# PRELIMINARY VALIDATION OF THE SMALL AIRCRAFT TRANSPORTATION SYSTEM HIGHER VOLUME OPERATIONS (SATS HVO) CONCEPT

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## Abstract

*This document provides a preliminary validation of the Small Aircraft Transportation System (SATS) Higher Volume Operations (HVO) concept for normal conditions. Initial results reveal that the concept provides reduced air traffic delays when compared to current operations without increasing pilot workload.*

*Characteristic to the SATS HVO concept is the establishment of a newly defined area of flight operations called a Self-Controlled Area (SCA) which would be activated by air traffic control (ATC) around designated non-towered, non-radar airports. During periods of poor visibility, SATS pilots would take responsibility for separation assurance between their aircraft and other similarly equipped aircraft in the SCA. Using onboard equipment and simple instrument flight procedures, they would then be better able to approach and land at the airport or depart from it. This concept would also require a new, ground-based automation system, typically located at the airport that would provide appropriate sequencing information to the arriving aircraft.*

*Further validation of the SATS HVO concept is required and is the subject of ongoing research and subsequent publications.*

## 1 Introduction

Americans have come to depend on the United States' National Airspace System (NAS) for the efficient and rapid movement of people, goods, and services. In 2000, more than 670 billion revenue passenger miles were flown [1]. Commercial air transport service has become so important that any major disturbance in its service is met by public outcry.

While the current system of hub and spoke operations has served its purpose well, it is beginning to reach a capacity plateau. Due to the increasing demand on the system and with only modest potential gains in the number of flights, the system will reach gridlock within the next 10-15 years [1,2]. Additionally, most airlines use the more economical hub and spoke system which causes people to travel significantly farther or longer to get to their destination. Nearly 70% of domestic air travelers are forced to fly through fewer than 35 of the United States' more than 18,000 landing facilities. These intermediate stops and layovers dramatically increase a traveler's overall door-to-door trip time. The rising success of air carriers and air charter services that specifically target more point-to-point travel provides evidence that people and businesses are seeking greater mobility through more convenient alternatives for air service [3].

Through the Small Aircraft Transportation System (SATS) Project, NASA, the FAA, and the National Consortium for Aviation Mobility are exploring the feasibility of increasing personal mobility and system capacity by expanding access to thousands of underutilized smaller airports across the United States. Many of these airports lack control towers and lie outside air traffic control (ATC) radar coverage, but do provide a unique potential for convenient access to small cities and business communities. New, small, efficient aircraft being developed by companies such as Honda, Avocet, Cessna, Diamond, Eclipse, Safire, Adam Aircraft, and others are touted to provide point-to-point air-charter service and make use of these small airports. Several air charter businesses are planning to use these new aircraft to provide their customers with point-to-point service.

When instrument meteorological conditions (IMC) restricts operations to Instrument Flight Rules (IFR) at non-towered, non-radar airports, ATC uses procedural separation that restricts operations to only one approaching or departing aircraft at a time – the "one-in/one-out" paradigm. While procedural separation is safe, it severely limits the operational throughput at these airports. Air charter operators might be compelled to use these airfields if the IMC operational efficiency can be improved. SATS breaks the one-in/one-out paradigm and expands capacity by allowing multiple, simultaneous operations while achieving a level of safety equal to today's system. The concept of operations (CONOPS) that achieves this goal is termed SATS "Higher Volume Operations" (HVO).

## 2 SATS HVO CONOPS Overview[4]

Key to this concept is the use of a newly defined area of flight operations called a Self-Controlled Area (SCA), established during periods of IMC around these SATS designated airports. This concept is based on a distributed decision-making environment that assumes the majority of the decision-making responsibility would remain with the pilot because it would provide pilots with the necessary procedures, tools, and information to enable safe operations within the SCA.

Within the SCA, pilots, using advanced airborne systems, would have the ability and responsibility to maintain separation between themselves and other similarly equipped airplanes. Aircraft operating in this airspace would need special avionics, e.g., automated dependent surveillance-broadcast (ADS-B), a two-way data link, and appropriate self-separation tools in order to participate. This concept would also require a new, ground-based automation system, the airport management module (AMM), typically located at the airport that would provide appropriate sequencing information to the arriving aircraft. The AMM provides an arrival sequence and broadcasts the total number of arriving aircraft in the SCA. It does not, however, provide separation, altitude assignments, or sequence departures.

