisation that they often make quick assessments of whether they can dissipate the energy in the aircraft quickly enough to accommodate a re-routing that reduces the track miles. In other words, they would anticipate that because of the reduced distance to fly, they are likely to arrive at the point in space and time, “too fast and too high”. Currently, pilots use a heuristic called the “3 times table” to estimate if they have adequate track distance to dissipate the energy in their aircraft. It is a heuristic that helps them assess their “stopping distance” in the air, and they often use it to answer the question, “can I do it?”, i.e. can the pilot arrive at a point in space at a particular time without being too high or too fast? A display is being designed to include this heuristic. This display can be embedded into previous design containers such as the ARLens display (one of the Year 1 prototypes) so that it presents the result of the energy computation at the centre of where the ARLens is pointing. Pilots and air traffic controllers could potentially benefit from such a tool, and controllers can use it as a planning tool.

There are three key points to note in this overview: (i) the 4D-Energy Trajectory is leading us in the direction of multi-dimensional displays that support the key cognitive dimensions of the ATC and pilot tasks, rather than just attempting to replicate a 3D spatial perspective, providing opportunities for development of visual forms for energy and probability representation; (ii) the work with anaglyph stereo displays and head and eye-position tracking is leading us in the direction of creating position-specific, proprioceptive “fish-tank” VR representations of the ATC and pilot workspaces; and (iii) the 4DET management tool core system is providing us with the means to experiment with alternative technologies for
3D and gestural interaction capabilities that would lead to more natural forms of interaction in the future.

2.1 3D as Multi-dimensional Information Rather Than Spatial Perspective

Through our research this year, it became apparent that the notion of 3D is normally taken to mean the representation of a spatial perspective view of the airspace. This assumption is unnecessarily limiting and may not lead to effective control of flight. According to a number of different theories such as Klein’s RPD (Klein, 1993) and Logan’s instance theory (Logan, 1988), expert decision makers recognize patterns and are able to refer very quickly to instances of patterns in their memory from which they diagnose, decide and act. We need to be able to create displays that support the perception of important invariant functional relationships or dimensions that allow controllers and pilots to off-load intensive mental computations onto visual representations that a pilot or an ATCO can use to plan, execute and adapt. Thinking of 3D as a representation of relevant dimensions, such as energy, rather than as a faithful view of the airspace allows better use of display resources. This process is aided by tools such as the Spatial-Temporal Design Framework (Wong, Rozzi, Amaldi, Woodward & Fields, 2006).

2.2 Aircraft Energy Management

From the reviews and, in particular, our study of the spatial-temporal information needs of airline pilots we conclude that energy management is a key task carried out by the pilots in relation to air traffic control. The management of the potential and kinetic energy of the aircraft as it approaches the runway is important to ensure that the airliner does not come in “too high and too fast” for a safe landing. For example, BA regulations state that the airliner needs to arrive at a point such as the approach or final ‘gate’ at 3,000 ft at 140kts with the right glide slope in order to land safely on the runway. What is crucial is the gradual dissipation of the aircraft’s energy over the path that leads to this final gate. The length of this path, or the ‘track miles’, is the actual distance travelled. This could be a longer curve rather than the straight line between the current point and the final gate. If this can be managed well, it can facilitate controlled descent and minimise fuel consumption on approach, in line with the concepts of Reference Business Trajectories and Controlled Time of Arrival under SESAR. Energy management underlies the coordination of many activities between pilots and ATC, especially during the approach phase. Thus, we propose to address the work concept of energy management that would facilitate the planning for arrival at target points in space in a timely and safe manner.
We also identified the main planning and execution activities during a flight (see Figure 2):

- Planning (both before a flight, pre-flight, and during a flight, in-flight)
- Execution
- Re-planning to adapt to changing circumstances

**Figure 2. Flight planning phases with respect to SESAR reference business trajectories**

The distinction between the different planning stages was used to emphasise where we are focusing our work. Through this we identified a ‘gap’ in the support provided to both pilots and air traffic controllers for reasoning about the aircraft energy levels during the in-flight planning and re-planning phases. Our research will continue to be directed in this ‘gap’. We recognize the already advanced nature of the work by Amelink and colleagues (Amelink, Passen, Mulder, & Flach, 2003) that addresses energy management during the real-time flight control of aircraft. Figure 3, shows an example of their Energy-augmented Tunnel-in-the-sky display, reproduced from their paper.
2.3 4DT => 4DET => 4DEPT

