Towards an Ecological Four-Dimensional Self-Separation Assistance Display

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In today’s airspace, rapidly increasing amounts of traffic are pushing the limits of capacity and safety. In an effort to optimize available airspace, various initiatives have been undertaken to investigate future air traffic management concepts. In these efforts, a shift towards trajectory-based environments can be identified, where user needs and performance capabilities are leading to user-preferred routing, using Airborne Separation Assurance Systems. This paper describes the initial research towards an ecological design of a four-dimensional Separation Assistance interface. Based on a work-domain analysis, several perspective projections of travel constraints are proposed, as well as an initial layout for the display concept. Key issues in the current design are discussed, with recommendations for future work.

Nomenclature

4D-SAI Four-Dimensional Separation Assistance Interface
AH Abstraction Hierarchy
ASAS Airborne Separation Assurance System
ATM Air Traffic Management
CPA Closest Point of Approach
EID Ecological Interface Design
ND Navigation Display
P-ASAS Predictive Airborne Separation Assurance System
PFD Primary Flight Display
PZ Protected Zone
SA Situation Awareness
SESAR Single European Sky ATM Research
SRK Skills, Rules, Knowledge taxonomy
VSAD Vertical Separation Assistance Display
VSD Vertical Situation Display
WDA Work Domain Analysis
X-ATP eXtended Airborne Trajectory Planning

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I. Introduction

In the current airspace environment, congestion problems are expected in the near future, due to rapidly increasing amounts of traffic. Because of the rigid nature of the airspace, which is divided in fixed volumes and route structures, this growth will result in higher workload for Air Traffic controllers, and reduced efficiency of trajectories. New concepts for Air Traffic Management, such as SESAR, permit a more flexible use of airspace, with airborne determination of user preferred trajectories.\textsuperscript{1,2} This flexible use is expected to increase airspace capacity, and reduce air traffic controller workload. However, because the separation task is shifted from the air traffic controller to the pilot, it is expected that the pilot needs to be assisted in this task.

Traditional Airborne Separation Assurance Systems (ASAS), such as Predictive Airborne Separation Assurance Systems (P-ASAS),\textsuperscript{3} have been developed to assist pilots in their task of self-separation. Generally, such systems support the pilot by presenting a limited set of explicit, ‘ready-to-use’, avoidance maneuvers as solution to a separation conflict. Such automated systems have proven to be effective in terms of conflict resolution and workload reduction, but they limit the pilot in exploring other solutions, and therefore, may prohibit full exploitation of the travel freedom offered by the airspace environment. Also, in a complex traffic environment, non-routine situations may arise, that may not have been foreseen in the automation design. In these exceptional cases, the pilot’s ability to improvise is vital for successful conflict resolution. It is therefore of key importance that automation and instrumentation promote a high level of Situation Awareness (SA).

At Delft University of Technology, extensive research is being performed on Ecological Interface Design (EID) of Airborne Separation Assistance Systems: displays designed to visualize the affordances the airspace provides. These displays assist the pilot in their task of self-separation, without relying on explicit resolutions provided by automation. Previously, several concept displays have been developed, for separation assistance in the horizontal plane, as well as the vertical plane (see Figure 1).\textsuperscript{4,5}

![X-ATP: Horizontal separation assistance display, presented on the Navigation Display.](image1)

![VSAD: Vertical separation assistance display, presented on the Vertical Situation Display.](image2)

Figure 1. Separation Assistance displays.

Although these displays successfully support pilot decision-making in the task of self-separation, they still map the essentially four-dimensional problem (space and time) onto two displays. A resulting drawback is that these separate displays cannot show the interaction between the horizontal and vertical constraints, and can therefore lead to suboptimal solutions. Also, they still require the pilot to mentally integrate the information from the two displays to create his/her internal model of the situation. This article presents the initial work towards a Four-Dimensional Separation Assistance Interface (referred to as 4D-SAI). The following two sections will, respectively, introduce the ecological approach that was applied in the design of the display, and illustrate the work domain analysis that preceded the actual design. The third and fourth sections present the functional modeling of the separation problem, and the initial design of the 4D-SAI, respectively. The article concludes with a discussion on the key issues in the current display concept, and with recommendations for future work.
## II. Ecological Approach

Ecological Interface Design (EID) is a design paradigm that originates from the domain of process control. It addresses the cognitive interaction between humans and complex socio-technical systems. Its approach to interface design gives priority to the worker’s environment (termed ‘ecology’), focusing on how the environment poses constraints on the worker.\(^6,7\) Rather than taking the worker’s cognitive capabilities as a starting point, EID tries to identify what elements in the environment shape the operator’s behavior. The interface should reveal the possibilities and constraints afforded by the work domain. In other words, EID promises a more systematic approach to unambiguously define ‘what is the situation’ the pilot should be ‘aware of’.\(^8\) By focusing on the affordances and constraints posed by the work domain, the worker can be supported in actions that go beyond the worker’s anticipated tasks.