This proposed operational concept emphasizes the integration with the current and planned near-term NAS. Additionally, the focus of the underlying design approach was on simplicity from both a procedural and a systems requirements standpoint. It was also assumed that any additional ATC workload must be minimized, and enroute procedures must be compatible with today's ATC system.

A joint NASA Langley Research Center and FAA Technical Center simulation study is focused on the SATS HVO and ATC transitions (i.e., SCA airspace design, and controller-pilot SCA transition procedures) to ensure additional ATC workload is minimized and SATS HVO integrates with today's ATC system.

The SATS HVO concept is a starting point or "template" for additional designs and analyses. No attempts have been made to optimize the size or shape of the proposed airspace. To date, the development focus has been on providing an operational concept that was safe, would enable more than one operation at a time, and would not require significant ground infrastructure costs or improvements.

GPS-T instrument approach procedures were chosen as a basis for this concept, although it can use other instrument approach procedures as well.

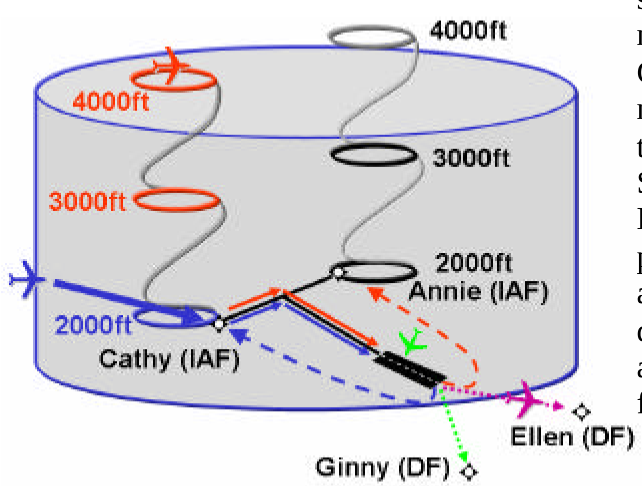


Fig. 1. SATS HVO Example

Many of the features of the GPS-T based SATS HVO concept are depicted in Figure 1. SATS arrivals (**Red** and **Blue** aircraft) with alternating missed approaches, and departures (**Green** and **Purple** aircraft) are depicted in a "snapshot" in time:

- **Blue** – entering the SCA having coordinated descent with ATC because the AMM provided: "lateral entry (no other aircraft assigned to Cathy), follow none, missed approach Cathy" (missed approach depicted as blue dashed path),
- **Red** – having arrived by IFR clearance to the transition fix at 4000ft, the AMM provided: "vertical entry (3000ft at Cathy is open), follow blue aircraft, missed approach to Annie," (missed approach depicted as red dashed path)
- **Purple** – departing SCA via departure procedure and contacting ATC,
- **Green** – released by ATC to depart; holding short and using on-board tools to find open slot in arrival stream to take the active runway and depart.

Aircraft arriving into the SATS airport will be under ATC clearance according to an IFR flight plan to a transition fix above the SCA. The transition fix is also the initial approach fix on a GPS-T instrument approach procedure. Prior to reaching the transition fix, the pilot would request a landing assignment from the AMM. The AMM responds with the SCA entry procedure (standby, vertical or lateral), relative sequence information (follow <Callsign>), and missed approach hold fix assignment (Annie or Cathy). The AMM only tracks arrivals and missed approach aircraft, not departures, and thereby allows up to four arriving aircraft in the SCA before denying entry (issuing a "standby"). Based on sequence info, and following the HVO procedure to "descend to lowest available altitude," pilots will be procedurally deconflicted from up to three other arriving aircraft (i.e., the AMM reserves space for up to four aircraft at the IAFs).

