Integration of Information in Synthetic Vision Displays: *Why, To What Extent,* and *How?*

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ABSTRACT

Current experimental synthetic vision systems present a spatially integrated presentation of physical constraints such as terrain and obstacles. This paper presents a number of assumptions regarding anticipated procedures and the use of a synthetic vision system, and addresses the desirability of integrating temporary constraints related to the airspace, the airport, and standard procedures. Following this, a number of examples are presented that illustrate a potential approach to integrate such information into a synthetic vision display. The paper ends with an overview of the results from an experiment in which the influence of an integration of temporary constraint information on pilot decision-making was examined.

INTRODUCTION

The rationale behind the use of synthetic vision display formats is to make the information regarding terrain and obstacles available to the pilot, independent of visibility conditions [1]. The way information is made available influences the way in which the information is used. When using a data presentation concept in which a certain amount of the required information is integrated, there is a likelihood that the other, non-integrated information is overlooked.

The integrated depiction of flightpath, obstacle, and terrain information in a synthetic vision display is intended to inform the pilot about the future flightpath and to provide sufficient awareness of the surrounding environment. Both in simulator and actual flight tests, a prototype of a synthetic vision display concept (Figure 1) has been used to demonstrate that with

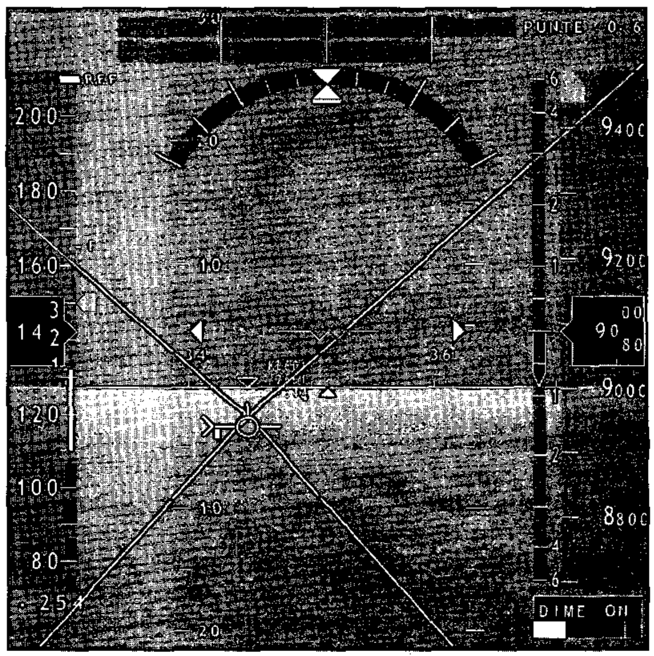

Fig. 1. Example format integrating terrain, obstacle, flightpath, traffic, and aircraft state information

respect to the guidance task, the display supports accurate manual control with low workload. With respect to the navigation task, the display provides a good awareness of the surrounding environment. In [2], the particular concept shown in Figure 1, also referred to as a Synthetic Vision Information System (SVIS), is described in more detail.

Figure 2 provides an overview of the data that is integrated in the display format shown in Figure 1, classified by age of the data. Static data comprises terrain elevation data (e.g., from the Shuttle Radar Topography Mission), obstacle data (e.g., from the FAA), airport data (e.g., from the Safe Flight 21 survey [3]), and route data (e.g., from the FMS database). During the operation, both event-related data (e.g., ATC instructions) and real-time data are integrated.

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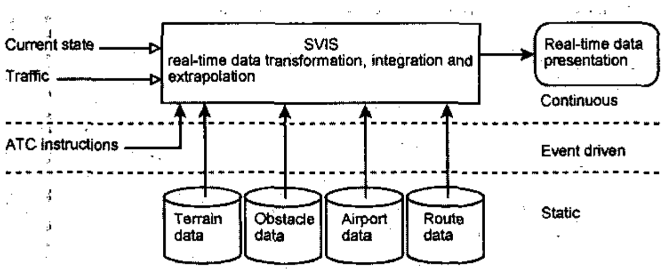

Fig. 2. Overview of the data integrated in the display format shown in Figure 1

Based on the classification of the used data by its age, the following section addresses potential consequences when other data, imposing additional constraints on the situation, needs to be considered.

