SATS HVO PROCEDURES FOR PRIORITY LANDINGS AND MIXED VFR/IFR OPERATIONS

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Abstract

This paper describes a pilot in the loop simulation experiment of the Small Aircraft Transportation System (SATS) Higher Volume Operations (HVO) concept for off-nominal conditions conducted at the Air Traffic Operations Lab (ATOL), NASA Langley Research Center. The experiment was designed to validate procedures for priority landing requests and pilot cancellations of approach requests with subsequent transitions to visual flight rules (VFR). Priority landing requests during approach operations allow pilots to land ahead of others in the sequence. Cancellations of approach requests allow participating aircraft to cancel an approach sequence and transition to VFR if desired. Preliminary results show that pilots find the procedures acceptable with no increase in perceived workload as compared to nominal SATS HVO operations while pilot performance and situation awareness metrics are consistently high. Overall, subject pilots welcome the increased potential efficiency the concept offers and the increased ability to self-control while flying SATS HVO procedures.

Introduction

The SATS HVO concept of operations was developed to address the forecasted capacity crisis in the National Airspace System (NAS). Its goal is to increase the utilization of non-towered, non-radar airports during periods of Instrument Meteorological Conditions (IMC) without a major impact to the Air Traffic Control (ATC) structure or workload. The concept relies on the establishment of a volume of airspace around designated airports referred to as the Self Controlled Area (SCA) where pilots accept responsibility for self-separation, a set of procedures governing operations transition to and within the SCA, and avionics that include Automatic Dependent Surveillance-Broadcast (ADS-B) and air-ground datalink communications. Approaching aircraft must communicate with a ground based automated facility known as the Airport Management Module (AMM) to obtain sequencing instructions. A complete description of the procedures and required equipment can be found in a prior report [1].

The concept of operations for nominal conditions was validated in a series of piloted studies and flight tests [2-5]. The experiments sought to determine if a pilot could safely and proficiently fly an airplane while performing SATS HVO procedures, and to assess pilot workload and situation awareness. Results showed that pilot performance was unaffected by the new procedures and that workload and situation awareness were significantly better when compared to today's procedural separation. Other studies in the validation process included formal analysis of procedures [6, 7] and en-route transition procedures [8].

Since a comprehensive concept of operations must include procedures to handle off-nominal conditions, SATS HVO was extended to address off-nominal operations, operational errors, and equipment failures [9]. Two such procedures were chosen to be tested in a piloted simulation study, procedures to handle cancellation of approach requests with transitions to visual flight rules (VFR), and priority requests from approaching aircraft. The choice of off-nominal procedures for this first study was based on the limited scope of the study, the expected likelihood of VFR transitions and the relative importance of priority landings. Clearly, further work needs to be done to fully test the remaining procedures.

Priority landing requests allow pilots to land ahead of others in the sequence. The procedure requires the priority pilot to inform other pilots via the traffic frequency of the condition and notify the airport management module (AMM) over datalink. Cancellations of approach requests allow participating aircraft to cancel an IFR approach and transition to VFR if desired.

This paper describes the off-nominal simulation experiment that focused on validation of these two SATS HVO procedures, and provides a detailed description of the experiment design and results. The organization of this paper is as follows: Section 1 provides a brief overview of the concept of operation for VFR transitions and priority requests of approaching traffic. Section 2 introduces the experiment methodology, simulation platform, and the experiment design. Sections 3 and 4 contain the analysis of the experiment results and concluding remarks.