Pilots given a "standby" sequence will be able to track the number of aircraft in the SCA to estimate their delay as they continue to their clearance limit and establish a standard hold above the SCA at the transition fix. When the pilot gets an AMM entry message with sequence and missed approach information, the pilot is assured an opening at 3000ft and will request descent from ATC. The pilot can then determine if further descent to the 2000ft hold is prudent by following the "lowest available altitude" procedure at the IAF, (clearing for traffic below is the pilot's self-separation responsibility in the SCA). A missed approach hold slot is also guaranteed by the AMM, so a pilot going missed would then climb to the "lowest available altitude" back at the IAF and is sent a new arrival sequence.

Pilots will initiate their approach once adequate spacing behind the lead aircraft has been met (determined through either a generic rule-based spacing procedure, i.e., safe for all combinations of aircraft performance, or by using an on-board self-spacing tool). For SATS departures, pilots will file flight plans with a SATS departure procedure to a departure fix (DF, i.e., Figure 1 Ellen or Ginny), obtain ATC clearance, and then use on-board information/tools to find a departure window, e.g., allowed to depart if there are no arriving aircraft within 5nm of the airport. The pilot would then depart and contact ATC according to the departure procedure.

## 3 Preliminary Validation Process

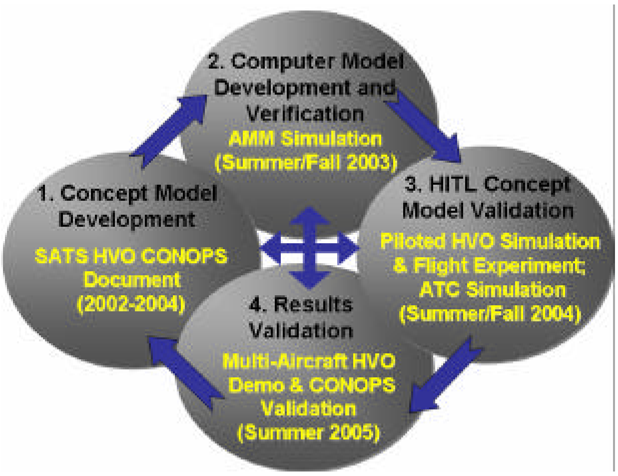


Fig.2. SATS HVO CONOPS Validation Process

The SATS HVO CONOPS [4] is being developed through a four phase, building block research process. Phase one in Figure 2 shows the CONOPS growing out of a need for developing the "concept model" and documenting it. A breadth of perspectives and expertise were used to formulate the concept over several months. The key safety properties of a draft HVO CONOPS were also established by a mathematical verification method based on formal logic and theorem proving [5]. This study began the process to formally verify that self-separation is maintained; assuming pilots adhere to the CONOPS procedures (including AMM logic). A complete formal verification of the CONOPS rules and procedures (and AMM logic) is still required. Phase two involved the development of a simulation environment (computer model) that included the AMM. The AMM was verified by testing its accurate function during a representative set of SATS HVO scenarios.

Phase three includes the bulk of the SATS HVO experimental work in validating the SATS HVO CONOPS (concept model) through human in the loop (HITL) studies. The preliminary analysis of workload and situation awareness ratings highlighted later in this paper resulted from the piloted simulation experiment completed in May 2004. An initial quantitative delay analysis comparing SATS HVO to today's one-in/one-out system is also included. Phase three also includes both a flight experiment (using a subset of the simulation scenarios) and an ATC simulation study focused on determining ATC acceptability of the concept model.

Phase four is designed as a proof-of-concept demonstration incorporating several aircraft flying the SATS HVO CONOPS procedures.

All phases provide feedback to the improvement of the SATS HVO CONOPS and ultimately toward recommending a viable way to improve upon the one-in/one-out procedure in place today.