WHY?

Potential Issues

The underlying assumption for the use of the guidance display is that the depicted path assures a conflict-free route. However, the update cycle of the FMS database from which the route is constructed, is typically three weeks. Temporary changes to a SID, STAR or MISAP within this cycle are published in a Notice to Airmen (NOTAM). The situation in which the pilot flies a path that, according to a NOTAM, is not to be flown should be prevented.

A category of constraints that is not integrated into the format depicted in Figure 1 is the one comprising the temporary constraints for the airspace and the airport environment. Such constraints may have either a non-physical nature; e.g., restricted airspace or a physical nature; e.g., a taxiway closed due to maintenance. With current operations, the pilot is informed about these constraints by means of NOTAMs. This has raised the question regarding the desirability of visually integrating the temporal constraints into the presentation. This question will be answered through an analysis of potential situations in which the constraints may become relevant and a pilot-in-the-loop experiment.

When is the Information Needed?

During normal operations, the path guarantees a conflict-free route, and the presentation of the terrain mainly serves to provide the pilot with a sufficient level of awareness regarding the surrounding terrain. This allows him to better take this information into account should the situation occur where he suddenly needs to deviate from the planned path.

In case the aircraft significantly deviates from the path, the pilot also needs to take into account any existing airspace restrictions. Besides for the separation with other traffic, he also relies on ATC to detect any potential (future) violation of restricted/prohibited airspace that may occur because of an error made by the pilot. Such an error may be caused by unawareness of the constraints or insufficiently accurate spatial awareness. Given the fact that terrain and obstacles are graphically represented in an ego–centered reference frame, whereas some of the airspace constraints are specified as text in a NOTAM, it is not unlikely that the accuracy of the location of the constraints in the pilots' mental spatial picture of the situation is less for these latter geospatial constraints.

Assuming that the situation of such a pilot error can occur, this raises the following questions:

- *Given the potential consequences, is it sufficient to rely on ATC to timely vector the pilot away from the restricted or prohibited airspace?*
- *Are there operations during which it is desirable to ensure the pilot has a more accurate awareness of the exact location of the constraints?*

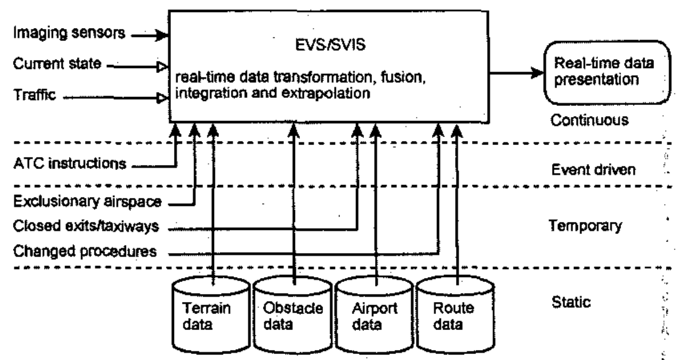

Fig. 3. Addition of real-time imaging sensor data can be used to provide a hybrid synthetic / enhanced image to the pilot

Given that ATC needs a certain amount of time to detect a potential airspace violation and vector the aircraft away from it, the need to ensure that the pilot has an accurate awareness of the location of restricted/prohibited airspace will increase with a decrease in temporal distance toward that airspace.

An example of an (experimental) operation during which an aircraft comes quite close to prohibited airspace is the river approach into runway 19 of Washington Reagan National Airport (KDCA). Alaska Airlines has defined an LNAV/VNAV path that allows this approach to be flown using the FMS. During such an operation, the pilot is a supervisor. At several points during the approach, the aircraft comes within 3000 feet from the prohibited airspace P56A over Washington.

