

# INCORPORATING DATA LINK MESSAGING INTO A MULTI-FUNCTION DISPLAY FOR GENERAL AVIATION AIRCRAFT

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## Abstract

*One objective of the Small Aircraft Transportation System (SATS) Project is to increase the capacity and utilization of small non-towered, non-radar equipped airports by transferring traffic management activities to an automated system and separation responsibilities to general aviation (GA) pilots. This paper describes the development of a research multi-function display (MFD) to support the interaction between pilots and an automated Airport Management Module (AMM). Preliminary results of simulation and flight tests indicate that adding the responsibility of monitoring other traffic for self-separation does not increase pilots' subjective workload levels. Pilots preferred using the enhanced MFD to execute flight procedures, reporting improved situation awareness over conventional instrument flight rules (IFR) procedures.*

## 1 Introduction

The Small Aircraft Transportation System (SATS) research and development project, led by the National Aeronautics and Space Administration (NASA) in partnership with the Federal Aviation Administration (FAA) and a consortium of U.S. industry, governments, and academia, is investigating many new challenges for single pilot instrument flight and technology development. An objective of this project is to increase the capacity of small non-towered, non-radar equipped airports by transferring traffic management activities to an automated Airport Management Module (AMM) and separation responsibilities to general aviation (GA) pilots. This challenge is associated with designing the

representational elements required for presenting dynamic messaging, sequence, procedure, and flight path conformance information on a multi-function display (MFD) to aid pilots in making flight decisions. Although an optimized interface was not the primary purpose of the research endeavor, inherent in the design of the display was the need to provide pilots with accurate information about the state of inbound and outbound airport operations as well as aircraft position through data link messaging and traffic symbology.

This paper describes the design of a display that incorporates data link messaging as a decision support tool to enable pilots to self separate while flying to SATS designated airports. Included is a discussion of two empirical investigations. Simulation and flight studies were conducted to examine the effects of SATS flight procedures and a related research MFD on GA pilots' perceptions of workload and situation awareness (SA).

## 2 Background

Currently, during instrument meteorological conditions (IMC) at small, remote airports, air traffic control (ATC) uses procedural separation that limits instrument flight rules (IFR) operations to only one approaching or departing aircraft at a time – the “one-in/one-out” paradigm – a safe yet capacity limiting operation.

The SATS Higher Volume Operations (HVO) concept breaks this paradigm and increases operational efficiency by allowing multiple, simultaneous operations [1].

Central to the SATS HVO concept is a set of procedural rules that enable self-separation and enhance throughput in a newly defined area of flight operations, a Self-Controlled Area (SCA). The SCA is established around SATS designated airports during periods of IMC. Within the SCA, it is envisioned that pilots will use advanced airborne systems to execute procedures by relying on automated dependent surveillance-broadcasts (ADS-B), two way data link, and appropriate self-separation tools. Additionally, an AMM (i.e., a new, ground-based automation system typically located at the airport) will provide appropriate sequencing information to arriving aircraft. However, in contrast to ATC, the AMM will not provide separation, clearances, or altitude assignments and will not control aircraft or sequence departures.

### 2.1 The SATS HVO “T” Procedure for Flight Operations

The smooth flow of self-separating traffic will depend on compliance with a SATS HVO procedure (Figure 1) adapted with a SATS HVO procedure (Figure 1) adapted from the Terminal Arrival Area basic “T” approach [2]. In the

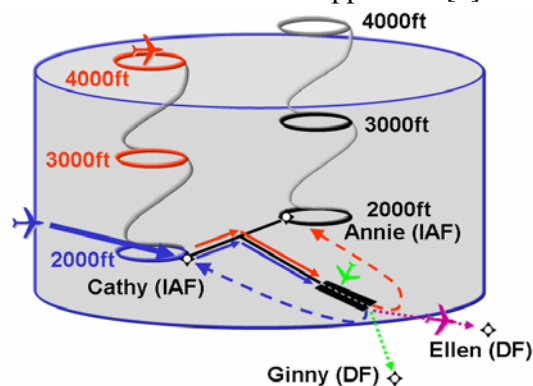


Figure 1: SATS HVO Procedure.

