THE DESIGN AND EVALUATION OF A TRAFFIC SITUATION DISPLAY FOR A SATS SELF CONTROLLED AREA

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Abstract

Graphical, interactive, and intelligent displays will be an integral part of the future of aviation cockpits. NASA's vision for a national Small Airport Transportation System based on Self Controlled Areas is a good test case for the challenge of designing avionics functionality to support pilots in performing new flight procedures – flight procedures that have the potential of improving the efficiency of our National Airspace System. The authors developed and evaluated a Primary Flight Display and Traffic Situation Display that includes elements of synthetic vision, Highway-In-The-Sky, conflict detection and artificial intelligence. The displays were evaluated in formal flight experiments to judge their value and effects in assisting pilots in performing NASA's proposed High Volume Operations. The experiments measured situation awareness, workload, approach accuracy, and decision quality.

SATS High Volume Operations

NASA has identified the opportunity for the United States to create a new Small Airport Transportation System (SATS). SATS would augment our current transportation systems to include air taxi services to and from the numerous community airports in nearly all weather conditions. Currently these airports have instrument restrictions that do not allow landings in weather conditions that can be conducted at larger airports with very expensive Instrument Landing Systems. The smaller airports are used primarily by private aviation and instrument approaches are restricted to one aircraft at a time on approach. SATS would be a cost-effective alternative for many travelers, increase the throughput of the National Airspace System (NAS), and provide economic benefits to the communities served by these smaller, underutilized airports. For more information about the SATS concept, see [1] and [2].

One of the key operating capabilities of NASA's SATS concept is High Volume Operations (HVO). High Volume Operations is a new set of flight procedures for use during Instrument Meteorological Conditions (IMC) at non-towered, non-radar airports. One of the features of HVO operations includes the use of ground-based software that issues sequences through a data link to the aircraft landing at the airport. NASA's implementation of that software is called an Airport Management Module (AMM). Another feature of the HVO concept is that during approach, the pilots of all the aircraft are responsible for maintaining separation between each other. In fact, the area around the airport is termed a "Self Controlled Area," (SCA) emphasizing that air traffic controllers are not responsible for HVO operations into one of these airports. Again, [2] is currently the leading reference for the HVO and SCA concepts. Additionally, [3] documents the abstract models used in verifying the HVO procedures and is a useful cross reference.

Following development of the HVO concept, NASA developed research avionics intended to support the pilot in performing the HVO procedures. NASA also provided partial funding to four other teams (called SATS Labs) to develop their own solutions, each emphasizing some unique capability. The five implementations have been used to perform experimentation and demonstrations of the HVO concept, including joint flight demonstrations for the public on June 6-7, 2005, in Danville, VA.

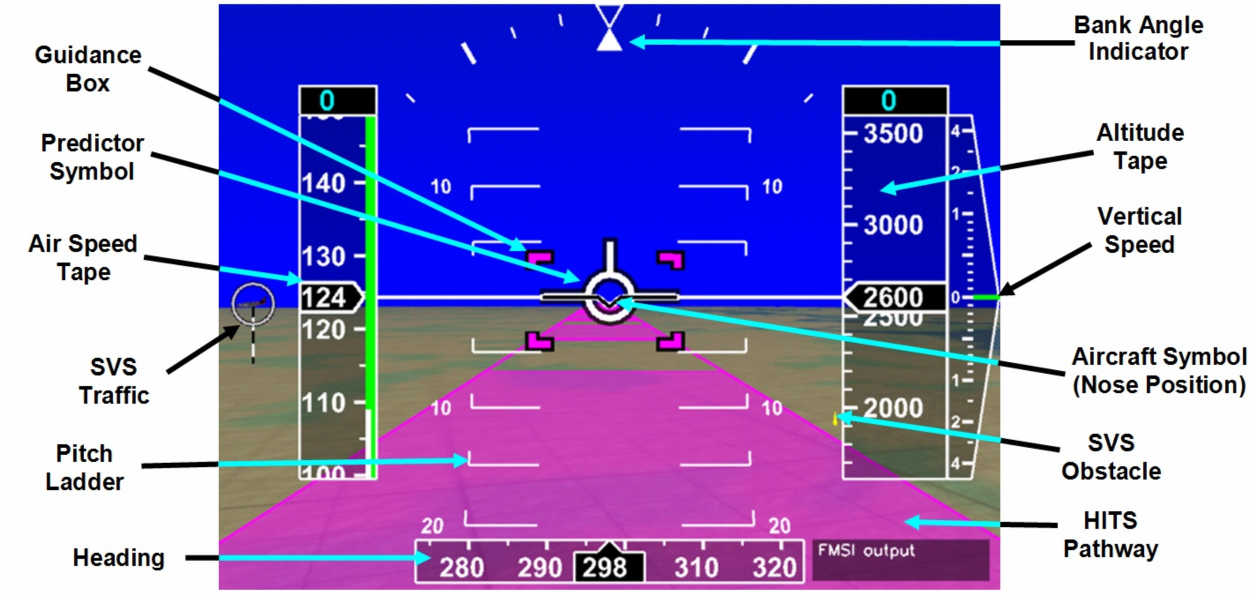

Figure 1. Primary Flight Display with Annotations

The authors participated in testing and demonstrating the HVO concept with the North Carolina and Upper Great Plains (NC&UGP) SATS Lab. The NC&UGP HVO solution includes two displays – a Primary Flight Display (PFD) and a Traffic Situation Display (TSD).