One cannot exclude the possibility that, due to some unforeseen event, a certain part of the depicted route suddenly is no longer conflict-free. Also, the automation may disconnect, requiring the pilot to take over manually. It is for these types of non-nominal situations that we think the concept of integrated presentation of airspace constraints has merit, both during a supervisory task and a manual control task.

Airport Data

The database used to depict the airport layout is the result of a survey effort. Temporary changes to the airport, such as closed taxiways and/or runways cannot always be timely provided through a database update. Similar to temporary changes in procedures, such constraints will be published in NOTAMs. This raises the question whether it is desirable to integrate this type of information in the surface guidance display(s). Under the assumption that the pilot is provided with a completely defined route from a specific runway exit to the desired gate, the information regarding closed taxiways and/or runways is not explicitly needed for the guidance task. If the pilot has a certain freedom in the choice of the runway exit, it is important that he/she is aware of closed exits.

Extensions to the Data Integration

If the system should include the possibility to integrate information regarding temporary changes in procedures and temporary airspace and airport restrictions, an additional layer of information needs to be added. Figure 3 shows how this layer fits into the overall structure of the SVIS depicted in Figure 2.

It is unlikely that a terrain and obstacle database is completely error-free. One approach that is being pursued to deal with this problem is the real-time integrity monitoring of the terrain database using measurements from the radar-altimeter [4]. The resulting system is also referred to as Database Integrity Monitoring Equipment (DIME). Integration with the display format would probably be in the form of a caution indication in case a mismatch is detected. Another approach to deal with situations in which either database errors or lack of information regarding other obstacles can reduce safety is the integration of real-time imaging data [5, 6, 7]. Figure 3 shows at which level this type of information is integrated into the proposed concept.

WHEN?

The discussion in the previous section has illustrated that, in certain situations, the quality of the pilot's decision is likely to be better when information about airspace and airport constraints is integrated in the SVIS.

Since the required level of awareness depends on the situation, this raises the question when the information about these constraints needs to be depicted. The following options exist:

- Always
- Pilot-selectable
- Pilot-selectable and automatic
- Automatic.

Depending on the amount of data that is added to the display, the first option can be undesirable for those situations in which the likelihood of the information becoming relevant is very low and/or the temporal distance to the constraints is

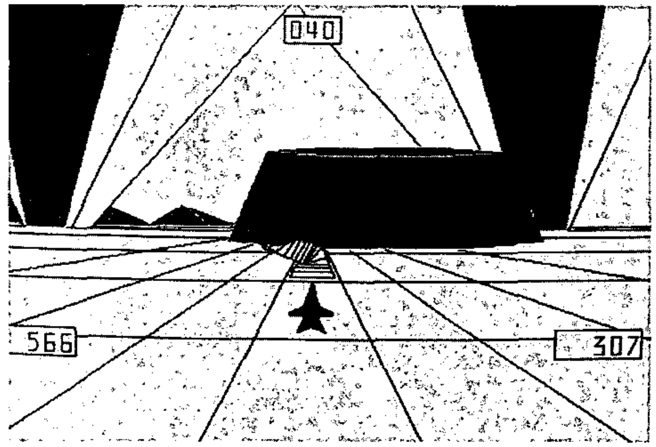

Fig. 4. Depiction of airspace with a high lethality due to SAM or AAA [8]