SATS procedure, pilots will either make a vertical or a lateral entry into the SCA. For a vertical entry, the aircraft (aircraft at 4000 ft) descends at increments of 1000 ft from a transition fix, outside the SCA, following other traffic within the airspace. If there are no other aircraft at the initial approach fix (IAF) to which the aircraft is assigned, a lateral entry directly to the IAF is possible (blue aircraft).

### 3 Development of the SATS HVO Research Multifunction Display (MFD)

The SATS HVO research MFD is shown in Figure 2. The platform for the research interface, an Avidyne® EX5000 MFD, was selected because the research aircraft [i.e., NASA Langley Research Center’s (LaRC) Cirrus SR22] has this MFD installed in its instrument panel. The interface was reproduced for use during a simulation study with the functionality being carried over to a flight experiment. The researchers examined the Avidyne® display’s existing capabilities to facilitate the integration of SATS requirements necessary to achieve the objectives established for HVO (i.e., the ability to self-separate, avoid conflicts, communicate with the AMM, and display traffic information).

The challenge for the human factors researchers was to prescribe, design, and position messaging elements required to convey critical data relevant to the pilot’s role in self-separation and in executing the IFR procedure. Consideration for the pilot’s instrument scan



Figure 2: SATS HVO Research MFD.

and mental workload was important since the display was intended to augment the information provided by the primary flight displays without depleting attentional resources [3]. Additionally, display requirements needed

to provide messaging, features, and symbols that were in compliance with industry accepted standards where possible. Assumptions made for guiding the display design included: 1) retaining useful features of the current Avidyne® display; 2) redefining actions for some of the softkeys to facilitate interaction with the AMM and the aircraft control and navigation systems; 3) gating data link messages to dedicated windows within the MFD; 4) easing search tasks via the location of text windows and map symbology; 5) making colour, size, and shape coding distinctive, intuitive, and salient; and 6) using phraseology as close to the current ATC lexicon as possible [5].

### **3.1 Task Analysis and Requirements Identification**

A typical IFR flight, without any failure modes occurring, was disaggregated into higher order tasks such as: communicating with ATC or requesting a sequence from the AMM (depending on whether a flight was a “baseline” flight using the current IFR system or a SATS flight) and initiating a procedure segment such as entering the airport or SATS airspace, descending to a lower altitude, holding at fixes or transition points on a descent or climb, or flying directly to the IAF, holding at the IAF, initiating the approach, executing a missed approach, or landing or departing.

For each task, requirements for information, actions required to make electronic requests or retrieve information, and modalities for representing information were identified. For this research, computer generated aural commands or coupled tone-text presentations were not implemented. Of particular importance in the development of the phraseology for the messaging system was the need to provide information without controlling the pilot’s actions (i.e., the pilot must take responsibility for processing the information and making decisions to execute the instrument procedure based on the data received). Rather than display

a message such as “... cleared to 2000,” the message “open: 2000” was used to indicate that the pilot may advance along the approach path since no aircraft is located ahead of the ownship at the stated altitude (a safe vertical and horizontal distance is assured thereby preventing a conflict with another aircraft).

### **3.2 Map elements and related symbology**

Several features of the Avidyne® MFD were retained and layered on top of flight operation area bitmaps. These included: the active way point window, flight path renderings and colour coding, fixes, a top mounted and centered heading box and heading scales with range indication, and the range knob.