Overview of the HVO Concept of Operations

Normal HVO operations

Aircraft flying enroute to a SATS airport would be on a standard instrument flight rules (IFR) clearance with ATC providing separation services. Before entering the SCA airspace, pilots would take responsibility for separation assurance between their aircraft and other similarly equipped aircraft in the area. Figure 1 depicts a schematic view of the SCA that includes a Global Positioning System (GPS) "T" instrument approach diagram, with two initial approach fixes (IAF), Cathy and Annie, that also serve as the missed approach holding fixes (MAHF). There are also two departure fixes (DF), Ginny and Ellen, located outside the SCA. SATS arrivals (Red and Blue aircraft) with alternating missed approaches, and departures (Green and Purple aircraft) are depicted in a "snapshot" in time. While separation in the SCA is based on procedures and onboard equipment, landing sequence is established by a centralized, ground-based automated facility. Pilots initiate their approach in assigned sequence once adequate spacing behind their 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 HVO departures, pilots file flight plans with a SATS HVO departure procedure to a departure fix (DF, i.e., Figure 1 ELLEN or GINNY) in controlled airspace, obtain standard ATC clearance, and then use on-board information/tools to ensure a safe departure window locally, 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.

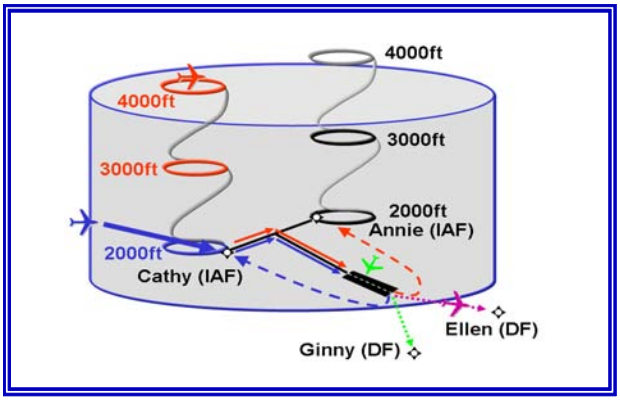

Figure 1. Schematic View of the SCA

Off-Nominal Operations

A complete list of off-nominal procedures defined in the SATS concept of operations can be found in [9]. The design of these new procedures was based, to the extent possible, on similar existing VFR operations or non-radar IFR operations. A brief discussion of the off-nominal conditions evaluated in this experiment is presented in this section.

VFR Transitions

Upon encountering visual meteorological conditions (VMC) SATS HVO pilots may choose to continue VFR, canceling their AMM sequences and transitioning to visual approaches. The canceling aircraft is required to communicate the cancellation to the AMM and to the other pilots (over CATF [1]). They would then be identified as a non-participating aircraft to other aircraft in the SCA who may in turn be re-sequenced by the AMM depending of the relative position of the canceling aircraft. As in today's operations, all aircraft in VMC are expected to follow see and avoid rules.

Priority Request

A priority request procedure would be used for an aircraft with an assigned approach sequence that must land immediately, typically an emergency situation. The requesting pilot must announce the emergency and his intent over CTAF, and to the

[1] Common Advisory Traffic Frequency

onboard avionics, which in turn relays this information to the AMM. However, the requesting aircraft will not be assigned a new approach sequence. As soon as possible, the priority aircraft would begin the approach, procedurally maintaining spacing from prior approach aircraft. If the approach spacing interval becomes too close, the pilot of the priority aircraft has the responsibility to request the proceeding aircraft to perform a missed approach. If the priority aircraft was initially higher than the normal approach altitude at the IAF, they would only descend after crossing the intermediate fix inbound on the approach, still accommodated by a normal descent rate (e.g., 500 fpm). The other aircraft in the SCA identify the priority aircraft on their cockpit display of traffic information (CDTI). If in holding, they remain in holding at constant altitude, making themselves most predicable. If already on approach they continue, unless advised by the priority aircraft that a missed approach would be required. After the priority aircraft lands the AMM re-sequences all other aircraft. An additional safety feature of the procedure is that the AMM can notify ATC of the SCA priority status.