By thinking beyond spatial dimensions, we can design visual tools that would help pilots and ATCOs reason beyond trajectories in space and time, and about the factors that influence the physics of the flight. In this way, the concept of a 4D trajectory (4DT) can be expanded to include the notion of energy and how that energy is gained and dissipated along the aircraft’s trajectory.

These tools can also be used to help ATCOs consider routings that minimise the use of strategies that disrupt the gradual dissipation of energy, improve safety and decrease environmental impact. By sharing appropriate information, representations and tools between ATC and pilots, it is possible to reduce the coordination needed between them to assess the suitability of re-routing, allowing the ATCO to anticipate whether a particular change in route due to, say, weather, is viable given the aircraft’s current energy profile.
Figure 4. 4D energy trajectory (4DET) re-planning process flow: an Example

Figure 4 illustrates the 4DET re-planning process flow as an example of how we integrate the different concepts such as energy profile support, track miles, awareness of traffic situation, etc, and how this operational concept will provide the basis for combining the later visual and interaction elements in a sensible way. For explanatory purposes, we have used one of the scenarios identified during our CTA interviews with pilots to investigate the spatial-temporal demands as ATC requests a route change which drastically shortens the track miles that the aircraft will have to fly. This means that the aircraft, unless it does something to drastically reduce its speed, will arrive 'too high and too fast' at the gate. This scenario is illustrated in Figure 5.

Figure 5. An actual re-routing scenario that required a drastic reduction in track miles
A display design that incorporates the energy dimension could be referred to as the 4DET, 4D and Energy Trajectory. Expanding further on the idea of 4DET, it is possible to incorporate the notion of uncertainty into these representations (Lee & Milgram, 2008). Rather than simply representing the “tube” as a tunnel in the sky defined by the aircraft safety separation distances, the displays could also present fields of safe travel, showing the probabilities of where the aircraft could be in space at a pre-defined time in the future.

![Figure 6. Example of probability pattern generated by two planes (within circles) caused by uncertainty in velocity (from Lee and Milgram, 2008).](image)

This leads to another concept, which we call the 4DEPT, or 4D Energy and Probability Trajectory. The probability space can be projected based on past and present information, including flight plans, and approved and agreed changes in real-time routings. When several 4DEPT paths are presented, they can also be used for representing areas of potential conflict or outputs from conflict detection algorithms.

The 4DET and 4DEPT are examples of how the display should be considered as a representation of multi-dimensional data rather than as a veridical representation of 3D space.
2.4 The scalable workflow

SESAR calls for a management structure that will deal with a 200-300% increase in air traffic. Recent studies have found that controllers would not be able to control many more aircraft than they do already. Halving the size of all sectors would be administratively difficult, and make it more difficult to increase traffic in the future.

A different approach is to look for ways to make ATC scalable. The current ATC model leaves the executive controller responsible for most of the work performed, even though there is a planner available. Adding more controllers per sector would not lead to improved sector capacity.

One of the major problems that controllers face is detecting potential conflicts. They currently deal with this problem by limiting the number of potential intersections, and thus simplifying the search space. If we are to take full advantage of technologies like PRNAV, this strategy will not be feasible. Aircraft may intersect at any point in space. This makes the problem much more difficult.

\[ C = \frac{n(n-1)}{2} \]

The number of possible conflicts in free flight airspace is determined by the equation above, where the number of collisions (C) is determined by the number of aircraft (n). Current controllers deal with up to 20 aircraft per sector, meaning 190 possible intersection points. Airspace with 40 aircraft would have 780 possible intersection points, a quadrupling of workload. Given that current controllers use known route intersection points to simplify the problem, the actual increase in workload is probably much greater.