Crucial to the task of self-separation was the pilot’s requirement for knowledge regarding the status of the airspace and airport within the SCA. Standards for electronic displays vary among organizations allowing some flexibility in coding, selecting designs, and locating windows for gating data linked information. Based on general recommendations, it was decided that traffic information would be incorporated into the display so that the pilot could identify the lead aircraft as well as traffic within the SCA. Rather than use range buffers or arcs to indicate protected zones, pilots were cued by an alert and a “Pilot Advisor” message indicating that their airspeed or flight path deviations might be impacting operations. Ranging off the mileage marker incorporated into the heading scale helped pilots orient the ownship relative to other traffic or the airport depending on the segment of flight. Data tags with registration numbers, ground speed, climb and descent arrows [based on traffic alert and collision avoidance (TCAS) II guidelines], and relative altitudes were added to facilitate SA and reduce scan to acquire targets [4]. To assure correspondence between IFR chart symbols where possible, dashed lines were used to indicate missed approach paths.

By design, the SATS HVO procedure should prevent the intrusion of one aircraft upon

another. However, an important requirement was to indicate when the proximity of an aircraft might pose a conflict. Look ahead times were based on time and distance considering the aircraft speed profiles and state vectors. TCAS II color-coding was used in the algorithms for conflict detection, but the paradigm stopped short of providing resolutions at this stage. The aircraft symbols used were chevrons that changed color and characteristic, thereby providing redundant coding, rather than the shape changes prescribed by the TCAS document [4, 5]. Chevrons provided intuitive directional information by virtue of their orientation.

### 3.3 Text messaging

With the exception of departures and non-normal situations, no communications between controller and pilot are required once the aircraft enters the SCA. Inside the SCA, the pilot uses the Common Traffic Advisory Frequency (CTAF) to announce intentions and for party line communications with other aircraft. Communications occur between the AMM and other aircraft via dynamic messaging tailored to the segment of the approach. The AMM and the ADS-B data link communications are used to generate messages to guide the pilot's decisions regarding following a particular aircraft, adhering to the flight path, and monitoring aircraft performance to assure self-separation. As a result of this messaging, the pilot executes an approach procedure and monitors the flight path. If transgressions from the flight path and performance profile occur, the aircraft system advises the pilot that speed, heading, or altitude should be adjusted to prevent loss of separation from traffic aircraft.

Based on Drury's model of intelligent search, the research MFD's windows were sited to guide the pilot's attention to specific elements [3]. For example, the data transmitted by the AMM (i.e., airport identifier, approach, missed approach fixes, and sequence data) are depicted in a dedicated AMM window. Similarly, flight path conformance as well as speed and altitude

transgressions, based on a speed profile and a defined containment area, appear in a dedicated Pilot Advisor (PA) window.

### 3.4 Text windows and gated data link messages

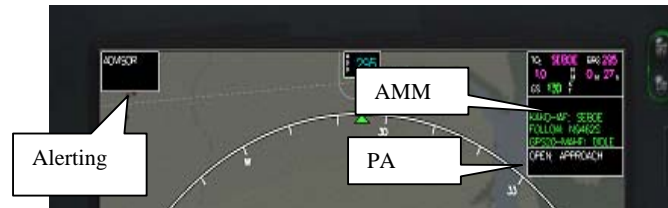


Figure 3: Dynamic windows

The researchers positioned three windows in the upper periphery of the display, level with the lateral scan of the pilot. The alert window was placed in the upper left corner, and the AMM and PA windows were situated in the upper right corner below the active waypoint window (Figure 3). The following are highlights of each window's features.

#### 3.4.1 Alert Window

The alert window provides alerting messages to the pilot. New and changed information is identified and prioritized. After a dwell time, irrelevant alerts deselect themselves, and the window disappears. Alerts include: "AMM" to indicate messaging in the AMM window; "REQ SEQ" to indicate that the pilot may request a sequence via a "Sequence/Request" on-condition button located on the left side of the display (Figures 2, 3); "Advisor" to instruct the pilot to attend to the PA window for procedural information; "Message" to advise the pilot that messages can be accessed through the "MSG>" button located on the right side of the display (Figure 2); and "Traffic" (in reverse background amber or red) to alert the pilot to impending conflicts.