Primary Flight Display

Figure 1 is a screenshot of the NC&UGP Primary Flight Display, which includes a Synthetic Vision System (SVS) view of the terrain and Highway-In-The-Sky (HITS) guidance. The PFD replaces the conventional flight control instruments with a single display and adds more advanced capability. Figure 2 shows the display installed in the team's research aircraft, a Piper Aztec.

The terrain displayed by the SVS includes shadowing and texture to give it a 3-dimensional appearance. It always shows the scene for a sunny day with the sun shining from over the pilot's right shoulder in order to provide shading and help with depth perception. Additionally, the terrain is mottled and has an overlaid grid that also helps provide depth perception.

The SVS system also displays obstacles and other features, such as towers, airports, and traffic. A tower is shown on the PFD in Figure 1 and is pointed out as "SVS Obstacle". Towers and other obstacles are depicted as yellow pyramids. Traffic is also shown on the PFD in Figure 1. The other aircraft traffic is placed on the PFD based on relative position from the aircraft. This traffic is placed on the screen based on locations from Automatic Dependent Surveillance – Broadcast (ADS-B) information obtained directly from the

Figure 2. PFD Installation in Piper Aztec.

aircraft or (for aircraft not equipped with ADS-B) from Traffic Information Services – Broadcast (TIS-B) radar information provided by the FAA over the Universal Access Transceiver (UAT) data-link.

The airspeed tape is translucent to allow the synthetic terrain to be viewed through the tape. The airspeed tape has a box at the top of the tape (in Figure 2 the number in the box is 120) that displays reference airspeed. This airspeed is the airspeed at which the turns for the highway are referenced in order to fly a standard rate turn. The altitude tape is also translucent to allow the pilot to see the SVS data. The altitude tape also has a box at the top of the tape similar to the one on the airspeed tape, where the altitude for the HITS pathway being flown is displayed. The vertical speed is shown as a needle, in order to provide a quick, intuitive indication of vertical speed (based on the dominant recommendations from pilots involved in prior formal SVS/HITS experiments). The heading tape and vertical speed indicator are also translucent.

The predictor symbol, guidance box, and aircraft symbol are all shown in Figure 1. The predictor symbol is an indicator of where the aircraft will be in four seconds. In a faster aircraft, the predictor symbol may be set to be at ten or even twenty seconds in order to allow the pilot to comfortably fly the system. For the Piper Aztec used in our experiments, a four-second setting appears appropriate. The guidance box is located on the highway at four seconds ahead of the aircraft. So the guidance box is where the pilot wants to have the aircraft in four seconds, in order to be in the desired position on the highway. To fly an acceptable approach or flight plan, the pilot would always want to have the predictor symbol within the guidance box.

The HITS overlaid on the SVS terrain has proven to be a very effective technique for navigating in an airplane. For more information about our experience with SVS and HITS PFDS, see [4].

Traffic Situation Display

The Traffic Situation Display (TSD) is where the pilot receives most of the guidance related to HVO operations, including interaction with the Airport Management Module. The TSD includes a map display mode (as shown in Figure 3), an exocentric display mode, conflict detection and alerting logic, and several artificial intelligence modules. The following sections describe each of these features.


>>> ENTRY VERTICAL FOLLOW NASA IAF CUNAV MAHF JEDOR

STATUS
SEQ
IAF
CUNAV
ENTRY
VERTICAL
SEQ
FAATC
NASA
NCSATS
MAHF
JEDOR

PROCEED TO HOLDING PATTERN
CLEARED TO 4000 FT

OUTSIDE SCA
NEXT: VERTICAL ENTRY

TO
CUNAV
159
00:01:23

Figure 3. Screenshot of Traffic Situation Display

Map View

The Traffic Situation Display includes display of ADS-B and TIS-B traffic, north-up and track-up modes, zoom control, compass rose, and terrain background. The moving map supports the pilot in performing advanced procedures like High Volume Operations. The components of the Traffic Situation Display include the following:

The **AMM datalink scratchpad** is where messages to and from the AMM are displayed. In the example shown, the aircraft has received an AMM *follow notification*, which indicates that this pilot should execute a vertical entry at CUNAV, follow NASA on the approach, and fly to JEDOR if a missed approach must be performed.