![Figure 7. Sketch of a representation to support the Scalable Workflow concept. The screen on the left shows every aircraft. The screen on the right shows every pair of aircraft. By showing pairs and their relationships, collisions can be more easily detected.](image)

We have developed a prototype workflow and a proof of concept display which suggest that...
we could deal with this challenge by restructuring the tasks and adding additional controllers. One controller per sector would be responsible for detecting potential conflicts using a display that is specially designed for the task, rather than a veridical plan-view of the airspace (Figure 7). A pool of controllers is then available to resolve conflicts from any sector, using tools like the 4DEPT. If the number of conflicts starts to stretch the capacities of the resolution controllers, then the pool of controllers can be increased. The purpose of this concept is to distribute work in such a way that controllers can collaborate with scalable amounts of workload – each controller is responsible for a reasonably sized portion of the workload.

3. VISUALISING THE CONCEPTS

3.1 The Energy Management Problem

In energy management, the goal is to make a landing that is safe and timely. If an approach is made with too much energy, the aircraft may overshoot or overheat its brakes. If an approach is made with too little energy, the aircraft will need to increase thrust, which wastes fuel. Following from the work of the PHARE project (http://www.eurocontrol.int/phare/gallery/content/public/documents/97-70-09efms_4d_trajectory_prediction.pdf), we have developed 3D tubes to indicate whether trajectories in space intersect, incorporated with various dimensions and functional relationships relevant to the pilot’s and the ATCOs tasks. The tubes also convey the 3D aspects of travel more clearly, something that is likely to have a major impact on the use of descent rate to manage energy control on approach. The display would include and integrate the intended path, the track travelled, the energy profile of the aircraft, and probabilities describing the fields of safe travel. Moreover, by viewing these tubes in a 3D display, it is immediately obvious where these intersections occur, and thus where potential conflicts need to be resolved. This represents the content of a display that could potentially be used to support work and cooperative activities of pilots and ATCOs.

Normally, an aircraft flies on a navigable trajectory that is dependent on aircraft performance and other flight parameters. An aviation route may be defined by identifying suitable waypoints. However, only connected with these control points, you get several big straight lines, but there are only C^0, not C^1 between these straight lines, which is apparently not suitable as airplane’s aviation route. On the other hand, for a smooth curve, both C^0 and C^1 assure a more really accessible aviation route. On the waypoints of the trajectory, the aircraft changes its direction under a form of curve, as shown in Figure 8. Controllers use waypoints (the control points of the curve) to change the aircraft flight plan.
Because lower-degree polynomials give too little flexibility in controlling the shape of the curve, to transform a series of waypoints into a smooth curve we used B-Splines (a graphics technique for drawing a smooth curve by four defined points). As shown in the following formula, a 3rd degree curve C(t) passing through four control points $p_1$, $p_2$, $p_3$, $p_4$ is defined in B-Spline. General form of C(t):

\[
x(t) = p_1.x \times (1 - t)^3 + p_2.x \times 3t(1 - t)^2 + p_3.x \times 3t^2(1 - t) + p_4.x \times t^3
\]
\[
y(t) = p_1.y \times (1 - t)^3 + p_2.y \times 3t(1 - t)^2 + p_3.y \times 3t^2(1 - t) + p_4.y \times t^3
\]
\[
z(t) = p_1.z \times (1 - t)^3 + p_2.z \times 3t(1 - t)^2 + p_3.z \times 3t^2(1 - t) + p_4.z \times t^3
\]

with $0 \leq t \leq 1$.

In programming the target, we use B-Spline expression to transform every four neighbour control points into a series of very small lines, which is globally a smooth curve, when every line is small enough. Using this method, the curve will vary with waypoints and be deformed when we adjust those waypoints.