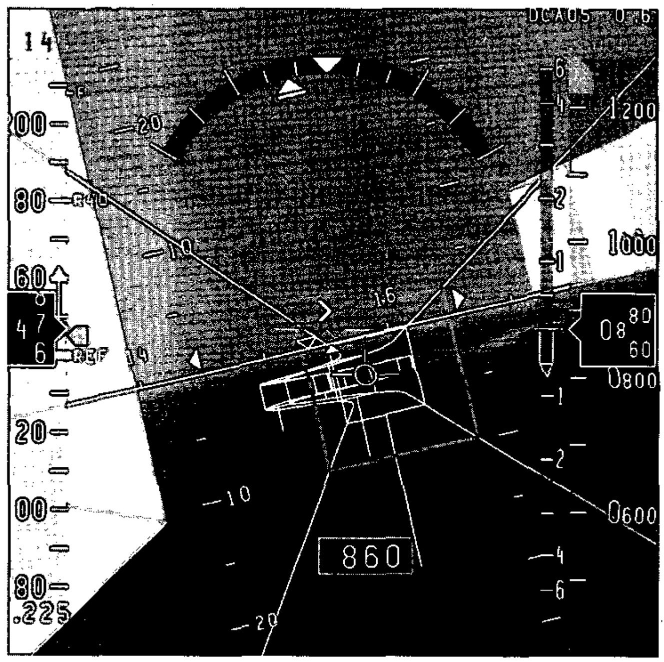

Fig. 5. PFD during river approach to Runway 19 of KDCA (July 2002)

(still) high. For navigation on the airport, the data that needs to be integrated in the display to indicate closed taxiways and/or runways is minimal. During rollout, the temporal distance toward a closed exit can be so small that it makes sense to always integrate these constraints in the display. On the other hand, the indication of restricted airspace can require a considerable amount of display space even when conditions are nominal and the aircraft is still far away from any particular exclusionary airspace. This increases the potential for clutter. Therefore, the pilot should at least have the option to deselect the depiction of restricted airspace. To ensure that when the information becomes relevant for the decision-making, it is

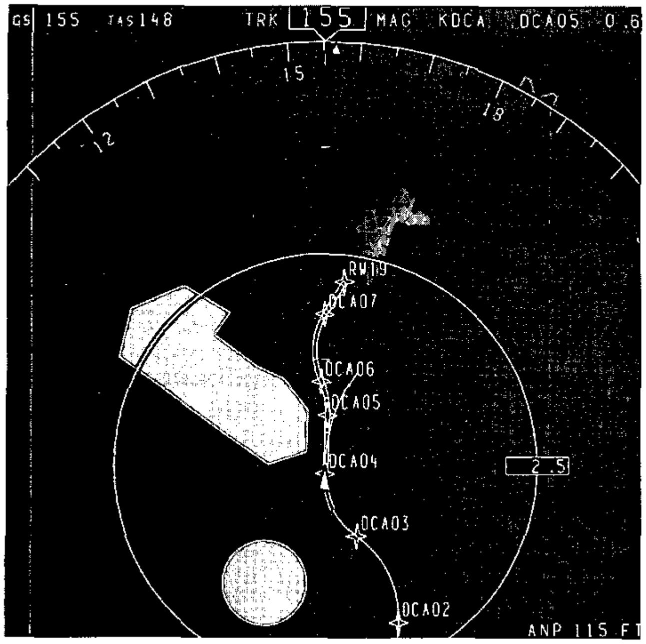

Fig. 6. ND for the situation depicted in Figure 5

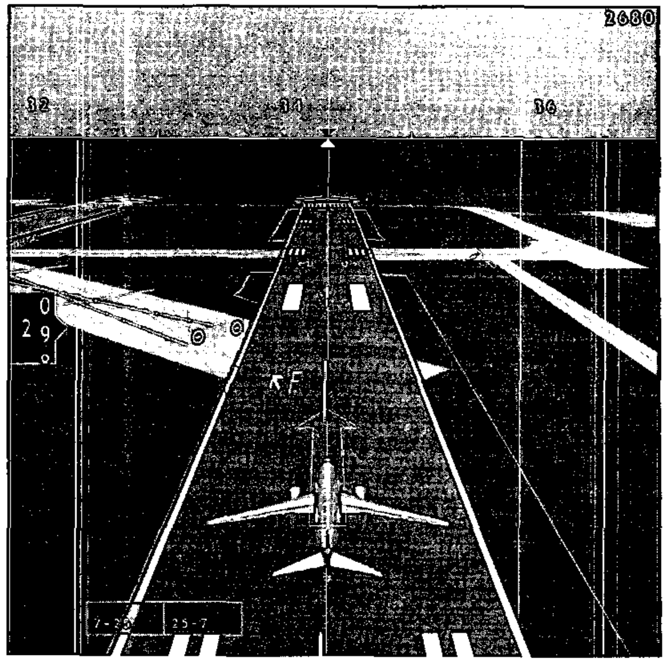

Fig. 7. PFD with no-entry signs to indicate the closed Foxtrot exit

available on the display, rule-based logic needs to be defined that automatically enables the depiction of exclusionary airspace. The design question here is what the rules are that trigger the depiction. Two potential situations are when the actual navigation performance is worse than the required navigation performance and the occurrence of a TCAS traffic advisory.