#### 3.4.2 AMM Window

The AMM window (Figures 4) provides airport information similar to that of a flight plan. When a sequence request is made, the AMM determines the aircraft's position in relationship to other aircraft within

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ENTRY:VERT
KMFV-IAF:AZBEJ
FOLLOW:N022GC
GPS03 MAHF:AZBEJ
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the vicinity and in the SCA and provides a sequence to the aircraft. In this case, a vertical entry, the airport identifier and IAF are provided. The sequence is in the form of “FOLLOW: <aircraft registration number>” rather than a queue number. The fourth line of information provided in this window shows the approach filed (GPS approach 03) and the location of the missed approach holding fix (MAHF) – AZBEJ. Irrelevant information disappears as the pilot proceeds along the approach. For example, upon entering the SCA, entry and airport information drop off. As the aircraft becomes the first for landing, “FOLLOW: N022GC” updates to “FOLLOW: NONE.” Only the approach type and missed approach continue to be displayed.

### 3.4.3 PA Window

Procedure information is gated to the PA window (below the AMM window) indicating when the aircraft is out of conformance with the flight path, when the airspace below is available for manoeuvring, the total time until the approach can be initiated, and when the approach is open for initiation. Messages associated with more urgent flight path conformance transgressions are blue. Figure 5 lists some of the messages relating to flight path progression as well as provides one of the conformance messages.

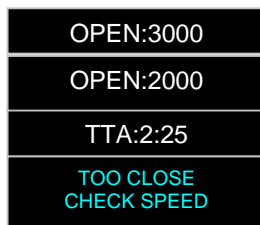


Figure 5: PA messages

### 3.5 Softkeys

The Avidyne® MFD has five softkeys located on each side of the display screen and two control knobs located below the display screen (Figure 6). Several of the softkeys were redefined as on-condition buttons to accommodate the requirements of



Figure 6: Softkeys

operating in a SATS environment and were dedicated to sequence requests and next leg functions. The on-condition labels appear during appropriate segments of flight. For example, the “Sequence/Request” action signals the AMM that an aircraft wants to enter the SCA and land. The “Next Leg” button is pressed to provide flight path guidance when a pilot skips or exits a hold or to execute a missed approach. The Alert and AMM windows and the button labels appear *only* when an action is required. The button labels disappear after buttons are pressed. During the simulation study described below, a “MSG>” button along with arrow buttons allow access to an automatic terminal information services (ATIS) message. The MSG> label was always present so that the pilot could retrieve current or updated ATIS information; this eliminates interruption tasks such as writing down flight critical information and reduces demands on the pilot’s working memory [6].

## 4.0 Preliminary Validation of the SATS HVO Concept

Two empirical investigations were conducted to validate the SATS HVO concept – a simulation study involving 15 subject pilots, and a flight test involving 12 subject pilots. The purpose of the simulation and flight studies was to answer the questions: “Can pilots safely and proficiently fly an airplane while performing SATS HVO procedures?” and “Do pilots perceive that workload, while performing HVO procedures, is no greater than flying in today’s system?” Dependent measures included flight technical error, subjective assessments of workload and SA, and observed aircraft throughput with respect to airport usage. Summary results associated with subjective assessments of workload and SA (including traffic awareness and navigation guidance awareness) are provided below. Coefficients for Mean (M), Sample size (N), Standard deviation (SD), and probability (*p*) are provided throughout the results sections.

### 4.1 Simulation Study Results

Fifteen instrument rated GA pilots, each with approximately 355 total flight hours ( $M = 355$ ,  $SD = 230$ ), participated in a simulation study conducted at NASA LaRC during May 2004. During the experiment, participants used a GA desktop simulator to fly five flight scenarios (i.e., one departure, three approaches, and one missed approach) according to baseline (i.e., current day) as well as SATS HVO procedures.

#### 4.1.1 Subjective assessments of workload

Participants used the Modified Cooper-Harper (MCH) Rating Scale to rate the level of workload that they experienced during each of the simulation study's 10 test conditions. Workload ratings could range on a scale from "1" (i.e., the instructed task was very easy/highly desirable; operator mental effort was minimal; and desired performance was easily attainable) to "10" (i.e., the instructed task was impossible; it could not be accomplished reliably) [7]. As reported below, the Wilcoxon Test (i.e., a nonparametric within-subject test appropriate for analyzing two related samples of ordinal data) was employed as a conservative method for analyzing workload ratings associated with discrete rating scale items [8].