The core of this project is to create a series of tubes whose centerline follows the previously defined spine. At each sample point $C(t)$ along the spine we need to form the Frenet frame in which we draw the tube’s circular cross section. First we find the curve’s tangent vector $T(t)$ at each sample point $C(t)$ which can be computed from the velocity vector:

\[
T(t) = \dot{C}(t) = (\dot{x}(t), \dot{y}(t), \dot{z}(t))
\]

The corresponding derivatives are:

\[
\dot{x}(t) = p_1.x \times (-3(1 - t)^2) + p_2.x \times 3(1 - 4t + 3t^2) + p_3.x \times 3(2t - 3t^2) + p_4.x \times 3t^2
\]
\[
\dot{y}(t) = p_1.y \times (-3(1 - t)^2) + p_2.y \times 3(1 - 4t + 3t^2) + p_3.y \times 3(2t - 3t^2) + p_4.y \times 3t^2
\]
\[ z(t) = p_1z \cdot (-3(1-t)^2) + p_2z \cdot 3(1 - 4t + 3t^2) + p_3z \cdot 3(2t - 3t^2) + p_4z \cdot 3t^2 \]

Now we need to find another vector that is not parallel to T(t): Where the spine is curved, the “acceleration vector" A(t) will be close to perpendicular to T(t):

\[ A(t) = \ddot{C}(t) = (\ddot{x}(t), \ddot{y}(t), \ddot{z}(t)) \]

The corresponding second derivatives are:

\[ \ddot{x}(t) = p_1x \cdot (6 - 6t) + p_2x \cdot (-12 + 18t) + p_3x \cdot (6 - 18t) + p_4x \cdot 6t \]
\[ \ddot{y}(t) = p_1y \cdot (6 - 6t) + p_2y \cdot (-12 + 18t) + p_3y \cdot (6 - 18t) + p_4y \cdot 6t \]
\[ \ddot{z}(t) = p_1z \cdot (6 - 6t) + p_2z \cdot (-12 + 18t) + p_3z \cdot (6 - 18t) + p_4z \cdot 6t \]

Now we can compute the binormal vector B(t), which will be perpendicular to T(t) via the cross product

\[ B(t) = T(t) \times A(t) \]

Finally, we compute the “normal vector" N(t) which is perpendicular to both B(t) and T(t) via the cross product

\[ N(t) = B(t) \times T(t) \]

Our three coordinate vectors defining our Frenet frame at t, after vector normalization, are (N(t); B(t); T(t)), as shown in Figure 9.

![Figure 9. Frenet frame (N(t); B(t); T(t))](image)

Figure 10 shows the cross section of our tube with radius R:
We approximate the circle with a polyline of \( M \) points

\[
\{ C(t) + R(\cos u_j \hat{B} + \sin u_j \hat{N}) \}_{j=0}^{M-1}
\]

where \( u_j = 2 \pi j / M \).

We also note that the corresponding surface normals (which have unit magnitude) are \( \{ \cos u_j \hat{B} + \sin u_j \hat{N} \}_{j=0}^{M-1} \). Then we connect the corresponding points on neighbour circular to draw the tube.

It is also difficult to correctly position the rings on the tube in order to correctly reflect the deployment of control surfaces. The position of the ring along the above B-Spline curve is determined by every four control points in term of variation of very small step in the circulation. The direction of the ring is achieved by rotating a torus with central symmetrical lines from initial \( S(0, 0, 1) \) to tangent vector \( T(t) \) along \( C(t) \). The corresponding rotated angle circled the axial is defined by calculating the angle between vector \( S \) and vector \( T(t) \). The rotated axis is defined by the cross product:

\[
R(t) = S \times T(t)
\]

In our prototype, users can manipulate the trajectory (different trajectories have different rates of loss) and the points at which control surfaces are deployed.

Since we know the airplane’s initial velocity as \( V_{\text{initial}} \) and mass as \( M \), we expect that following a suitable route will mean that the aircraft will arrive at the final gate with velocity \( V_{\text{target}} \) at time \( t_{\text{target}} \). The corresponding energies are expressed as:

\[
E_{\text{initial}} = \frac{1}{2} MV_{\text{initial}} + Mgh_{\text{initial}}
\]
As described in the above, we set the four tori along the tube, each positioned within one of the tubes, controlled with four control points in the tube as the point at which energy loss rate changes.

In Figure 11 we illustrate how a user can manage the energy and time of arrival of aircraft at a point in space, by dragging points on the trajectory and moving the rings. The energy profile of the aircraft is presented in the graph at the top right corner of the display represented by a filled circle on this graph; it currently shows that the changes made will result in the aircraft arriving late at the desired point, and with too much energy. This means that what was once a complicated set of verbal instructions is now described visually by the computer for use by pilots or autopilots.