The TSD also shows **traffic symbology**. The NC&UGP team decided to use symbology similar to the Traffic Alert Collision Avoidance System (TCAS) symbology. Other aircraft in the vicinity are shown using symbols with different shape and color, depending on the conflict level of the aircraft. The number above each symbol indicates the other aircraft's altitude above (+) or below (-) the current altitude of the aircraft in hundreds of feet. Below the symbol is the speed of the other aircraft in KIAS. A ↑ or ↓ indicates whether the other airplane is ascending or descending, respectively. In this example, the other traffic is the NASA aircraft, flying at 119 knots, at an altitude of 1900 feet below ownship.

The **ownship icon** is simply a white aircraft symbol.

The **SCA status** area shows the ownship status in the Self Controlled Area, the assigned Initial Approach Fix (IAF), and the assigned entry type. The possible values of the status field are:

- **NP** if the aircraft is currently a non-participant in the SCA.
- **STBY** if the AMM has placed the aircraft in a standby, acknowledging the request for landing but not issuing a sequence.
- **SEQ** if the aircraft has been sequenced for landing at this SCA airport.
- **PRIORITY** when ownship has requested and received priority landing.

The **sequence list** is the list of active aircraft in the Self Controlled Area that have been sequenced. Other aircraft in the sequence are listed in a green color. The ownship is listed in a white color. In Figure 3, the NCSATS aircraft is to follow NASA, which is following FAATC.

The **missed approach holding fix**, which is assigned by the AMM, is also listed on the display.

The **flight path** is shown on the map view as a magenta colored line. The flight path is automatically updated to reflect the current procedures that the pilot should follow. This feature is known as Path Guidance, and is discussed in more detail below.

The **alert messages** area is where traffic conflict messages are displayed, as are other alerts like data link failures.

The **next waypoint** lists the next waypoint, the heading to that waypoint, and the estimated time enroute. The Path Guidance feature automatically updates this field based on the HVO procedures.

The final two areas of the display, **Pilot Advisories** and **Procedure Guidance**, are where the "artificial intelligence" results are displayed. They are discussed in more detail in their own sections below.

Exocentric View

In addition to the standard map display, the TSD includes an exocentric mode which places the viewpoint outside of the aircraft in a perspective display (3D view). In exocentric view, all the SCA-specific display components (AMM datalink scratchpad, SCA status, etc.) are still available.

The exocentric view is based on the 3D avionics graphics libraries from Nav3D and includes the Highway-In-The-Sky guidance found on the PFD. Figure 4 is a screenshot of the exocentric display in a holding pattern. The ownship icon is shown in the middle of the screen as a black triangle with a white outline.

Other aircraft are depicted in Figure 4 as 3D aircraft models with white circles around their position. The vertical bars extending from the base of the aircraft to the ground improve the pilot's ability to judge the relative position and altitude of

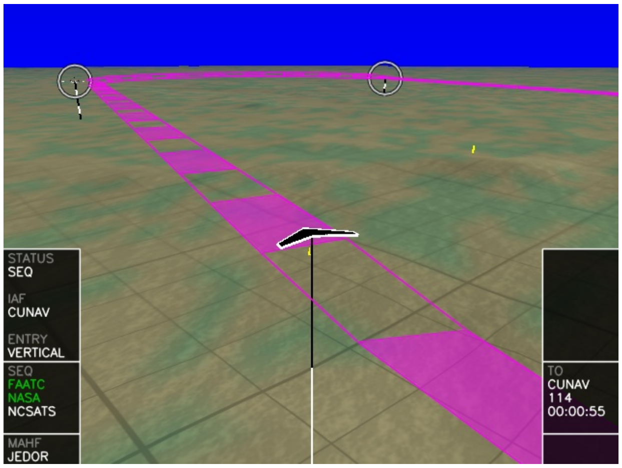

Figure 4. The TSD's Exocentric Display Mode

the traffic. Each change in color on the vertical bars indicate 500 feet. The pilot has the ability to zoom in and out and rotate the viewpoint around the aircraft.

Conflict Detection and Alerting

In addition to map and exocentric views of the Self Controlled Area, the Traffic Situation Display includes several software modules that assist the pilot in performing the High Volume Operations procedures. In the SCA, each aircraft is responsible for maintaining separation. The Conflict Detection and Alerting (CD&A) module of the TSD monitors the surrounding traffic and alerts the pilot to any potential airspace conflicts.

The NASA-designed conflict detection and alerting algorithms [5] are based on both the aircraft's state vector and intent, which are broadcast in the ADS-B messages. The NASA SATS program has yet to select algorithms for automated conflict resolution.