HOW?

Depiction of Airspace Restrictions

Until now, the graphical representation of the constraint data has not been addressed. Similar to the spatially integrated presentation of physical constraints in the SVIS through the depiction of 3-D volumetric objects, the non-physical constraints such as exclusionary airspace can also be presented through a depiction of their boundaries.

This idea was already proposed in the context of the pictorial format program [8], in which volumetric objects in a perspective presentation of the aircraft environment represented areas of high lethality due to enemy SAM sites or AAA (Figure 4).

Figure 5 shows an example of how the airspace over Washington is depicted on the Primary Flight Display (PFD) when flying the River approach into KDCA and Figure 6 shows the Navigation Display (ND) with a footprint of the prohibited airspace.

Depiction of Airport Restrictions

The depiction of airport restrictions is performed using a real-world analogy for the PFD and the usual X symbol for the ND. Figure 7 shows the PFD with a closed exit, and Figure 8 shows the ND for the same situation.

Integration of Imaging Sensor Data

The integration of imaging sensor data is an option to compensate for potential elevation and obstacle database errors and inaccuracies, and the detection of dynamic objects that are not provided by means of a datalink. Regal [5] discusses various options to fuse sensor data with a synthetic representation that were being considered for the Boeing high speed civil transport. In [6], an approach for the fusion of images with different spatial and temporal resolution is described, and in [7] the development of a synthetic vision system with a sensor inset is discussed. Figure 9 presents an example of a sensor inset into the PFD format presented in Figure 1. In the setup used to test the integration, the sensor image is integrated using a real-time capture of an RS-170 video signal from the sensor system. The ratio between the geometric field of view used for projection and the sensor field of view is used to compute the size of the inset, and the azimuth and elevation of the sensor relative to the aircraft body axis are used to compute the location of the inset. A filter is used to blend the edges of the sensor image into the synthetic scene. At present, a range of blending and filtering options are being investigated.

EVALUATION

To obtain initial feedback from pilots regarding the need for integration of this type of information, an experiment has been conducted. The experiment did only address the influence on pilot decision-making regarding the integration of NOTAM information about airspace and airport restrictions, and