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$$E_{target} = \frac{1}{2} MV_{target} + Mgh_{target}$$

These “energy rings” have an additional benefit. Pilots also need a way to determine the effects of deploying various control surfaces and drag effects – slats, flaps, gear etc – in order to devise approaches that are efficient and have minimal environmental impact. In Figure 11, each of the 3D “energy” rings can be moved along the future trajectory of the aircraft and will reflect the location where a given drag element should be deployed in order to estimate the energy of the aircraft and arrival time at a point in space, as shown in the above algorithm. Moreover, as aircraft performance and other flight parameters on a navigable trajectory, we can manage energy profile by regulating aviation route. The graph in the top right corner of the display immediately shows the effects of any change upon how the aircraft will meet its targets. In Figure 12, as an example, moving suitable waypoints on
the tube will result in a variation of the flight trajectory, and thus we can adjust energy profile at the desired gate point from aircraft arriving early with too much energy in the left-hand figure to aircraft arriving in time with target energy level in the right-hand figure. By combining the tubes and the rings, controllers and pilots can manage the energy profiles in a more efficient fashion, reducing missed approaches, improving arrival time accuracy and thereby increasing airport efficiency.

![Energy Management](image)

**Figure 12.** Energy profile varies with aviation of the trajectory, by which we can adjust the target energy and arriving time of the aircraft at a desired point

The effectiveness of this technique may be further improved, for example, users could move the 3D cursor to a control point on the tube and use a gesture to select the point, and then drag the point in any direction. The user stops dragging by ending or repeating the gesture. A different gesture could select the nearest "energy ring" and move it along the tube to control the deployment of drag elements. A third gesture could create a gate in space that the aircraft must pass through. The goal of this concept is to provide natural and effective interaction methods for 3D control.

### 3.2 Translucent tubes for 4DEPT

We can also differentiate planned paths, probable paths and possible paths by using tubes of varying transparency. Planned paths could be displayed as a solid tube; probable paths as, for example, a 70% transparent tube around the planned path representing a 'cloud of probability' of those paths occurring; and possible paths as a much less solid tube or probability cloud around that. All three levels would be visible, and the degree of solidity would indicate the level of confidence that we can have of an aircraft passing through a given point. This would provide one way in which we can visualise a 4DEPT (4D Energy +
Probability Trajectory). In addition, if this concept is combined with time, it is possible to use such a visual form to show overlapping clouds and therefore, paths of safe passage. We will develop this concept further in the next year.

3.3 The ‘Can I do it?’ display

We found that pilots often need to make rapid assessments of whether they can dissipate their energy quickly enough to accommodate a re-routing that reduces their remaining track miles. In other words, they need to determine whether the reduced distance to fly means they will arrive at the point in space and time “too high and too fast”. Currently, pilots use a “3 times table” heuristic to estimate track miles needed to dissipate the aircraft’s energy. The altitude in thousands of feet is multiplied by three to give the required track miles. For example, if the altitude is 12000ft, the aircraft needs 12 x 3, or 36 nautical miles to dissipate its energy. The heuristic is a rough estimate of their “stopping distance” which is often used to answer the question, “can I do it?” i.e. can the pilot arrive at a point in space at a particular time without being too high or too fast?

When pilots are flying the downwind leg of their approach phase, they commonly use TCAS to determine where the aircraft ahead of them are being turned inward to intercept the ILS. The location and magnitude of the turn can be used to determine the remaining track miles (Figure 13).

![Figure 13. A diagram how turns size and distance to turn relate to track miles remaining](image)

The “can I do it?” display graphs the relationship of energy to the position and angle of the turn (Figure 14). Turns resulting in angle/distance combinations on the middle line are perfect for the current energy. Combinations that are above the top line are impossible. Combinations between the top and bottom lines are possible, but may require unusually rapid or unusually slow energy loss. Combinations below the bottom line will require thrust to achieve. This implementation uses variations of the 3 times table heuristic to implement.
Future implementations will reflect physics more accurately. The display constantly updates to reflect the state of the aircraft. Future implementations will reflect physics more accurately.