In the absence of specific guidance from the SATS program regarding display symbology, the NC&UGP team used traffic symbology that is analogous to the symbology used by TCAS. The symbol for normal traffic is a white circle. If the CD&A software detects a potential conflict within 30 seconds, the symbol for the airplane involved will become a yellow diamond. In this case, the time to conflict is also displayed. If a conflict occurs, the symbol becomes a red square. Figure 5 shows a conflict situation with an aircraft N5923A, as viewed in the exocentric display mode.

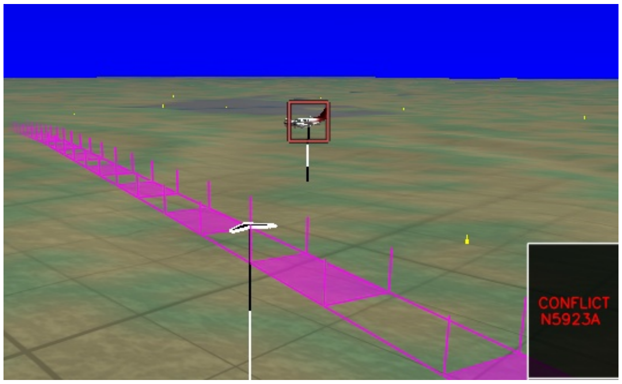

Figure 5. Screenshot of Conflict Alert

Procedure Guidance

Procedure Guidance is another display component that assists the pilot in performing the HVO procedures. Procedure Guidance is based on a state-based specification of the HVO procedures. That is, the HVO procedures can be modeled as a series of flight stages through which the aircraft progresses. The aircraft begins in flight segment "Outside SCA." From "Outside SCA," a pilot can perform a "Vertical Entry" or "Lateral Entry" depending in the instructions provided by the Airport Management Module. The HVO procedures that NASA has defined could be modeled with the following list of flight segments:

- Outside the SCA
- Lateral Entry
- Vertical Entry
- In High Hold
- Descending to Low Hold
- In Low Hold
- On Approach Base Segment
- On Approach Intermediate Segment
- On Approach Final Segment
- On Missed Approach
- Landing
- Ready to Depart
- On SCA Departure

The state diagram of Figure 6 was created by the authors to describe NASA's HVO procedures.

The process of Flight Segment Interpretation involves making a continuous decision about the current flight segment of an aircraft. This challenge, and a specific solution to this challenge known as hypertrapezoidal fuzzy membership functions, has been described in [5], [7], and [8].

There are two aspects to the challenge of calculating Procedure Guidance during HVO operations – knowing which segment the pilot *should be in* and knowing which segment the pilot *is operating in*. The first decision is called Procedural Flight Segment Interpretation (P-FSI). We use the word "Procedural" because the P-FSI decision is based on the procedural rules of the SCA and events that are largely outside the control of the pilot. The second decision is termed State-based Flight Segment Interpretation (S-FSI). We use the word "State" to signify that this decision is based largely on the state of the aircraft, over which the pilot had direct control.

In [9], the specific Flight Segment Interpretation solution used by the NC&UGP software is described in detail. In summary, we use fuzzy logic to classify the current operating state into the possible flight segments. Fuzzy or probabilistic models are a natural choice for Flight Segment Interpretation because the boundaries between the flight segments can not be definitively defined in the state space of the aircraft's operating conditions. That is, the boundaries between some of the states are "fuzzy" when all one has to work with are the state variables of the aircraft.

The Flight Segment Interpretation results are used in the Pilot Advisories and Path Guidance processes. To generate reasonable pilot advice and to direct the path of the highway, the software must "know" what the pilot is doing and what the pilot should be doing. In addition, to supporting those functions, the NC&UGP has experimented with displaying the FSI results directly to the pilot. The display of the FSI results directly to the pilot is what we are terming Procedure Guidance. It is a topic that deserves more research.

At this time, our implementation displays both the Procedural ("*should be in*") and State ("*is operating in*") FSI results on the Traffic Situation Display. The specific details of the display depend on whether the Procedural and State-based results match or at least follow a reasonable progression. Consider the following three cases, each with an example from the TSD.