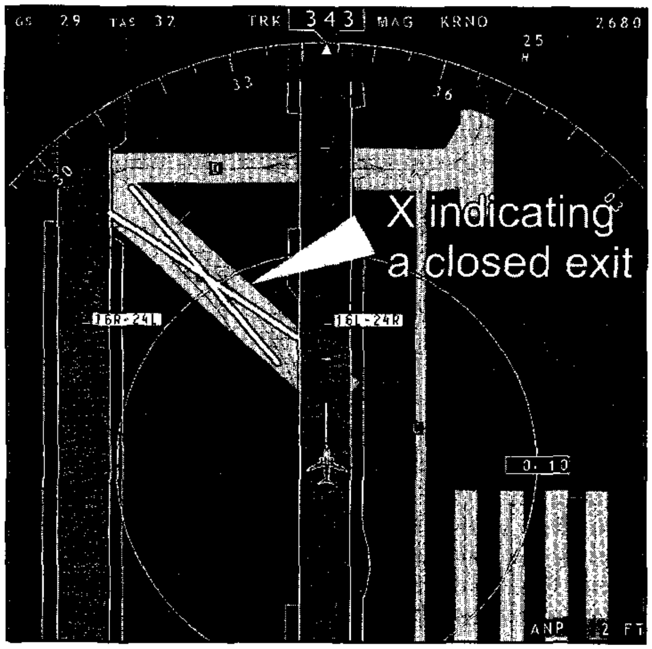

Fig. 8. ND with a yellow cross to indicate a closed exit

NOTAM information about changes to routes. Some of the scenarios used in the experiment contained an event that generated a conflict with the planned path. In the situations in which NOTAM information was not integrated in the display, the decisions made by the pilots suggest that sometimes they were unaware of the location of certain airspace restrictions. With the integrated depiction of the information, this never occurred. Pilot comments indicate that including relevant NOTAM information in the SVIS decreases workload and has positive effects on level 3 situation awareness. However, before the integration of relevant NOTAM information into the SVIS can successfully be implemented, several issues need to be resolved. The issues mentioned below are the ones that were encountered during the analysis of existing NOTAM reports, the development of the NOTAM functionality, or mentioned by the participants during the experiments.

- Only relevant NOTAMs are to be shown; *How can it be decided (by the system) whether or not information is relevant?*
- *How can different kinds of NOTAM information best be represented on the SVIS?*
- *(When) does clutter play a role?*
- *When is the information presented automatically/ (de)selectable?*
- *Is it possible that, in some cases, the presentation of NOTAM information will actually influence decision-making in a negative way?*

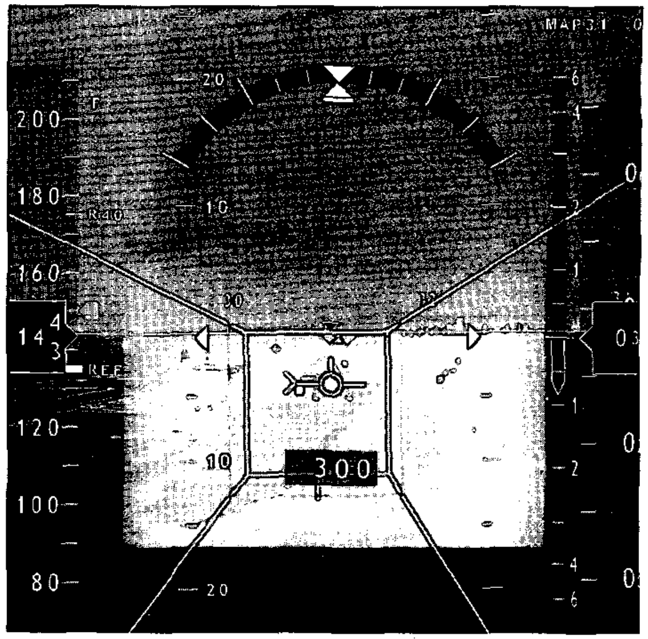

Fig. 9. Example of integrated sensor information in the SVIS PFD

- *Is it necessary that the source of the information is visible (in other words; that pilots can easily distinguish between database/NOTAM information)?*

SUMMARY AND CONCLUSIONS

This paper has discussed the addition of an another layer of information to a synthetic vision information system that integrates information about temporary spatial constraints. The layer contains information about additional constraints that the pilot may need to take into account during non-nominal situations. At present, this information is conveyed using charts and NOTAMs.

Both qualitative and quantitative data from initial pilot-in-the-loop evaluations indicate that the graphical integration of the additional constraint information increases the pilot's awareness of these constraints and reduces the likelihood of errors. Pilot comments indicate that the proposed integration is a desirable feature.

A way to allow the pilot to easily distinguish between different types of exclusionary airspace needs to be addressed, since situations may occur in which the pilot has to make the least bad decision.

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ABBREVIATIONS AND ACRONYMS

AAA	Anti Aircraft Artillery
ATC	Air Traffic Control
CDU	Control Display Unit
DIME	Database Integrity Monitoring Equipment
FAA	Federal Aviation Administration
FMS	Flight Management System
LNAV	Lateral Navigation
MISAP	Missed Approach Procedure
ND	Navigation Display
NOTAM	Notice to Airmen
PFD	Primary Flight Display
RA	Resolution Advisory
SAM	Surface to Air Missile
SID	Standard Instrument Departure
STAR	Standard Arrival Route
SVIS	Synthetic Vision Information System
TCAS	Traffic-alert and Collision Avoidance System
VNAV	Vertical Navigation