EID consists of two steps. The first step aims at determining the goal-relevant properties of the work domain (i.e., what to display), and the second step addresses the actual interface presentation (i.e., how to display). In the first step, a workspace analysis tries to identify functionalities, constraints, and means-end relationships within the work domain. The main tools for this analysis are the Abstraction Hierarchy (AH), and the Skills, Rules, and Knowledge taxonomy (SRK), both developed by Rasmussen.\(^9,10\) Following the workspace analysis, EID advocates visualization of the constraints and means-end relationships in the environment in such a way, as to fully take advantage of the human capacity to directly perceive, and act upon cues from the environment.

## III. Work Domain Analysis

The first step of ecological interface design consists of a workspace analysis, using Rasmussen’s Abstraction Hierarchy.\(^10\) The abstraction hierarchy is a stratified hierarchical description of the workspace, defined by means-end relationships between the adjacent levels, see Figure 2. Along the vertical axis, the five levels of the AH represent the constraints at decreasing levels of abstraction, starting at the top with the purpose(s) for which the system was designed, all the way down to the spatial topology and appearance of the components that make up the system on the bottom level.\(^10,11\) Along the horizontal axis, components and constraints are arranged from internal items on the left, to external items on the right.

At the functional purpose level, the goals of the system are defined. In the case of ASAS applications, these are flying safely, productively, comfortably and efficiently through unmanaged airspace. Aside from issues such as staying within the flight envelope, safety in aircraft locomotion is assured by maintaining sufficient separation from potentially hazardous objects, such as other aircraft and terrain. For ASAS self-
separation applications,\textsuperscript{12} this means adhering to the defined separation minima between aircraft. Although more complex in reality, in this paper it is assumed that work is productive, as long as the distance to the destination is decreasing. For flight in general, comfort poses constraints such as upper limits on maneuver accelerations. The realization of efficiency is much more complicated, however, as it depends not only on fuel efficiency, but also on time and position constraints with respect to a flight schedule.

The abstract function level describes the underlying causal relationships that govern the realization of the purposes of the system. In the case of air travel, this level contains the general physical laws that dictate absolute and relative locomotion, and separation.\textsuperscript{13}

The general function level describes how the functions at the abstract function level are achieved, independent of the actual implementation of the system. Properties such as weight, lift, thrust and drag, and the maneuvering performance of the aircraft all impose internal constraints on aircraft behavior. External obstructions further constrain aircraft motion, and dictate the (lack of) separation. On the bottom of the abstraction hierarchy, the physical form and functions are described by modeling the internal layout of aircraft components, and external airspace properties such as other traffic, weather, and terrain. The physical function level describes the various components, and their capabilities, and at the physical form level the appearance and location of components, the airspace, and other aircraft are described.

In this paper, the workspace content and boundaries are limited to trajectory planning functions in direct relation with conflict resolution and prevention during cruise flight, and in situations with multiple aircraft. Functions related to aircraft control and stability, like staying within the flight envelope, and accounting for passenger comfort, are largely kept out of the analysis. The time interval in which this workspace is analyzed is determined by the applicability of conflict management, and is more or less situated between 60 seconds and around 15 minutes. Below 60 seconds, collision avoidance systems like TCAS II must take over in order to prevent collision.\textsuperscript{14} A 15 minute upper threshold is chosen because the vast majority of conflict resolution and recovery maneuvers take place in less than 15 minutes.