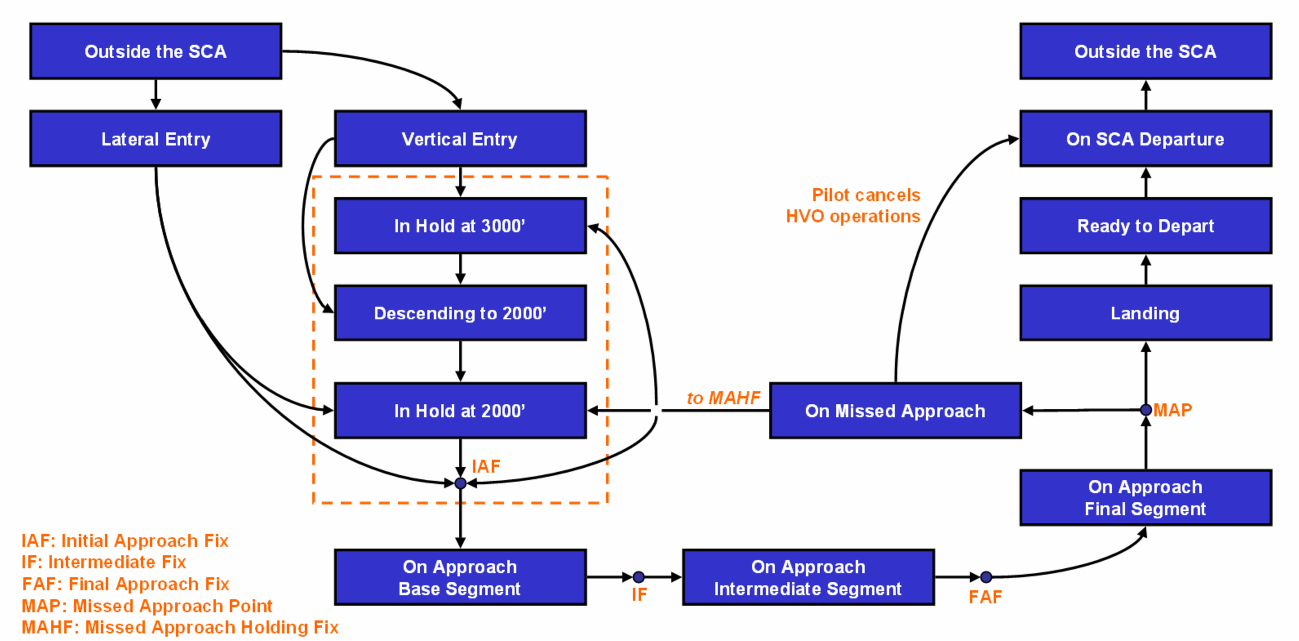

Figure 6. State Diagram Model of HVO Procedures.

Case 1: Both the Procedural and State-based FSI agree. That is, the pilot seems to be performing the procedure that is required at the moment. In this case, the TSD displays the FSI result, in green, as shown in Figure 7.

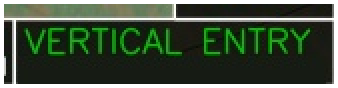
VERTICAL ENTRY

Figure 7. Procedure Guidance for Matching P-FSI and S-FSI.

Case 2: The P-FSI and S-FSI do not match, but the P-FSI (i.e., *should be in*) reasonably follows the S-FSI (i.e., *is operating in*) result. For example, the pilot is still holding at the higher SCA holding altitude, but there is no reason that the pilot can not begin the descent to the lower holding altitude. In this case, the S-FSI would be “Holding High.” The P-FSI would be “Descending.” For these situations, we display the Procedure Guidance as shown in Figure 8. It says to the pilot, “You are currently holding high, but you should begin descending to the lower altitude.”


HOLDING HIGH
NEXT: DESCENDING

Figure 8. Procedure Guidance for Nominal Sequence of Flight Segments

Case 3: The P-FSI and S-FSI do not match and the pilot seems to be performing a procedure that the pilot should not be performing. Figure 9, for example, is displayed if the pilot seems to be performing a vertical entry, but should remain outside the SCA. Notice that the top line, which in all three cases is the State-based FSI result, changes to a yellow color.


VERTICAL ENTRY
NEXT: OUTSIDE SCA

Figure 9. Procedure Guidance when Pilot Is Not Following the Flight Procedures

The design of the Procedure Guidance display deserves more research. In fact, it is still an open question about whether or not the FSI results should be displayed at all. Regardless of whether the results are displayed, correct Flight Segment Interpretation is critical for Pilot Advisories and Path Guidance, as described in the following sections.

Pilot Advisories

An expert system designed by Texas A&M University researchers advises the pilot during High Volume Operations. Among other things, the Pilot Advisor tells the pilot when to start the approach and what the appropriate holding altitude/airspeed should be in the Self Controlled Area. The messages are displayed in the lower center area of the Traffic Situation Display. If multiple alerts are active at one time, they are displayed in a prioritized order.

There are two basic categories of Pilot Advisory messages that the NC&UGP team displays in Pilot Advisories area – Conformance Monitoring and HVO Procedures.

Conformance Monitoring

Part of the NASA HVO concept includes *conformance*, which indicates whether or not an aircraft is following the correct procedures in the Self Controlled Area. Conformance is defined by NASA in [5] and includes location, altitude, and speed components.

An aircraft’s conformance is used primarily in the conflict detection algorithms. If an aircraft is in conformance, then the conflict detection is performed using the aircraft’s broadcast intent information. If the aircraft is not in conformance, then the conflict detection algorithms revert to a state vector calculation.