Objectives and Methodology

The overall goal of the experiment was the validation of newly defined SATS HVO procedures for off-nominal conditions. The question posed was if pilots could safely and proficiently execute SATS HVO procedures for priority landing requests and VFR transitions. During this experiment, subject pilots were asked to manually fly a GA aircraft simulator in instrument meteorological conditions (IMC) or marginal visual meteorological conditions (VMC) during a series of approach scenarios. Two types of procedures were modeled by the experiment scenarios: 1) SATS HVO scenarios (referred to as SATS scenarios from now on) included only normal HVO operations. 2) Off-nominal scenarios included landing priority requests and VFR transitions (referred to as Off-nominal scenarios from now on). The study measured flight technical error, perceived workload, and situation awareness of pilots throughout the operations associated with both, the SATS and Off-Nominal scenarios. Workload and situation awareness data was collected at the end of each scenario and usability questionnaires were administered after the completion of all runs. The overall hypothesis of the experiment was that pilots would be able to perform off-nominal procedures as well as normal SATS HVO procedures and that they would experience equivalent levels of workload and situation awareness.

Experiment Description

Evaluation pilots (EP) were asked to perform types of scenarios representing either normal SATS HVO operations or an off-nominal condition (i.e. a landing priority request or VFR transitions). All scenarios were simulated at Melfa airport in Accomack County, Virginia.

Scenario Description

At the beginning of all scenarios, aircraft are positioned inside the SCA as shown in Figure 2. All scenarios end after the last aircraft lands.

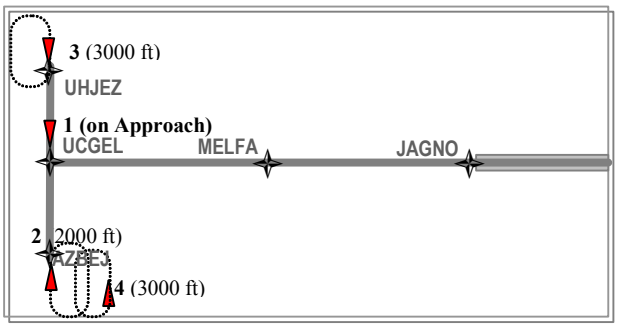

Figure 2. Initial Position of aircraft in the SCA

During Normal SATS HVO conditions, all four EPs are expected to complete landings in their initially assigned sequence. During landing priority requests scenarios, a single EP was asked to request landing priority. The requesting EP was in a different position in the SCA for each different scenario. During VFR scenarios, either 2 or all 4 EPs were instructed to cancel their sequences and follow procedure for VFR transitions.

Simulation Platform

The simulation platform consisted of four pilot stations and an airport management model with a plan view display. The pilot stations included a GA aircraft simulator, two flat panel displays for instrumentation, and a large plasma display for the out-the-window view as shown in Figure 3. Also,

and a joystick and mouse for flight control and instrument interaction and a set of head-phones/microphone allowed pilots to interact with other pilots and a simulated air traffic control station. All the pilot interface functionality designed for the SATS HVO operation was displayed in the experimental multifunction display (MFD) shown below. The MFD included a moving map with approach and path information, traffic and conflict detection and alerting symbology, procedure support functionality and an AMM communications window for pilots to request and receive sequencing information. Both nominal SATS and priority scenarios had simulated IMC to minimum decent altitude (400ft. AGL[2]) while VFR transition scenarios had IMC above 1500ft.

Figure 3. GA Pilot Station

Experiment Design Matrix

As described above, this experiment included two types of procedures: SATS and Off-nominal. A single scenario was used to simulate normal SATS HVO operations. Off-nominal procedures included four priority scenarios where one EP requested landing priority and executed the approach ahead of those in the sequence, and three VFR transition scenarios where one or more EP canceled assigned AMM sequences and completed visual approaches.

The experiment design used for data collection consisted of 8 Scenarios, within-subject design in which the same 16 participants (i.e., low time instrument rated pilots) were assigned to each experimental cell (i.e., test condition). As shown in Table 1, EP 1 through 16 (EP 1-16) were asked to perform all 8 test conditions.