### III.A. Internal Constraints

The internal aircraft constraints that are relevant for this work domain analysis, mainly result from the Abstract Function and the Generalized Function of the Work Domain Model. They relate to the various limitations on the performance of the aircraft, such as bank limits, turn dynamics, available engine power, stalling, structural considerations, buffet characteristics, and requirements on external noise production, and passenger comfort. These limitations result in several constraints relevant to the task of trajectory planning, such as maximum turn rates, maximum and minimum operating speeds, fastest and steepest steady climb and descent, and the steepest steady climbing and descending turn. Another important, although not directly perceivable constraining factor is the energy state of the aircraft: For an aircraft, speed and altitude cannot be changed independently of each other. The mechanism that underlies the coordination of the controls, is the management of the aircraft’s energy state. Speed and altitude are directly related to the kinetic and potential energy of the aircraft. The total amount of energy is determined by the throttle, whereas the elevator is used to control the exchange of kinetic and potential energy.\textsuperscript{15} The total energy state of an aircraft essentially determines the affordances for maneuvering in terms of speed and altitude.\textsuperscript{16} Together these internal constraints determine the reachable area for a certain timespan.
III.B. External Constraints

In unmanaged airspace, the reachable area that was defined by the internal constraints is further constrained by external factors, such as weather, terrain, other traffic, and the boundaries of the unmanaged airspace. In this analysis, the focus lies on the constraints imposed by other traffic. Traffic constraints are shaped by a minimum horizontal and vertical separation between any two aircraft, that should be adhered to at all times. With common values of 5 nautical miles horizontal, and 1,000 feet vertical separation, this results in a three-dimensional Protected Zone (PZ): A flat, three-dimensional disc around each aircraft, that should remain clear of other traffic, see Figure 3.

Intrusion of this space is referred to as a loss of separation. A conflict is defined as a future loss of separation, within a certain observation timespan (e.g., 5 minutes). In Figure 4, ownship is flying with velocity $\mathbf{V}_{own}$, and will eventually lose separation with the intruder aircraft, if no further action is taken. The point where separation is at a minimum is called the Closest Point of Approach (CPA). It can be seen that even when ownship turns away from the conflict situation, separation can still be lost.

![Figure 4. Future loss of separation](image)

IV. Functional Modeling of Aircraft Behavior and Separation

Although a work-domain analysis provides insight in the structure and content of the work domain, it still requires a translation of this analysis into a practical interface design. Based on the Ecological Interface Design (EID) concept developed by Vicente, this translation is done through Functional Modeling. Functional Modeling tries to formulate the behavior of a system relevant to achieving its ends. For trajectory planning this implies that the goal-relevant affordances must be visualized in such a way, that the pilot’s perception of these cues directly triggers desired goal-relevant steering actions.

In the context of airborne separation, the behavior of the system is highly complex, as it is governed by the multi-variable, non-linear dynamics of several aircraft, moving relative to each other. Because such a system has too many degrees of freedom to combine in a usable interface, a lower-dimensional description is required. This description should relate inputs that match common flight practice, to the goals and affordances of the system. In cruise flight, pilots control their aircraft by manipulating velocity, heading, and altitude settings, using the autopilot, or by modifying the planned route in the Flight Management System. A successful separation assistance interface should relate these variables to the affordances of the airspace. Figure 4 already illustrated that presenting conflicts in absolute space is problematic: The closest point of approach is not a constant factor, but varies as a function of ownship and intruder velocity, position, and heading. Therefore, steering away from a conflict based on the presentation in Figure 4 will also move the
IV.A. Traffic constraints in the relative velocity field

With the design of a horizontal and a vertical separation assistance display, previous studies illustrated that conflicts can be better presented in a relative velocity field. Under the assumption that intruder and ownship intent remain unchanged in the near future, a conflict can be predicted using the relative speed of ownship, with respect to the intruder aircraft:

\[
\vec{V}_{\text{rel}} = \vec{V}_{\text{int}} - \vec{V}_{\text{own}}
\]  

When the line extended from the relative velocity vector crosses the intruder protected zone, a loss of separation will occur in the near future, see Figure 5. By drawing lines through the ownship position, that are tangent to the intruder PZ, a three-dimensional wedge-shaped area can be defined, which marks the constraints that other traffic imposes on ownship relative motion with respect to an intruder aircraft (Figure 5). The constraints on ownship velocity can be obtained by translating the wedge-shaped area by the intruder velocity, see Figure 6.

An obvious way to present these three-dimensional constraints would be to make use of a perspective display. However, this introduces problems of loss of context and orientation, image distortion, and occlusion. Non-distortion approaches to access the internal details of 3D structures make use of cutting planes, layer removal, and transparency. Earlier designs of separation assistance displays reduce the complexity of the problem by relating several key controllable variables to a planar projection of the three-dimensional conflict situation: The X-ATP display presents the affordances for aircraft airspeed and heading using a horizontal projection of the conflict situation, whereas the VSAD interface relates airspeed and vertical speed to a vertical projection of the constraints, see Figure 1.