## 4 Preliminary Delay Analysis

An initial quantitative analysis of system performance was conducted to explore the delay times associated with SATS HVO and baseline operations using a simulation tool, called the General Aviation Airport Traffic generator (GAAT). The GAAT was developed as part of the simulation environment in the Air Traffic Operations Lab (ATOL) at NASA Langley Research Center (LaRC). The GAAT runs in two modes: *real time* as the virtual traffic generator for the HITL experiments, and in *batch mode* as a very flexible, random traffic generator that includes a pilot model and an Air Traffic Control (ATC) model. The GAAT tool allows virtual aircraft types and performance characteristics to be configured to simulate different airport traffic combinations. Traffic patterns can also be configured to represent different sources of arrival streams with configurable rates. Both the pilot and ATC model implement all the necessary interactions to perform baseline and HVO operations. The pilot model enables the virtual aircraft to follow the sequence instructions given by the AMM model as well as maintain self separation and proper spacing from lead aircraft while in the SCA, descend or climb to appropriate altitudes and maintain intended speeds. The ATC model assigns holding altitudes outside the SCA, provides departure clearances to all departing aircraft and approach clearances in baseline scenarios.

The simulation study was designed to analyze the performance of HVO operations under increasing traffic loads. The simulated traffic consisted of one departure and four arrival streams with exponentially distributed inter-arrival times. The approaching traffic pattern consisted of four fix sources of various aircraft types. All virtual aircraft followed procedures and ATC instructions, and no non-normal operations were simulated. The independent variable of the study was the average input operation rate that was increased for each run of 10 simulated hours of operations from 2 to 20 operations per hour. Operations were on average 50% arrivals and 50% departures. In each run, input traffic stopped after 10 hours but the simulation continued until all approaches in stand-by and all departures were completed. The simulation was stopped when the number of aircraft on the stand-by queue was more than 10.

Four sets of runs were performed that correspond to SATS and Baseline operations, with and without a 20% probability of missed approaches respectively. Data for maximum and average performance was collected that included arrival and departure delays, queue lengths, number of concurrent operations in the SCA, types of entries granted by the AMM, etc.

Preliminary results from the study show that SATS HVO operations can support high traffic loads with reasonable delays (i.e. less than 30 minutes) while baseline operations degrade very rapidly.

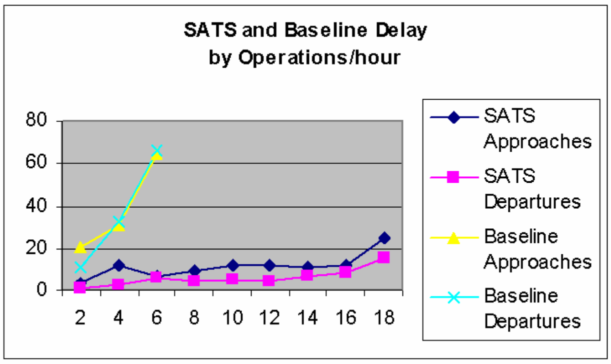


Fig. 3. SATS and Baseline Delay

Figure 3 shows a comparison of maximum operation delays for SATS and baseline operations with no missed approaches. The delay is calculated as the time elapsed between a pilot's request (to either the AMM or ATC) and the operation completion. Each data point represents a single run of 10 hours of operations. The horizontal axis indicates the input rates and the vertical axis shows delay times in minutes.

Baseline operations quickly degrade after an average input rate of 4 operations per hour. SATS operations sustain maximum delays of no more than 25 minutes for up to 16 operations per hour. Only three data points are shown for the baseline curves but the growth trend of the data continues beyond the segment shown in the diagram.

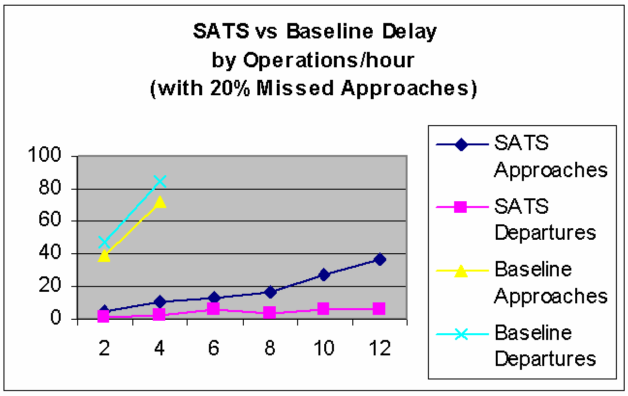


Fig. 4. SATS and Baseline Delay (with 20% Missed Approaches)

A similar behavior is observed in Figure 4 that shows maximum operation delays with a 20% probability of missed approaches. In this case, baseline operations sustain long delays at low traffic loads while SATS operations support up to 12 operations per hour with maximum delays no more that 35 minutes.