[2] Above Ground Level

Table 1. Experiment Design Matrix

Scenarios							
Nominal	Priority Requests				VFR Transitions		
SATS 1	pr 2	pr 3	pr 4	pr 5	vfr 6	vfr 7	vfr 8
EP 1-16	EP 1-16	EP 1-16	EP 1-16	EP 1-16	EP 1-16	EP 1-16	EP 1-16

Primary dependent measures included pilot flight technical error and subjective workload (as assessed using the Modified Cooper Harper - MCH Rating Scale), situation awareness (as assessed using the Situational Awareness Rating Technique - SART). Usability questionnaires were administered that reflected pilot preferences and opinions on procedures and interface issues.

Subjects

EPs were drawn randomly from a pool of pilots that met the following specified criteria:

- Hold either a private or commercial pilot certificate.
- Be instrument rated pilots.
- Meets FAA currency requirements for instrument flight.
- Have a high performance aircraft endorsement.
- Have less than 1000 total flight hours.
- Have flown 5-50 hours within the last 90 days.
- Desired experience using a Horizontal Situation Indicator (HSI).

The evaluation pilots (EP) included sixteen instrument rated, male subjects, 50% with commercial certificates and 50% with private pilot certificates. All EPs were IFR rated and current. All EPs were high performance capable. One pilot had received their certified flight instructor rating. All EPs held less than 1000 hours total flight time. EPs experience included 10.9 hours using the GPS as a primary navigation instrument with a mean of 2.1 instrument approaches conducted per pilot. All EPs had experience in simulators and 93% had experience with a Horizontal Situation Indicator (HSI).

Subjective Measures

After each procedure was performed, EPs were asked to complete two subjective questionnaires to assess workload and situation awareness. The workload scale used was the Modified Cooper Harper Scale (MCH) [10], a one-dimensional scale that results in a single value based on the subject's assessment of the qualities of the interaction with the system. The MCH provides a global assessment of overall workload experienced during the operations performed.

The situation awareness (SA) scale used was a combined scale comprised of the three dimensional SART scale and two independent scales for traffic awareness and navigation guidance [11]. The Situational Awareness Rating Technique (SART) provides an index of the pilot's understanding of the dynamic situation and environment within which s/he works. The SART employs a multi-dimensional rating scale for pilots to report their perceived situational awareness (SA) and examines the key areas of SA: understanding, supply and demand. SART was used because it did not require the interruption of the flight task in order to gather information and is used for its simplicity.

Analysis of Results

Workload Ratings

Pilots used the Modified Cooper-Harper (MCH) Rating Scale to rate the level of workload that they experienced during each of the experiment's 8 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). As reported below, nonparametric tests were employed as a conservative method for analyzing workload ratings associated with discrete rating scale items.

Wilcoxon Tests [12] (i.e., nonparametric within-subject test appropriate for analyzing two related samples of ordinal data) were performed on the mean workload ratings to determine if there were any statistically significant differences.

Results indicated that there were no statistically significant differences in the level of workload EPs experienced between the SATS procedure and the Off-Nominal test cases as shown in Figure 4. Workload measures for both priority requests and VFR transitions showed that EPs experienced an equivalent level of workload regardless of whether they performed normal SATS procedures or were part of Off-Nominal scenarios.