The pilot is expected to “stay in conformance” while performing HVO operations in an SCA. In the NC&UGP solution, if ownship is out of conformance, warning and advisory messages indicate to the pilot which conformance rules are violated and suggest the corrective actions. Not surprisingly, the conformance rules are predicated on the current flight segment. That is, the result of Flight Segment Interpretation (described in the Procedure Guidance section) determine which set of conformance rules are checked.

Examples of conformance pilot advisories include the following:

> **OFF THE COURSE TO SIDLE** – if the pilot should be performing a lateral entry, but is not headed towards the assigned initial approach fix (SIDLE in this example).
>
> **OUT OF HOLDING PATTERN** – if the pilot has exited the holding pattern while he should still be holding.
>
> **INIT APPROACH SPEED 120 KNOTS** – If the aircraft's speed drifts away from the approach speed which was broadcast to the other aircraft for the purpose of maintaining spacing.

HVO Procedures

In addition to conformance monitoring, the pilot advisory messages include messages to assist the pilot in following the prescribed procedures for High Volume Operations. The HVO procedures require that the pilot monitor both the AMM data link *and* the actions of the other aircraft. For example, if a pilot is holding at the higher SCA holding altitude, he is expected to descend once the pilot at the lower holding altitude begins the approach. There is no support in the Airport Management Module for cueing the pilot to begin the descent. Either the pilot monitors the traffic on the traffic display, or onboard software monitors the traffic and alerts the pilot when he is expected to descend.

The following are examples of advisory messages which alert the pilot to the correct HVO procedures:

> **ADVISED TO SEND LANDING REQUEST** – The pilot is approaching a Self Controlled Area and should request a landing from the Airport Management Module.
>
> **CLEARED TO DESCEND TO 3000 FT** – The pilot holding at 3000 feet has begun the approach. Ownship, which was holding at 4000 feet, can now descend to the lower holding altitude.
>
> **CLEARED FOR APPROACH** – The aircraft that ownship is to follow is sufficiently into its approach, that we can now begin our approach.

Path Guidance

Given that the Flight Segment Interpreter "knows" in what stage of the HVO procedures the pilot *should be* operating, it is possible to automatically command the Highway-In-The-Sky (HITS) to direct the pilot to that location. For example, if the P-FSI indicates that the pilot *should be* holding at the higher SCA holding altitude, the Highway-In-The-Sky should either climb or descend from the current altitude to the desired altitude and draw a holding pattern at that location.

The NC&UGP team implemented a first-cut at this type of functionality. While the feature is far from polished, the effect is stunning during flight. When the pilot should proceed to the next stage in the HVO procedures, the HITS automatically adjusts to reflect that change. For example, when the pilot should descend to the lower holding altitude, the HITS guidance shows a pathway descending to the lower holding pattern. When the lead aircraft is sufficiently far into the approach, the HITS takes the ownship out of the holding pattern and onto initial approach. From the pilot's perspective, he/she just follows the magenta path. Again, it should be emphasized, that we implemented this feature as a proof of concept toward the end of the program and it deserves more attention in future work.

Flight Experiments

The NC&UGP team conducted a flight experiment to determine if pilots using an aircraft equipped with a Traffic Situation Display (TSD) can maintain self-separation and fly acceptable instrument approaches within a Self Controlled Area (SCA). The subject pilots used the TSD while flying the aircraft in simulated Instrument Meteorological Conditions (IMC) on both conventional round dial instrumentation and a Primary Flight Display (PFD). The flights were performed in the Piper Aztec shown in Figure 10. The PFD was mounted into the panel of the cockpit. However, because of limited panel real estate, the TSD was displayed on a NavAero T-Pad 800^{TM} kneeboard display.

Figure 10. Piper Aztec Used in Flight Experiments.

For the investigation, six experienced subject pilots were selected to determine if the PFD with Synthetic Vision System (SVS) and HITS combined with the TSD increases pilot Situation Awareness (SA), decreases pilot workload, and increases the accuracy of the approach when performing approaches to Lower Landing Minimums (LLM) in a SCA than is currently allowed for standard Global Positioning System (GPS) approaches using conventional round dial instrumentation. The subject pilots were all employees of L3-Com Flight International and all had at least 8,000 flight hours. A non-precision approach was used as a baseline for the test flights. The approach was a GPS area navigation (RNAV) approach to runway 20 at Wakefield Municipal Airport, VA, (AKQ). Due to weather, aircraft and pilot availability, and a non-flight critical hardware failure, the investigation was not able to complete all six pilots through the testing process. During the flight with the fifth pilot, a failure occurred in the experiment hardware thereby causing the Test Director to stop the investigation flight at that time. The investigation was completed with four pilots.