While these are only preliminary results, they are very encouraging since they show that the SATS HVO concept of operations can improve capacity at SATS designated airports.

## 5 Preliminary Human-In-The-Loop Results

The SATS HVO Simulation Study was conducted in NASA Langley Research Center's (LaRC) Air Traffic and Operations Lab (ATOL) during the spring of 2004 in order to determine: 1) if a pilot can safely and proficiently fly an airplane while performing SATS HVO procedures; 2) how the workload level that a pilot experiences when using HVO procedures and tools compares with the workload level experienced when flying in today's system; and 3) how the level of situation awareness that a pilot experiences when using HVO procedures and tools compares with the level of situation awareness experienced when flying in today's system.

## 5.1 Experiment Design

The experiment design used for data collection was a 2 (Procedure Type) x 5 (Scenario Type), within-subject design in which the same 15 participants (i.e., low time instrument rated pilots) were assigned to each experimental cell (i.e., test condition). The experiment design matrix is shown in Figure 5.

| SCENARIO TYPE | | Baseline | SATS |
|---|---|---|---|
| | **1** | $S_{1-15}$ | $S_{1-15}$ |
| | **2** | $S_{1-15}$ | $S_{1-15}$ |
| | **3** | $S_{1-15}$ | $S_{1-15}$ |
| | **4** | $S_{1-15}$ | $S_{1-15}$ |
| | **5** | $S_{1-15}$ | $S_{1-15}$ |

**PROCEDURE TYPE**

Figure 5 Experiment design matrix.

## 5.2 Independent Variables

The two independent variables used in the experiment design were procedure type and scenario type. Each test condition involved asking participants to fly a GA desktop simulator according to a given combination of procedure type and scenario type, as shown in the experiment design matrix (Figure 6). The two procedure types (i.e., Baseline and SATS) were selected so that SATS procedures could be compared with current day procedures. The five scenario types [i.e., (1) One Aircraft on Departure; (2) One Aircraft on Approach; (3) Three Aircraft on Approach at the Opposite Instrument Approach Fix (IAF); (4) Missed Approach; (5) Multiple Pilot Participation] were selected so that a representative set of aircraft operations could be investigated.

### *5.3 Dependent Measures*

The primary dependent measures obtained in this experiment included pilot conformance to procedures and subjective assessments of workload. Secondary dependent measures included subjective assessments of situation awareness and conflict detection and alerting statistics. Observed throughput was measured, as it represents an important validation result, and usability questionnaires were administered. Detailed results associated with subjective assessments of workload and situation awareness as well as general comments associated with usability are discussed in this paper. Additional results will be reported in subsequent publications.

## 5.4 Procedure

Three groups of four participants and one group of three participants (i.e., a total of 15 participants) completed a pre-experiment session, a "classroom" training session, a "hands on" simulator training session, 15 data collection flights, and a post-experiment debriefing session. Each participant group completed the entire experiment over approximately three, eight and a half hour days.

The pre-experiment session involved obtaining participants' total and recent flight hour data and asking participants to read and sign an informed consent form. During the "classroom" training session, participants were provided with an overview of: 1) the HVO element of the SATS Program, 2) the purpose of the current experiment, 3) the GA desktop simulator, 4) the experiment tasks and area of flight, 5) the Multi-Function Display (MFD) and its operation, and 6) the subjective workload and situation awareness estimate scales.

Following the "classroom" training session, participants were given "hands on" training to become familiar with the flight characteristics of the desktop simulator and all aspects of the tasks they would perform during data collection flights. Data collection flights were performed during the afternoon of the first day as well as during the second and third days of the experiment. Participants completed the test conditions in partially counterbalanced order and provided subjective assessments of workload and situation awareness after each data collection flight. A debriefing session after the final data collection flight completed the experiment's schedule.