The permanent nature of this display means that the pilot can respond to a request by a controller without needing to interact with the system at all – they can simply read the suitability of the instruction from the display.

Note that this display does not require any of the capabilities defined under SESAR, but simply reflects the current state of technology. The simplicity of the display means that it could conceivably be implemented in the near future.

Figure 14. The “Can I do it?” display. The distance to the turn and the angle of the turn are used to calculate the suitability of the energy profile

4. INTERACTING WITH CONTAINERS

Before computers, humans used their head and eyes for exploration, their feet for movement and their hands for manipulating. In the modern world, we overload the use of hands. For example, the mouse as a 2D interaction and control device is often used for all three purposes, with the function of the eyes reduces and the feet eliminated. While adaptable, it is difficult to use the mouse in, say, 3D spaces or in spaces that require movement and selection of multiple objects in depth. We will be applying a number of new techniques that are based on adapted commercially-off-the-shelf tracking systems (such as the Wiimotes) creating new spatial interaction techniques with various contents that will allow some degree of accuracy to select points in the multi-dimensional space, while allowing users to return to the more natural division of labor. As much of this work is still at early stage, the demonstrations may require wired devices. Another alternative also being trialed to support spatial interaction is the 3D data gloves (the P5 Data Glove). This will afford the ability to create chorded gestures that can potentially increase the number of actions that can be controlled via spatial interaction without the use of menus. For example, a 3-finger gesture
could be associated with Action A, while a 5-finger gesture could be associated with Action B. Combining this with the ARToolkit used in the development of Year 1 prototypes, this would open up a very powerful array of interaction possibilities that could lead to a more natural, un-encumbered, environment for interacting with technology on the flight deck and at the CWP under SESAR.

4.1 Fish-tank Virtual Reality

When a person views a scene through a window, the view of the scene changes as the user moves their head. In this sense, a window is very different from that on a computer screen. Additional cues like motion parallax mean that users can perceive depth more effectively (Deering 1992). The feeling is much more realistic, and is one category of desktop virtual reality (VR). Careful use can even provide the illusion that objects are in front of the screen (Figure 15).

![Figure 15. The Fishtank VR display. The two images show the same set of tubes from different points of view. The user changes the view by moving their head.](image)

By combining the Nintendo Wiimote and the Ogre graphics engine, we created a 3D desktop
VR environment that allows cheap and rapid prototyping of display and interaction concepts. We have also used anaglyph stereo effects to make the effect even more powerful. While the anaglyph technique limits the colours that can be used in the display, we are exploring recent display technologies to overcome this limitation. In the future it is hoped that we will be able to move towards visualization technologies that do not encumber the viewer at all. This concept allows the user to use head movements to explore the environment in a way that is both far more intuitive and powerful.

4.2 **Wii Balance Board Navigation**

Modern computer users do not use their feet very much. This limitation is unusual, considering the utility of foot controls. Drivers use foot pedals to shift the load of speed control away from the hands. Pilots use feet to control the rudder, organists use their feet to press pedals, and controllers may use their feet to control the radio, or not at all.

The Nintendo Wii Balance Board allows users to control the computer with their feet (Figure 16). Using our test environment, users can navigate through and around their environment by shifting the weight of their feet on the board, meaning that the workload on the hands is drastically reduced.

![Figure 16. A user manipulating trajectories using an ARToolkit 3D mouse and Fishtank VR with anaglyph stereo. The Wii Balance Board is used for navigation.](image)

4.3 **The ARToolkit Mouse**

The ARToolkit interaction used by the Tangible Lens and the AR in Your Hand described in our Year 1 Report, can be harnessed to provide users with 3D control. Users mount a
marker on the back of the hand and a webcam tracks the marker in space. Movements of the hand can be translated into movements of a 3D mouse pointer.

The equivalent of mouse buttons is provided by either holding a wireless mouse or by using additional markers on the fingers. Curling the fingers into the hand occludes these markers. By curling in different fingers the user can produce “chords” that allow for up to 32 different control instructions with a single hand. The ARToolkit mouse with wireless mouse selection has been implemented in the 4DET concept (Figure 16).