An often heard comment from pilots, in the evaluation of these previous designs, was, that while it featured as a valid and equal option in both displays, velocity changes are rarely used when resolving a conflict. Based on this feedback, this study investigates cutting planes based on constant velocity to project the 3D situation onto a 2D display.

IV.B. Constraint cutting plane for relative velocity

The first cutting plane is based on a constant relative velocity of the intruder aircraft, with respect to ownship, see Figure 7. The intersection of a sphere, with its radius equal to the magnitude of the vector \( \vec{V}_{\text{rel,int}} \), and the three-dimensional wedge shape from Figure 7, represents all velocities with equal magnitude of the intruder relative to ownship that correspond with possible future loss of separation. The constraint area is

\[
\vec{V}_{\text{rel}}
\]
indicated as $S_{\text{rel},\text{int}}$ in Figure 7. Next, this constraint area is projected onto the surface of an imaginary sphere, with its radius equal to the distance from ownship to intruder, together with the current relative speed, and the contour of the intruder PZ, see Figure 8. Here, $\vec{V}'_{\text{rel},\text{int}}$ is the projected relative velocity vector, $S'_{\text{rel},\text{int}}$ is the projection of the relative velocity constraint area, and $PZ'_{\text{int}}$ is the projection of the intruder PZ. This projection results in a (ice-hockey) puck-like shape, shown in Figure 11. In principle, every intruder aircraft can be visualized with its own puck. In that case, the size and direction of the relative speed vector would give information on how a possible conflict will evolve. If the relative speed vector lies in its constraint area, the intruder and ownship are in conflict. The direction of $\vec{V}_{\text{rel},\text{int}}$ indicates how ownship and the intruder will pass each other, whereas its size shows how closely they will pass. To indicate whether $\vec{V}_{\text{rel},\text{int}}$ is aimed towards, or away from ownship, four lines are drawn from the boundaries of the puck towards the velocity vector tip, when $\vec{V}_{\text{rel},\text{int}}$ is aimed towards ownship. The curvature of the puck is caused by the circular shape of the protected zone, and changes as a function of the vertical position of the intruder, relative to the ownship.

IV.C. Constraint cutting plane for ownship velocity

The puck shows the relative speed of the intruder, i.e., its relative movement, the urgency of the potential conflict, and the area in which the relative speed vector should not be positioned. It does not show, however, and this is crucial, what the pilot of ownship can do to keep the relative velocity out of conflict. In the current concept, this is one of the main challenges. In order to present the pilot of ownship any useful information about what he can do about a particular situation, a constraint area is required that relates to his own velocity vector.

To realize this, a second projection can be created which uses a cutting plane based on constant ownship velocity. Based on pilot feedback regarding the use of speed changes in resolving conflicts, it is assumed at this stage that velocity is kept constant by the pilot. Future design iterations will investigate what exactly can be done in order to visualize the effects of changes in ownship velocity. Figure 9 gives an example of how a sphere of constant ownship velocity would intersect with the 3D constraint wedge. The resulting area is marked in light-grey in Figure 9. This shape shows the constraints for the ownship Flight-Path Angle (FPA), that are imposed by the intruder’s motion, for the current speed of ownship. The next step is then to project this constraint area on the perspective projection sphere that is also used for presenting the puck, see Figure 10.
IV.D. Projecting constraint areas onto a 2D display

As the four-dimensional separation assistance interface (4DSAI) to be developed is likely to contain perspective elements (using the projection sphere centered around ownship), the visual angle design principle, also successfully applied in ecological synthetic vision overlays,\textsuperscript{17} was adopted. The translation from the projection sphere to a two-dimensional display is made using an equidistant cylindrical projection. This projection directly relates zenith ($\phi$) angle and azimuth angle ($\theta$), to x and y screen coordinates, respectively:

\begin{align*}
x &= \theta \\
y &= \phi
\end{align*}

(2)

This method of projection results in size and shape distortions for large azimuth angles. However, the influence of this effect on the perception of combined internal and external constraints can be considered small, as aircraft flight-path angle $\gamma$ will never grow very large for commercial aircraft. Figure 11 and Figure 12 show some examples of this projection for the puck and the flight-path angle constraints, respectively.