Experimenters carried out specific duties during the pre-experiment session, the "classroom" training session, the "hands on" training session, and the data collection flights. The experimenters cued up the appropriate flight scenarios and ensured that the appropriate information appeared on the participants' MFDs; solicited and collected the participants' test condition workload and situation awareness ratings; and provided simulated ATC instructions to the participants as part of the prescribed experiment flight tasks.

## 5.5 Results

### *5.5.1 Subjective Assessments of Workload*

Participants used the Modified Cooper-Harper Rating Scale to rate the level of workload that they experienced during each of the experiment's 10 test conditions. Workload ratings ranged 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) [6]. Since participants performed each of the five Baseline scenarios once and performed each of the five SATS scenarios twice, each participant provided 15 workload ratings. For each participant, the two workload ratings associated with a given SATS scenario were averaged together to yield a set of five SATS scenario workload ratings. Therefore, five mean SATS scenario workload ratings and five Baseline scenario workload ratings were associated with each participant. As reported below, nonparametric tests were employed as a conservative method for analyzing workload ratings associated with discrete rating scale items.

#### 5.5.1.1 Procedure Type

When workload ratings were averaged across the five scenario types, participants reported experiencing a workload rating 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 (i.e., a nonparametric within-subject test appropriate for analyzing two related samples of ordinal data) was performed on the mean workload ratings to determine if participants reported experiencing different levels of workload when performing the two types of procedures [7]. This test revealed that participants reported experiencing a lower level of workload when they performed the SATS procedures than when they performed the baseline procedures ($p \leq 0.05$).

#### 5.5.1.2 Scenario Type

Since the results associated with the procedure type main effect and the Procedure Type x Scenario Type interaction are of primary interest, the results associated with the scenario type main effect are not discussed in this paper.

#### 5.5.1.3 Procedure Type x Scenario Type

Participants reported experiencing the following workload ratings when they performed different types of scenarios using baseline procedures and SATS procedures:

- Scenario 1 (Baseline Procedure, One Aircraft on Departure): $M$ = 2.60, $SD$ = 1.35, $N$ = 15;
- Scenario 2 (SATS Procedure, One Aircraft on Departure): $M$ = 1.57, $SD$ = 0.62, $N$ = 15;
- Scenario 3 (Baseline Procedure, One Aircraft on Approach): $M$ = 2.00, $SD$ = 1.00, $N$ = 15;
- Scenario 4 (SATS Procedure, One Aircraft on Approach): $M$ = 1.50, $SD$ = 0.42, $N$ = 15;
- Scenario 5 (Baseline Procedure, Three Aircraft on Approach at Opposite IAF): $M$ = 3.20, $SD$ = 1.57, $N$ = 15;

- Scenario 6 (SATS Procedure, Three Aircraft on Approach at Opposite IAF): $M = 1.80$, $SD = 0.59$, $N = 15$;
- Scenario 7 (Baseline Procedure, Missed Approach): $M = 2.73$, $SD = 1.28$, $N = 15$;
- Scenario 8 (SATS Procedure, Missed Approach): $M = 1.87$, $SD = 0.52$, $N = 15$;
- Scenario 9 (Baseline Procedure, Multiple Pilot): $M = 2.40$, $SD = 1.45$, $N = 15$; and
- Scenario 10 (SATS Procedure, Multiple Pilot): $M = 1.70$, $SD = 0.53$, $N = 15$.

A Wilcoxon Test was performed to determine if participants reported experiencing different levels of workload when different types of scenarios were performed using different types of procedures [7]. Since the differences between the workload ratings associated with particular pairs of scenarios were of primary interest (i.e., Scenarios 1 vs. 2, 3 vs. 4, 5 vs. 6, 7 vs. 8, and 9 vs. 10), only the results of the Wilcoxon Test associated with these scenario pairings are discussed here.

As shown by the mean workload ratings plotted in Figure 6, participants reported experiencing higher levels of workload when scenarios were performed using the baseline procedures than when scenarios were performed using the SATS procedures.