The hypotheses predicted an improvement in situational awareness (SA), a decrease in pilot workload, and an increase in pilot accuracy. Additionally, the researchers gathered data to assess the quality of decisions at four key points in the scenarios. The following sections summarize the results more fully documented in [10].

Situational Awareness

SA was evaluated in two ways. First, pilots rated themselves on each of the two displays. Second, the observer rated each pilot's three levels of SA as defined by Endsley's taxonomy of SA [11]. Level 1 SA includes the perception of the status, attributes, and dynamics of relevant elements in the environment. Level 2 SA goes beyond that of Level 1 and includes an understanding of the significance of those elements in light of one's goals. Finally, Level 3 SA includes the ability to project the future actions of the elements in the environment at least in the very near term. This level (Level 3) forms the highest level of SA. Level 3 SA is achieved through knowledge of the status and dynamics of the elements and a comprehension of the situation (both Level 1 and Level 2 SA).

The results of the investigation show that the hypothesis for SA was *not* proved. For Level 1 and Level 2 SA, there was no difference in using either the conventional instruments or the PFD. For Level 3 SA, the results show that the use of conventional instruments allowed the pilots in this investigation to have slightly better Level 3 SA. The Level 3 SA result could be due to the fact that the pilots were much more comfortable flying the familiar conventional instruments than they were the new PFD and TSD. The pilots generally felt that the TSD increased their own situational awareness as measured in the Post Experiment Questionnaire.

Pilot Workload

Workload was evaluated in three ways. First, the observer subjectively rated pilot workload during the test flight. Second, upon completion of the flight the pilots rated themselves on how much they thought each display increased (or decreased) their workload (self-rating). Third, to gather additional confirming evidence, the NASA Task Load Index (TLX) was administered to all pilots who participated in the flight test. (The TLX is a multi-dimensional rating procedure that provides a workload score based on ratings on 6 subscales: Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort, and Frustration.)

The results of the investigation were mixed with respect to workload. The results were mixed because one of the four subject pilots had an extremely poor opinion of synthetic vision displays in general. That bias against synthetic vision systems definitely biased the workload data – particularly since the sample set (N=4) is so small. Figure 11 shows the results for all the pilots. The STD data are for the standard instruments. The PFD data are for the primary flight display (with SVS and HITS). A lower TLX score is considered the better score.

We also analyzed the data by considering the SVS-resistant pilot as an "outlier." Eliminating that participant's data significantly changes the overall pattern of results. Now we see in Figure 12 that the PFD generally showed the lowest levels of workload on the NASA TLX subscales. The only subscale that showed a higher level in the PFD was "Perform" in which pilots rate how they felt about their own performance during the experiment.

The best that can be said is that there is evidence that the PFD does indeed reduce workload requirements as measured by both the observer and the NASA TLX. While one cannot entirely confirm the workload hypothesis, it is the opinion of the researchers that had additional data been gathered the trend toward confirmation of this hypothesis would have been supported. Additionally, had the TSD had been installed in the instrument panel, rather than as a kneeboard display, the researchers believe the workload would have been further reduced.

Approach Accuracy

The hypothesis for approach accuracy was proven. Calculating the mean and standard deviation for the final segments of the approach show that the subject pilots flew the final segment of the approach almost 4 times more accurately based on comparing the means and almost 8 times more accurately when comparing the standard deviations. This result closely matches previous results in [4] and [12]. Figure 13 is a plot of the mean and standard deviations for the cross track error of final approaches flown with the Highway-In-The-Sky (HITS) and those flown with conventional instruments in this experiment. (MILUE is the name of the final approach fix).

Decision Quality

The researchers measured decision quality by observing the pilots' responses to traffic conflicts that were intentionally added into the scenarios during experiment design. Two of the subject pilots were much better at noticing the intruding traffic than the other two subject pilots and their decisions improved as they became more familiar with the TSD. The researchers believe that the kneeboard installation of the traffic display hampered the ability of all the pilots to monitor the traffic situation. With the TSD on a kneeboard display, the pilots had to look down in their lap to look for traffic – while flying the airplane using a conventional instrument scan for conventional instruments and a modified scan when using the PFD. It is recommended that further research be conducted in a simulation environment to

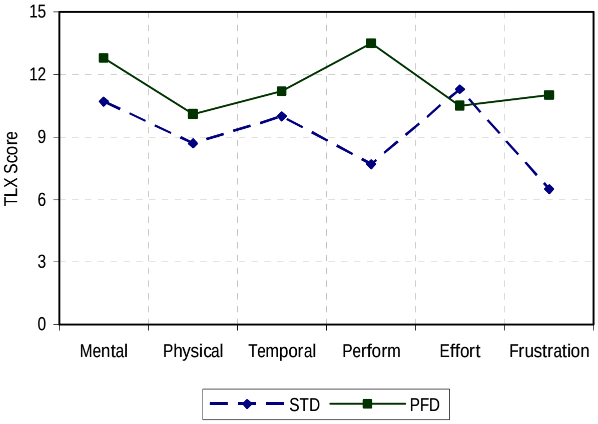

Figure 11. Task Load Index Results (N=4)