IV.D.1. Projection of the puck

Figure 11 shows some examples of what the puck may look like, for three different situations. In Figure 11(a) the relative speed constraint area has grown, indicating that the probability of a loss of separation has become larger. Note that the puck would have grown too in size on what is essentially a three-dimensional perspective projection. From the location of the tip of the velocity vector we can see, however, that no loss of separation will actually occur in this situation, as it is located outside of its constraint area. In this case, we can also see that the intruder aircraft moves upward and to the left, relative to ownship. In Figure 11(b) the relative velocity vector is such that it points directly at ownship, and therefore is located in the center of its constraint area. This means that in this situation a collision would occur, if no further action is taken. Note that when both the ownship as well as the intruder aircraft are equipped with the same interface, their representations would be very similar. In Figure 11(c) a situation is shown where the relative velocity vector
is still inside its constraint area, and a loss of separation will occur when nothing is done. Also, the intruder aircraft will move to the right and ascend relative to ownship.

**IV.D.2. Projection of the FPA constraint area**

Figure 12 shows several shapes that the flight-path angle constraint area can take. Figure 12(a) shows the result of the example projection from Figures 5-10. In this case, the intruder aircraft is situated to the right of ownship, flying at the same altitude. If ownship is flying level, ownship and intruder will eventually lose separation if no further action is taken. Figure 12(b) shows a situation where the ownship velocity-sphere intersects the constraint-wedge twice. This can happen when an intruder is flying at a greater velocity than ownship, and intruder and ownship’s tracks will be crossing sharply ($\Delta \psi \simeq 90^\circ$). Figure 12(c) shows a situation where an intruder is overtaking ownship from directly behind, flying at a higher altitude. Because the intruder is close to ownship, almost all climbing maneuvers of ownship would lead to a loss of separation.

Note that the current derivations of the puck and the flight-path angle avoidance zone, assume instant state changes. It can be shown that this is a safe assumption when a predicted conflict is still in the far future. However, maneuver dynamics will start to play a larger role when conflicts become more imminent: in the case of tactical maneuvers (within 10 minutes of a predicted conflict), unmodeled dynamics will cause significant errors, particularly speed maneuvers.\textsuperscript{18, 19} To compensate for these inaccuracies, future iterations of the 4D-SAI concept will incorporate maneuver dynamics in the presentation of airspace affordances.

**V. The 4D-SAI Display Concept**

Figure 13 illustrates the first design prototype of the separation assurance interface. The concept presents the separation assistance display elements introduced in the previous section, on a equidistant cylindrical projection of the airspace surrounding ownship, similar to what is used for a Primary Flight Display. The line-of-sight moves with the ownship track angle, but azimuth offset $\theta_0$ is fixed, making it an ‘outside-in’ representation. Clearly, to visualize the separation assistance information regarding all intruder aircraft located within time-vicinity (e.g., 5 minutes separation in time), several different options are available. One could, for instance, present the aircraft in front of the ownship ($\pm 90$ degrees) on the PFD, and then have a "rear-view mirror" to present all intruder aircraft behind the ownship (from $-180^\circ$ to $-90^\circ$ and from $180^\circ$ to $90^\circ$). Although the current implementation uses a complete "omni camera"-like heading presentation, other presentations will be considered as well in future experiments and designs.

**V.A. Display components**

In the current concept, the horizontal axis represents the full heading range, $\pm 180$ degrees, and behaves like a compass. This means that when ownship changes heading, the separation elements on the display shift horizontally, corresponding to the change in heading. The vertical axis of the current concept presents the azimuth angle, in an inertial frame of reference, ranging from $-90$ to 90 degrees. Vertical ownship maneuvers are visualized with the vertical offset of the flight-path vector symbol $\theta$, from the center-line of the display. Together with the flight-path angle, the energy angle is shown as well $\phi$, i.e., the flight-path the pilot can select to realize a steady climb or descent. Climbing / descending internal constraints are shown with the curved line $\phi$, and dashed lines $\phi$. The curved line, $\phi$, shows the maximum steady flight path angle that can be achieved in a climbing turn. The steepest steady climb and descent for the current velocity are shown with the double dashed lines $\phi$. 
Intruder aircraft that are in conflict with ownship, or can get into conflict with ownship within the prediction horizon, are shown using the puck \( \bullet \). The center of the puck represents the location of the intruder, relative to ownship. The arrow and its four lines indicate the direction and (projected!) magnitude of the relative velocity of the intruder. When the lines are present the intruder is moving towards ownship, when they are absent the intruder is moving away from ownship. The size of the puck depends on the distance to the ownship (smaller is further away). The shaded area in the puck represents the constraints for the velocity of the intruder, relative to ownship. If the tip of the relative velocity vector is located inside this area, and has the four lines attached, a loss of separation will occur within the look-ahead horizon.