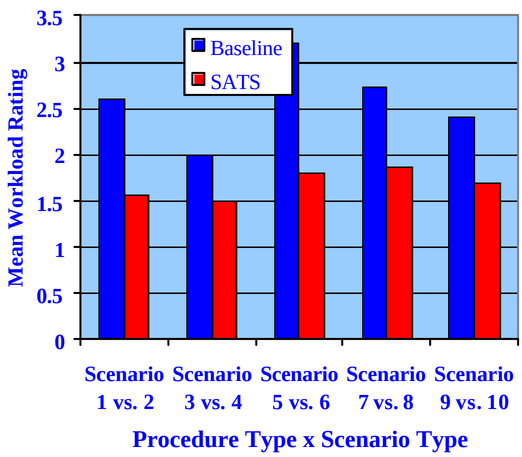


Fig. 6. Mean workload ratings associated with Procedure Type x Scenario Type.

However, the Wilcoxon Test revealed that at a statistically significant level, participants reported experiencing higher levels of workload when performing Scenario 1 as compared with Scenario 2 and when performing Scenario 5 as compared with Scenario 6 ($p < 0.05$).

### 5.5.2 Subjective Assessments of Situation Awareness

Situation awareness refers to a pilot's perception and interpretation of information relevant to a particular task [8]; in this case – a procedure for landing at an airport. Participants were administered 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. Using the formula,

$$SA = \text{Understanding} - (\text{Demand} - \text{Supply})$$

scores ranging from 3 to 13 were calculated. A score of 13 represented a high level of SA, and a score of 3 represented a low level of SA.

It was hypothesized that a pilot's situation awareness using the modified MFD would be equivalent to the situation awareness experienced during the baseline conditions. However, preliminary analysis indicates that mean SA was higher across the scenarios for the SATS condition over the baseline condition. The mean SART Scale ratings are plotted in Figure 7 and illustrate the higher SA perceptions of the pilot.

#### 5.5.2.1 Procedure Type

SART ratings were averaged across the five scenario types resulting in a mean SA rating of 9.6 for the SATS procedures ($M=9.6$, $SD=1.97$, $N=75$). The SA scores for the baseline scenarios indicated that pilots' situation awareness was slightly lower with a mean rating of 8.05 ($M=8.05$, $SD=2.68$, $N=75$). A paired samples $t$-test was performed to compare the overall mean for the SATS procedures vs. the baseline procedures. The results of this test indicated that SA ratings associated with the performance with SATS procedures were higher than SA ratings associated with the performance of the baseline procedures ($p<0.001$).

#### 5.5.2.2 Scenario Type

Since the results associated with the procedure type main effect and the Procedure Type x Scenario Type interaction are of primary interest, the results associated with the scenario type main effect are not discussed in this paper.

#### 5.5.2.3 Procedure Type x Scenario Type

Participants reported experiencing the following SA ratings when they performed different types of scenarios using baseline procedures and SATS procedures:

- Scenario 1 (Baseline Procedure, One Aircraft on Departure): $M = 9.6$, $SD = 1.81$, $N = 15$;
- Scenario 2 (SATS Procedure, One Aircraft on Departure): $M = 10.5$, $SD = 1.92$, $N = 15$;
- Scenario 3 (Baseline Procedure, One Aircraft on Approach): $M = 7.67$, $SD = 2.82$, $N = 15$;
- Scenario 4 (SATS Procedure, One Aircraft on Approach): $M = 9.7$, $SD = 1.49$, $N = 15$;
- Scenario 5 (Baseline Procedure, Three Aircraft on Approach at Opposite IAF): $M = 7.3$, $SD = 2.71$, $N = 15$;
- Scenario 6 (SATS Procedure, Three Aircraft on Approach at Opposite IAF): $M = 9.2$, $SD = 2.19$. $N = 15$;
- Scenario 7 (Baseline Procedure, Missed Approach): $M = 7.73$, $SD = 2.4$, $N = 15$;
- Scenario 8 (SATS Procedure, Missed Approach): $M = 9.1$, $SD = 1.87$, $N = 15$;
- Scenario 9 (Baseline Procedure, Multiple Pilot): $M = 8.0$, $SD = 3.16$, $N = 15$; and
- Scenario 10 (SATS Procedure, Multiple Pilot): $M = 9.5$, $SD = 2.2$, $N = 15$.