When workload ratings were averaged across the five types of flight scenarios, participants reported experiencing a workload level of 1.69 when performing the SATS procedures ( $M = 1.69$ ,  $SD = 0.54$ ,  $N = 75$ ) and reported experiencing a workload level of 2.59 when performing the baseline procedures ( $M = 2.59$ ,  $SD = 1.37$ ,  $N = 75$ ). A Wilcoxon Test revealed that, at a statistically significant level, participants reported experiencing a lower level of workload when they performed the SATS procedures than when they performed the baseline procedures ( $p = 0.05$ ). When examining the workload ratings that participants provided when they performed different types of scenarios using baseline procedures and SATS procedures, Wilcoxon Tests revealed that, at a statistically significant level, participants reported experiencing higher levels

of workload when they performed the baseline departure procedure as compared with the SATS departure procedure ( $p = 0.04$ ) and when they performed the baseline approach #2 procedure as compared with the SATS approach #2 procedure ( $p = 0.04$ ).

#### 4.1.2 Subjective assessments of SA

SA refers to a pilot's perception and interpretation of information relevant to a particular task [9]; in this case – a procedure for departing from or arriving at an airport. After performing each test condition, participants completed a Situational Awareness Rating Technique (SART) instrument that included the three dimensions of demand, supply, and understanding as well as two independent dimensions of traffic awareness and navigation guidance awareness. Global SART ratings can range from 1 (representing a low level of SA) to 14 (representing a high level of SA). In the current study, participants' SART ratings ranged from 3 to 13. For traffic awareness and navigation guidance awareness, scores ranging from 2 to 7 on a scale of 1 (low) to 7 (high) were collected from the participants. As reported below, Wilcoxon Tests were used to analyze the participants' SART, traffic awareness, and navigation guidance awareness ratings.

SART ratings were averaged across the five types of flight scenarios resulting in a mean rating of 9.6 for the SATS procedures ( $M = 9.6$ ,  $SD = 1.97$ ,  $N = 75$ ) and a mean rating of 8.05 ( $M = 8.05$ ,  $SD = 2.68$ ,  $N = 75$ ) for the baseline procedures. The results of a Wilcoxon Test indicated that, at a statistically significant level, the SART ratings associated with the performance of the SATS procedures were higher than those associated with the performance of the baseline procedures ( $p = 0.02$ ). When examining the SART ratings that participants provided when they performed different types of scenarios using baseline procedures and SATS procedures, Wilcoxon Tests revealed that, at a statistically significant level, participants reported experiencing higher levels of SA when lateral approaches were

performed using the SATS procedures rather than the baseline procedures ( $p = 0.02$  and  $p = 0.03$  respectively).

Traffic awareness ratings were averaged across the five types of flight scenarios resulting in a mean rating of 6.55 for the SATS procedures ( $M = 6.55$ ,  $SD = 0.72$ ,  $N = 75$ ) and a mean rating of 5.59 ( $M = 5.59$ ,  $SD = 1.43$ ,  $N = 75$ ) for the baseline procedures. The results of a Wilcoxon Test indicated that, at a statistically significant level, the traffic awareness ratings associated with the performance of the SATS procedures were higher than those associated with the performance of the baseline procedures ( $p = 0.0003$ ). When examining the traffic awareness ratings that participants provided when they performed different types of scenarios using baseline procedures and SATS procedures, Wilcoxon Tests revealed that, at a statistically significant level, participants reported experiencing higher levels of traffic awareness when all approaches (including the missed approach) were performed using the SATS procedures rather than the baseline procedures ( $p \leq 0.02$ ).