Constraints on ownship flight-path vector are shown with a shaded area \( \hbar \). Note that the this area is only valid for the current speed. Conflict urgency can be indicated by varying the shading of the flight-path constraint area. Intruder flight-path vectors are shown as dots on the display \( \mathbb{D} \). Moving the ownship flight-path vector towards one of these dots to resolve a conflict will lead to a very inefficient resolution, as this maneuver will cause ownship to fly parallel to the intruder.

V.B. Dynamical behavior of the display

Because the display projections depend not only on relative speed, but also on relative position of the intruder aircraft, the projection elements will change shape over time, even when no corrective action is performed to resolve a conflict. Figure 14 illustrates this dynamic behavior over time, with an example where one intruder aircraft passes behind ownship. In the example, ownship is flying north at an altitude of 20,000ft. The intruder is flying level at 36,000ft with an airspeed of 130 kts. The intruder is flying just behind ownship, at around 105° to the right, with a track angle of 320°. The intruder has a velocity of 175 kts, at a distance of 24 NM. The resulting \( \vec{V}_{rel, int} \) is directed just behind ownship, resulting in the intruder passing behind ownship during the course of the scenario.

The scenario illustrates the emerging behavior of the flight-path constraint area. Figure 14(a) shows the situation at \( t = 0 \). The intruder is illustrated with the puck, and the constraint area for the ownship Flight-Path Vector (FPV) is split into two parts. Both FPV constraint areas grow over time, up to the point that the larger of the two is stretched over the sides of the interface, as illustrated in Figure 14(c). In Figure 14(d), the larger area 'opens up', and stretches over the whole top of the display. In Figure 14(d) and Figure 14(e), the small and large constraint areas grow towards eachother, until they merge in Figure 14(f). After that, the stretched area shrinks again and becomes smaller, up to the point where it finally disappears in Figure 14(j).
Figure 14. Example of intruder aircraft passing behind ownship on several moments in time
VI. Discussion

The goal of the current study was to work towards a separation assistance display, that combines horizontal and vertical affordance information, that were presented separately in previous studies. An ecological approach was adopted, where results from a work-domain analysis on multiple levels of abstraction were translated into a visual representation of the travel constraints. It is clear that the step from work domain analysis to display concept is far from a trivial one, and more than one iteration between analysis and design will be required to work towards a fully functional, and mature design.

One of the main design challenges, is to make use of an aircraft pilot’s existing ecology. For travel planning and avoidance, pilots already make use of the outside view and existing cockpit instruments, to perceive the affordances of the airspace. The challenge is therefore not to replace, but to enhance this perception. One way to do this is to find a compatible display to adapt with the separation assistance elements. For instance, the X-ATP display used the existing Navigation Display (ND) to present a horizontal projection of the travel affordances, and the VSAD projected the situation onto a modified Vertical Situation Display (VSD). The current concept would be most compatible with the Primary Flight Display (PFD), since they both present their information in the heading/flight-path-angle space. However, a problem with this combination is that a PFD presents its information in an “inside-out” fashion (i.e., the aircraft symbol is stationary, whereas the horizon moves). This is an unfavorable situation when separation avoidance elements are shown on this display. Because these elements are related to the orientation of the ownship, they will move and rotate with the horizon, making them more difficult to interpret. It is expected that a lot of the pilot criticism would relate to this issue.

Another consequence of the current choice of cutting-planes is that the visualized affordances that relate to ownship motion relate to heading and vertical speed changes, however, they do not show the affordances in terms of ownship velocity. Although pilot feedback in the evaluation experiments of the previous concepts already indicated that velocity changes are rarely used when resolving conflicts, the ‘perfect ecological interface’ would ideally present the affordances for all of the pilot’s maneuvering options. This will also be addressed in the upcoming design iterations.

VII. Conclusions

The design of a separation assistance display described in this paper was motivated by the fact that the earlier designs map an essentially four-dimensional problem onto two displays. Using Vicente’s Ecological Interface Design paradigm, a first attempt was made with the design of a four-dimensional Separation Assistance Interface. The initial design, presented in this paper, uses a spherical projection of the separation conflict based on a constant velocity. The resulting elements are a flight-path avoidance zone, and a projection of the intruder aircraft Protected Zone, which includes information on the intruder’s relative speed with respect to ownship.

The most important issues in the current design are the choice of a compatible display to present the separation assistance elements in. A second issue is that the current presentation of affordances related to the ownship flight-path vector does not yet show the effect of varying the ownship speed. These issues will be addressed in the next design iteration step, and in an upcoming experiment, evaluating the first concept in a flight-simulator.

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