To determine when participants reported experiencing different levels of situation awareness when different types of scenarios were performed using different types of procedures, a series of paired samples *t*-tests was performed. Since the differences between the SA ratings associated with particular pairs of scenarios were of primary interest (i.e., Scenarios 1 vs. 2, 3 vs. 4, 5 vs. 6, 7 vs. 8, and 9 vs. 10), only the results of the paired *t*-tests associated with these procedure pairings are discussed here. Figure 7 provides a summary of the mean SART scores with procedure and scenario type.

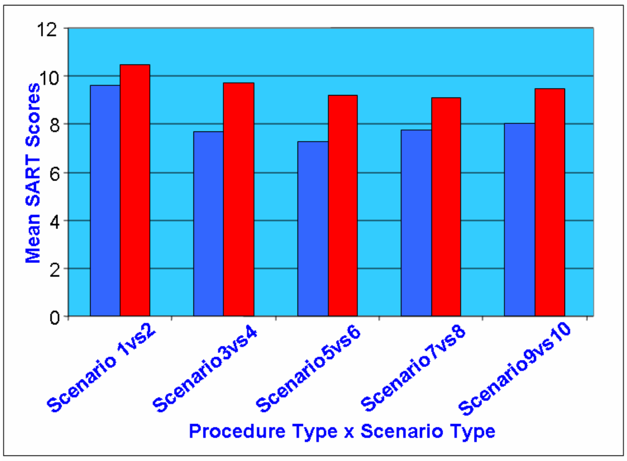


Fig. 7. Mean situation awareness ratings associated with Procedure Type x Scenario Type.

### 5.5.3 General Comments Regarding the Usability of the SATS Procedures

Although the quantitative data collected to assess the ability of participants to safely and proficiently fly an airplane while performing SATS HVO procedures have not yet been analyzed, qualitative data collected via a post-experiment usability questionnaire provide some evidence of the acceptability of SATS procedures. For example, 100% of the participants described the SATS procedures as being either "easy to follow," or "very easy to follow." Similarly, 100% of the participants described the sequencing information provided during the scenarios performed using SATS procedures as being either "straightforward" or "very straightforward." Finally, when asked to compare the baseline procedures and the SATS procedures:

- 20% of the participants rated the SATS procedures as being "equally as complicated" as the baseline procedures;
- 20% of the participants rated the SATS procedures as being "slightly less complicated" than the baseline procedures;
- 26.7% of the participants rated the SATS procedures as being "less complicated" than the baseline procedures; and

- 33.3% of the participants rated the SATS procedures as being "significantly less complicated" than the baseline procedures.

These qualitative findings indicate that pilots participating in the current research endeavor responded very favorably to the SATS HVO concept to which they were exposed.

## 6 Future Work

Planned and ongoing SATS HVO research includes the HVO flight experiment to validate a subset of the HVO simulation scenarios. Also planned is a joint NASA Langley and FAA Technical Center ATC simulation study focused on determining ATC acceptability of the SATS HVO CONOPS. Once HVO research results are published, a proof-of-concept demonstration incorporating several aircraft flying the SATS HVO CONOPS procedures is planned in the summer of 2005.

Expanding HVO research and development into non-normal operations is critical to creating a viable system in the near term. Once the concept model for non-normal SATS HVO is developed, batch and HITL simulations, validated by in-service flight experiments will be key to full-system validation. Formal verification of SATS HVO CONOPS procedures and system logic is still recommended as well.

Further research should be conducted to improve the SCA design, both in terms of optimizing it's geometry and in increasing the capacity of the SCA. Additionally, research on display features, functionality and design should be conducted to enhance the processing of both text and aural and visual information.

## Summary

This document provides an overview of the preliminary validation of the Small Aircraft Transportation System (SATS) Higher Volume Operations (HVO) concept for normal conditions. Initial results reveal that the concept provides reduced air traffic delays when compared to current operations without increasing pilot workload. Further validation of the concept is required and should be the subject of ongoing research and subsequent publications.

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