Navigation guidance awareness ratings were averaged across the five types of flight scenarios resulting in a mean rating of 6.45 for the SATS procedures ( $M = 6.45$ ,  $SD = 0.65$ ,  $N = 75$ ) and a mean rating of 5.44 ( $M = 5.44$ ,  $SD = 1.30$ ,  $N = 75$ ) for the baseline procedures. The results of a Wilcoxon Test indicated that, at a statistically significant level, the navigation guidance awareness ratings associated with the performance of the SATS procedures were higher than those associated with the performance of the baseline procedures ( $p = 0.001$ ). When examining the navigation guidance awareness ratings that participants provided when they performed different types of scenarios using baseline procedures and SATS procedures, Wilcoxon Tests revealed that, at a statistically significant level, participants reported experiencing higher levels of navigation guidance awareness when all five flight scenarios were performed using the SATS

procedures rather than the baseline procedures ( $p \leq 0.05$ ).

## 4.2 Flight Test Results

Twelve instrument rated GA pilots drawn from the simulation study's subject pool, each with approximately 400 total flight hours ( $M = 407$ ,  $SD = 258$ ), participated in a flight experiment conducted by NASA LaRC during July – October 2004. During the flight test, participants used NASA LaRC's Cirrus SR22 research aircraft to fly three flight scenarios (i.e., two approaches and one missed approach) according to baseline as well as SATS HVO procedures.

### 4.2.1 Subjective assessments of workload

Participants used the MCH scale to rate the level of workload that they experienced during each of the flight test's six test conditions. When workload ratings were averaged across the three types of flight scenarios, participants reported experiencing a workload level of 1.57 when performing the SATS procedures ( $M = 1.57$ ,  $SD = 0.43$ ,  $N = 36$ ) as compared to a workload level of 2.35 when performing the baseline procedures ( $M = 2.35$ ,  $SD = 0.62$ ,  $N = 36$ ). A Wilcoxon Test revealed that participants reported experiencing a lower level of workload when they performed the SATS procedures than when they performed the baseline procedures ( $p = 0.02$ ). When examining the workload ratings that participants provided when they performed different types of scenarios using baseline procedures and SATS procedures, Wilcoxon Tests revealed that participants reported experiencing higher levels of workload when lateral approaches performed using the baseline procedures as compared with the SATS procedures ( $p = 0.04$  and  $p = 0.005$  respectively).

### 4.2.2 Subjective assessments of SA

After each test condition, participants' SA ratings were collected via a SART instrument that included two independent dimensions of traffic awareness and navigation guidance awareness [9]. Participants' global SART

ratings ranged from 1.5 (indicating a relatively low level of SA) to 11.5 (indicating a relatively high level of SA). For traffic awareness, scores ranging from 2 to 7 on a scale of 1 (low) to 7 (high) were collected from the participants, and scores ranging from 1.5 to 7 on a scale of 1 (low) to 7 (high) were collected for navigation guidance awareness.

When SART ratings were averaged across the three types of flight scenarios, a mean rating of 7.74 was calculated for the SATS procedures ( $M = 7.74$ ,  $SD = 1.84$ ,  $N = 36$ ), and a mean rating of 6.03 ( $M = 6.03$ ,  $SD = 2.46$ ,  $N = 36$ ) was calculated for the baseline procedures. However, a Wilcoxon Test revealed that a statistically significant difference did not exist between the mean SART rating for the SATS procedures and the mean SART rating for the baseline procedures ( $p = 0.08$ ).

When examining the SART ratings that participants provided when they performed different types of scenarios using baseline procedures and SATS procedures, Wilcoxon Tests revealed that, statistically speaking, participants reported experiencing higher levels of SA when lateral approach was performed using the SATS procedures rather than the baseline procedures ( $p = 0.02$ ).