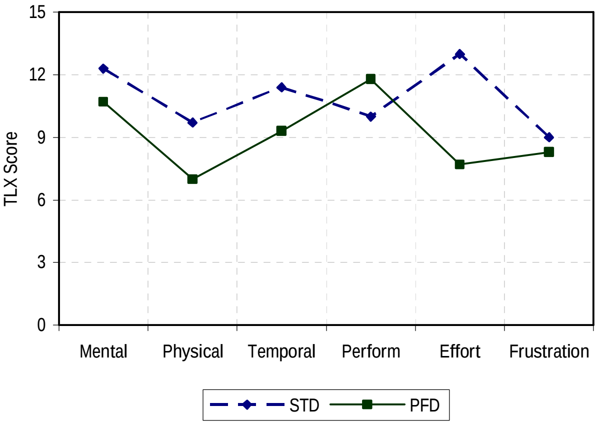

Figure 12. Task Load Index Results (N=3)

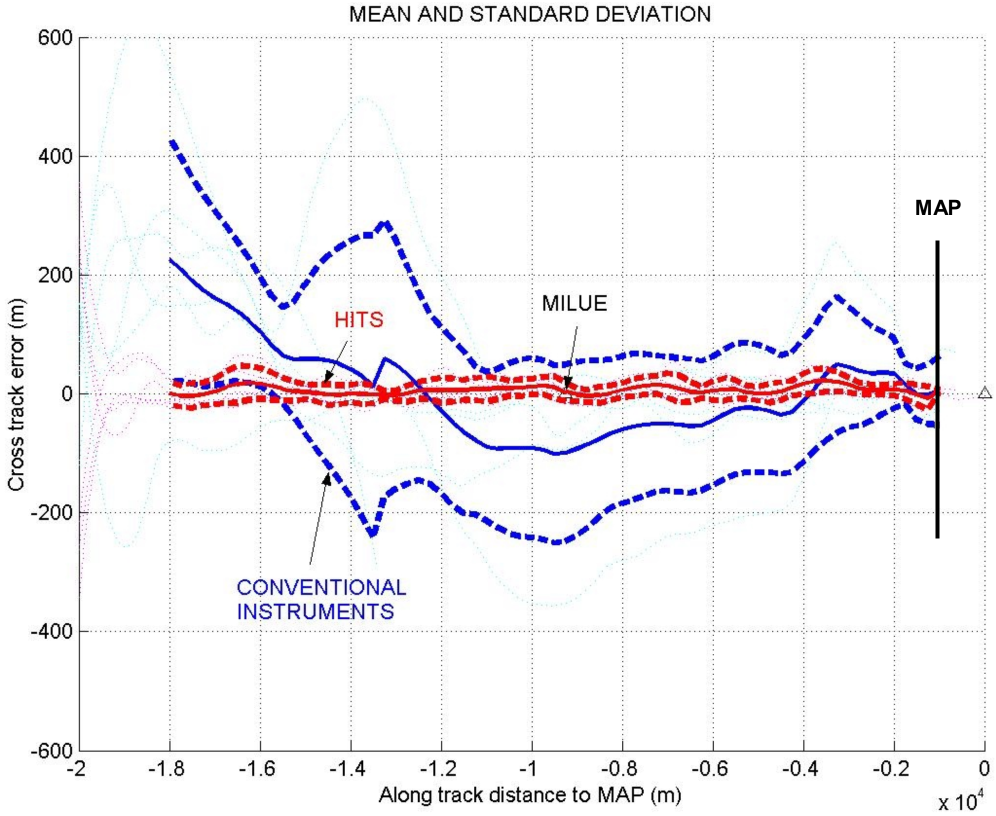

Figure 13. Mean and Standard Deviation of Approach Accuracy

investigate the use of the TSD while it is installed in the instrument panel.

The researchers did observe a training effect during the investigation. It is recommended that future studies or experiments should be conducted to investigate the possibility of a training effect in depth.

Additional Comments

The Post Experiment Questionnaire provided valuable feedback on using a PFD/TSD combination in a Self Controlled Area.

- On average, the pilots found the TSD to be neither easy or difficult to use. (For example, one subject pilot marked it as *very easy* and one marked it as *very difficult*.)
- The graphical symbology on the TSD was judged to be *useful*.
- The pilots recommended that traffic alert messages be replicated on the PFD so it would be more readily seen.
- Using a kneeboard display for TSD functionality was judged inadequate. The TSD should be in the normal scan for the pilot and installed in the instrument panel.

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