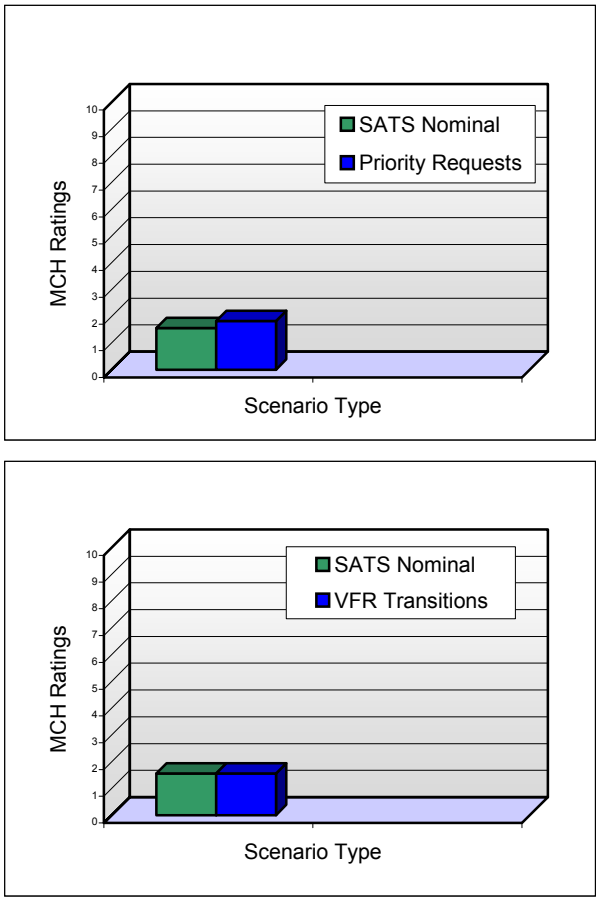

Figure 4. MCH Workload Ratings

Subjective Assessments of Situation Awareness

After each of the experiment's test conditions, all EPs completed a SART instrument that included the three SART dimensions of demand, supply, and understanding as well as two independent dimensions of traffic awareness and navigation guidance. For the dimensions of demand, supply, and understanding, pilots used a scale ranging from 1 to 7 to report a score for each dimension. 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, calculated 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 EPs. The results of a Wilcoxon Test [12] indicated that SA does not decline during priority operations or VFR transitions since there is no significant difference in the SART ratings associated with the performance of the SATS procedures over those associated with the performance of the priority operations procedures. Figure 5 shows the SART ratings for both priority requests and VFR transitions procedures.

Subjective Assessment of Traffic Awareness

Traffic awareness, pertains to the pilot's ability to track other aircraft operating in the SCA. During the course of each scenario, EPs are instructed to monitor the traffic display and always be aware of where other aircraft are located. There were no significant differences between the SATS scenario and either of the Off-nominal sets of scenarios. EPs reported experiencing equivalent levels of traffic alertness regardless of the type of procedure performed.

Subjective Assessment of Navigation Guidance Awareness

Navigation guidance refers to the pilot's understanding of the flight track and path being currently followed and the path to follow in the future. Neither the priority operations nor the VFR transitions produced a significantly different level of SA from the baseline SATS procedures during which a normal operation was flown. The following is a more detailed discussion of the EP's ratings on navigation guidance for the two types of procedures.