Traffic awareness ratings were averaged across the three types of flight scenarios resulting in a mean rating of 6.33 for the SATS procedures ( $M = 6.33$ ,  $SD = 0.77$ ,  $N = 36$ ) and a mean rating of 5.44 ( $M = 5.44$ ,  $SD = 1.47$ ,  $N = 36$ ) for the baseline procedures. The results of a Wilcoxon Test indicated that, statistically speaking, the participants reported equivalent traffic awareness ratings when they performed the SATS procedures and when they performed the baseline procedures ( $p = 0.08$ ). When examining the traffic awareness ratings that participants provided when they performed different types of scenarios using baseline procedures and SATS procedures, Wilcoxon Tests revealed that, at a statistically significant level, participants reported experiencing higher levels of traffic awareness when later approach and the missed approach were performed using

the SATS procedures rather than the baseline procedures ( $p = 0.04$  and  $p = 0.01$  respectively).

Navigation guidance awareness ratings were averaged across the three types of flight scenarios resulting in a mean rating of 6.43 for the SATS procedures ( $M = 6.43$ ,  $SD = 0.48$ ,  $N = 36$ ) and a mean rating of 5.29 ( $M = 5.29$ ,  $SD = 1.40$ ,  $N = 36$ ) for the baseline procedures. The results of a Wilcoxon Test indicated that, at a statistically significant level, the navigation guidance awareness ratings associated with the performance of the SATS procedures were higher than those associated with the performance of the baseline procedures ( $p = 0.004$ ). When examining the navigation guidance awareness ratings that participants provided when they performed different types of scenarios using baseline procedures and SATS procedures, Wilcoxon Tests revealed that, at a statistically significant level, participants reported experiencing higher levels of navigation guidance awareness when lateral approaches were performed using the SATS procedures rather than the baseline procedures ( $p = 0.05$  and  $p = 0.01$  respectively).

### 4.3 Usability

The purpose of the experiment was not to optimize the MFD but to see if pilots could safely execute the procedures. However, the communications between aircraft and air-to-ground as well as violations of conformance and alerting of potential conflicts had to be delivered through an effective interface. At the end of the simulation a formal usability questionnaire was administered to obtain the pilots' perspective of the arrangement of text windows, the symbology, the delivery of information and alerting schemes. Generally (93%), pilots liked the moving map noting they could see traffic and that it was intuitive to use. Pilots did want terrain rendering and the ability to tailor the display based on their preferences. SA was reported to be greatly enhanced by the map.



A high percentage of the subject pilots (47%) felt the Alert Window was helpful. The alert messaging directed the pilot to a particular position on the screen where information/symbology was changing, eliminating random search activities. Two pilots were confused about the type of information in the windows and noted that they didn't scan the alert window; rather, they scanned for refreshed information in the AMM and PA. Pilots did feel that the alert window should blink on initial presentation or that they had already noticed changes to symbology. The AMM window was considered very useful by 60% of the pilots and useful to 33% of pilots citing good feedback, extremely helpful at unfamiliar airports, and important for updating operational information relating to aircraft on approach. No negative comments were received. The PA window was considered useful to very useful by 93% of the pilots.

Pilots were more critical about the color coding scheme, recommending changes in brightness of the greens, changing cyan to a color that is more distinctive, and requesting colors that had better contrast. Several comments regarding attentional attributes were made such as coupling blinking with color. Symbol coding and size were considered adequate by most pilots (73%) with 27% reporting the symbols as somewhat appropriate.

## **5.0 Conclusions**

In both the simulation and flight tests, considering the lower workload and higher SA data for SATS over baseline scenarios, it could be inferred that the SATS HVO research display was an effective interface for assisting pilots in the execution of SATS IFR approaches. This implies that dynamic messaging, tailored to the SATS operational domain and coupled to the phase of flight in a logical, progressive sequence facilitated pilots in their decision making while flying in IFR conditions. Gating the messages to dedicated windows and providing on-condition cueing via softkeys provided a sufficient level of information to

assure task execution without negatively impacting workload or SA. Future research endeavors will focus on minimum equipment for SATS operations through assessing the utility of the Pilot Advisor in self-separation tasks, non-normal conditions such as emergencies or instrument-to-visual flight rules transitions, aural alerting, and alternative MFD design configurations.

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