4.4 Spaceball5000

The Spaceball 5000 (Figure 17) has a ball that allows isometric translation or rotation to control the position of the screen pointer. Twelve buttons also allow gestures for different types of on screen object selection. Unlike the other interaction technologies described here, the user’s hand remains on the desk, much like using a mouse. While the mapping between movement and the effects on the screen may be less intuitive, it may be found that the interaction is less tiring and more suitable for long periods of use.

![Figure 17. A user manipulating trajectories using Fishtank the Spaceball 5000.](image)

The Spaceball 5000 has been used for some concepts, and will be implemented in the 4DET in the near future.

4.5 Wiimote Pointer

A Wiimote could be held in the user’s hand and used as a virtual laser pointer (Figure 18). The pointer would be positioned where the pointer intersects with an object on the screen. The Wiimote has 11 buttons that could be used to provide the gestures necessary for control. Once a gesture is made, dragging the Wiimote in 3D would have the effect of dragging the pointer and any selected object. This concept will be implemented in the future.
Figure 18. A user manipulating trajectories with the Wiimote pointer.

4.6 P5 data glove

The P5 data glove (Figure 19) can be tracked in absolute space and has finger sensors to indicate hand gestures. Like the ARToolkit mouse, curling or uncurling fingers could be used to provide up to 32 different gestures. This technology will be implemented in the future.

Figure 19. The P5 data glove allows position sensing and chorded interaction.

4.7 Gyration 3D Air Mouse

The Gyration 3D air mouse uses accelerometers and gyros to track motion in 3D. There are 15 buttons that allow users to gesture select and deselect objects. This technology will be implemented in the future.
5. CONCLUSIONS

Through our efforts this year, we have achieved a number of important technical steps for advancing the work of developing novel human-systems interfaces for pilots and air traffic controllers.

a. We have developed the ability to interface with COTS (commercially-off-the-shelf) equipment, such as Nintendo Wiimote and Balance Board, without the need for custom hardware, and we are able to use these devices to provide new methods and techniques for containing and controlling the visualisations in different combinations. Having such a capability allows us to rapidly investigate the effects of alternative technologies to reveal new ways of working for the controllers and the pilots under a future SESAR scenario.

b. We have investigated and evolved a tool chain that can be used to facilitate multi-partner, distributed development efforts. We now use of the Open Source OGRE (Object-Oriented Graphics Rendering Engine) tool, a scene-oriented, flexible 3D engine, for rapid production of 3D visualisations.

c. In addition, we have implemented COM interfaces that allow native C++ and Managed C# to communicate, allowing some inter-operability between different operating environments.

We have also come to understand a number of operational issues as they affect the future design of systems that have yet to exist for SESAR. These include:

a. Although in the work domain of air traffic control and aviation in general, 3D is often used to refer to a 3D spatial perspective and faithful representation of the airspace in a virtual reality-type of computer display, we have realised that this interpretation can be limiting. As such, we have adopted a much broader concept of representing multi-dimensional ATC or flight related dimensions of the cognitive work, rather than 3D spatial perspective views. This has enabled us to devise new forms of 3D representations, rather than the need for a faithful representation of the airspace.

b. Energy management is difficult to plan for and execute, and difficult to assess, and often requires additional amounts of coordination between controllers and pilots to derive a trajectory that allows the aircraft to arrive at a designated point on approach that is not “too high or too fast”. Developing a distributed planning and coordination tool for use between pilots and controllers can reduce verbal coordination requirements during approach. In addition this has the potential for extending to other 4DT / RBT concepts.
c. Workflow scaling can be realised by changing the way information about the task is provided by re-representing traffic conflict information as a “white box” instead of as a “black box” as is currently the case with MTCDS and other conflict detection algorithms. We can visualise the constraining properties of aircraft conflict by creating an alternative way of representing the relationship between pairs or sets of aircraft. We portray closing distances in a display such that those aircraft with the greatest chance of closure and the behaviour of this closing distance is presented in the middle of the display. This concept will be further developed in Year 3.

6. REFERENCES