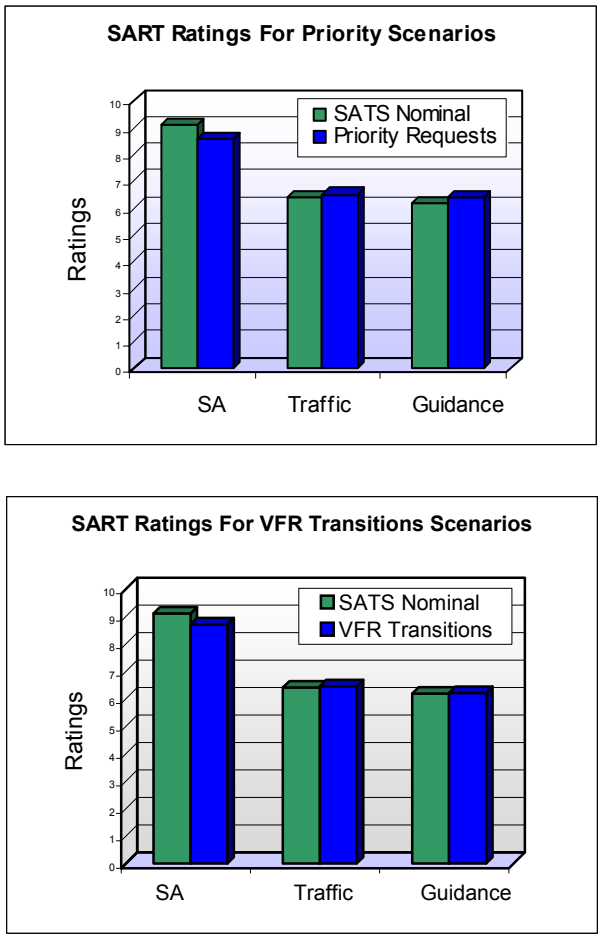

Figure 5. SART Ratings

Conformance to Procedures and Pilot Proficiency

The study sought to determine if aspects of a priority operation or VFR transitions would have any impact on the pilot's proficiency or ability to follow the new procedures. Conformance, airspeed, altitude and lateral path deviation were measured during the experiment to assess the FTE of pilots flying normal SATS procedures, priority landing requests and VFR transition scenarios.

Conformance pertains to the pilot's ability to stay within the boundaries of a containment area around the flight path by maintaining a prescribed altitude, airspeed and course heading along the approach during normal operations. However, the

nature of the off-nominal procedures tested required the pilot to deviate from the approach path and from normal procedures. In those cases conformance involved communicating with other pilots and the AMM as required and maintaining safe separation from other aircraft in the SCA. During the experiment, EPs followed all procedures as instructed, maintaining safe separation from other aircraft and frequent voice communications with other pilots. FTE measures reflect pilot's proficiency while on the approach path and as before were of limited use during off-nominal scenarios. Results showed that in priority request scenarios pilots used speed adjustments to accommodate the priority landing ahead of sequence while maintaining separation. Similarly, EPs flying VFR approaches frequently deviated from the approach and adjusted their airspeed as they saw necessary. Results also show that EPs maintained approach altitudes with equivalent accuracy both in normal SATS operations and in off-nominal cases.

Usability Questionnaires

Participants were asked a number of questions regarding the HVO procedures and the experimental interface designed for the simulation. Table 2 shows the procedure based questions and the summary of the responses given by the participants. Overall all EPs found the off-nominal procedures easy to follow and not more demanding that normal SATS procedures.

Table 2. Usability Questionnaires

	Question	Summary of Responses
1	In any of the scenarios did you declare priority when operating in a terminal area?	100% responded yes.
2	In any of the scenarios, did other aircraft declare priority while you were sequenced in the arrival stream for an approach?	93% responded yes
3	. What effect, if any, did the SATS HVO emergency procedure have on your ability to maintain safe flight when an emergency/priority operation was declared?	50% responded very positive and the other 50% ranged from positive to no effect.
4	Were the SATS HVO procedures for accommodating an emergency operation acceptable?	43.75% responded Completely acceptable and the rest ranged from acceptable to very acceptable.
5	How were you able to adapt to the SATS HVO procedures when the aircraft declared an emergency?	31.25 % responded extremely easy and the rest ranged from easy to very easy.
6	What effect, if any, did the SATS emergency operation have on your perception of where traffic was located?	62.5% responded they were aware of traffic at all times, 31.25% almost all the time and 6.25% most of the time.

Conclusions

From these data, we can conclude that pilots find the off-nominal procedures tested acceptable with no increase in perceived workload as compared to nominal SATS HVO operations while pilot performance and situation awareness metrics are consistent with those of Normal SATS HVO operations. The evaluation of off-nominal procedures through piloted studies is an important step in the validation process of SATS HVO operations. Overall, subject pilots welcome the increased potential efficiency the concept offers and the increased ability to self-control while in the SCA.

Summary

This paper provides a description of a human in the loop simulation experiment conducted as part of the validation process of the SATS HVO concept

of operations that focused on a small subset of procedures for off-nominal conditions: specifically landing priority requests and VFR transitions. The experiment sought to demonstrate that these newly defined procedures are not more difficult to perform than the normal SATS HVO procedures and that pilots would be able to execute them with equivalent proficiency and similar levels of workload and situation awareness. Results from the experiment are very positive and encouraging for the HVO concept since they confirmed the experiment hypothesis. Additionally, pilots reported high acceptability and offered supporting feedback.

Further work needs to be done to thoroughly assess other off-nominal procedures from both a pilot usability and safety perspectives.

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