

THE SMALL AIRCRAFT TRANSPORTATION SYSTEM (SATS), HIGHER VOLUME OPERATIONS (HVO) CONCEPT AND RESEARCH

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Abstract

The ability to conduct concurrent, multiple aircraft operations in poor weather at virtually any airport offers an important opportunity for a significant increase in the rate of flight operations, a major improvement in passenger convenience, and the potential to foster growth of operations at small airports. The Small Aircraft Transportation System, (SATS) Higher Volume Operations (HVO) concept is designed to increase capacity at the 3400 non-radar, non-towered airports in the United States where operations are currently restricted to “one-in/one-out” procedural separation during low visibility or ceilings. The concept’s key feature is that pilots maintain their own separation from other aircraft using air-to-air datalink and on-board software within the Self-Controlled Area (SCA), an area of flight operations established during poor visibility and low ceilings around an airport without Air Traffic Control (ATC) services. While pilots self-separate within the SCA, an Airport Management Module (AMM) located at the airport assigns arriving pilots their sequence based on aircraft performance, position, winds, missed approach requirements, and ATC intent.

The HVO design uses distributed decision-making, safe procedures, attempts to minimize pilot and controller workload, and integrates with today’s ATC environment. The HVO procedures have pilots make their own flight path decisions when flying in Instrument Meteorological Conditions (IMC) while meeting these requirements.

This paper summarizes the HVO concept and procedures, presents a summary of the research conducted and results, and outlines areas where future HVO research is required. More information about SATS HVO can be found at <http://ntrs.nasa.gov>.

HVO Concept

The Future and The Problem

Secretary of Transportation Norman Mineta recently predicted the tripling of air traffic in the United States

in the next 15 to 20 years, and projected the substantial impact new transportation modes such as jet taxis and unmanned aerial vehicles will have on the character and volume of future traffic. He stated, “The changes that are coming are too big, too fundamental for incremental adaptation...We need to modernize and transform our global transportation system, starting right now.”¹ Congress funded the Small Aircraft Transportation System (SATS) Program, a partnership between NASA, the National Consortium of Aviation Mobility (NCAM), and the FAA. The Program identified several key areas in the forecasted National Airspace System (NAS) of 2010 that needed resolution, and as a result the SATS Higher Volume Operations (HVO) Project was created to address the projected increase in traffic.² Although this increase in traffic cannot be supported by the already saturated 35 major hub airports, the 3400 under-utilized non-towered non-radar airports in the United States could accommodate a significant portion of that increase. Furthermore, using these local airports would also significantly lower the traveler’s door-to-door travel time since these facilities are generally closer to their homes than the major hubs.³

However, a major reason cited for limited services at local airports is “Procedural Separation” is imposed on aircraft operations when poor weather occurs at these airfields.⁴ Arrival and departure operations drop from over 40 per hour in visual flight rules to around 5 per hour or less when Air Traffic Control (ATC) needs to increase separation and spacing criteria to compensate for their inability to “see” the aircraft during poor visibility and/or low ceilings. This causes delays and increased fuel consumption, driving up costs.

The Higher Volume Operations Solution

A solution is to implement the SATS HVO concept. During poor weather, a block of airspace is established around the airport within which pilots will separate and space themselves from other similar SATS HVO equipped aircraft. A ground based system provides the pilots their arrival sequence. All participating aircraft within this airspace provide their own separation using a combination of procedures and specialized tools, including localized surveillance data.⁵

HVO relies on participating aircraft to broadcast critical flight information, such as position, heading, airspeed, and projected flight path to other aircraft (e.g., ADS-B). Flight information is received by all aircraft and displayed to the pilot. The pilot's awareness of this traffic, along with HVO procedures, enables a distributed decision-making environment where the pilot maintains separation and spacing regardless of low visibility or ceilings (precision approach minimums). Procedures for off-nominal operations (runway change, emergencies, etc.) are covered in another paper.⁶

The SATS HVO concept does not depend on a control tower or designated approach times but rather allows the pilot to descend and then follow the preceding aircraft on the instrument approach with appropriate spacing. The pilot uses the onboard equipment to verify that the altitude and location to which his aircraft is descending is free of other traffic. Once adequate spacing behind the preceding aircraft is achieved and can be maintained throughout the approach, the pilot would begin the approach.⁷

Instrument Approach Design

The HVO concept has the potential to work for any type of approach, however the research team selected the GPS-T configuration since it is the FAA's instrument approach procedure of choice for airports with little or no ground infrastructure. The HVO approach consists of an Initial Approach Fix (IAF), an approach path, and a missed approach procedure to the Missed Approach Holding Fix (MAHF) as shown in Figure 1. A second IAF increases the number of aircraft ready to immediately start the approach, reducing time between approaches. To minimize workload, the entire approach and missed approach procedure is contained within the Self-Controlled Area (SCA) (i.e., no frequency change required or transfer of separation responsibility required). These features led to the most unique features of the HVO concept: the IAF and the MAHF is the same point, and there is a missed approach procedure to each IAF/MAHF.

To ensure the ability to self-separate even during off-nominal conditions, the maximum number of landing aircraft allowed in the SCA is determined by the total number of IAFs and the associated holding pattern altitudes at those IAFs. In the case shown in Figures 1 and 2, four arriving aircraft are allowed within the SCA, whether approaching the IAF, in holding at the IAF, on approach, or on missed approach.

Generic Self-Controlled Area (SCA) Design

The airspace surrounding the instrument approach, within which the pilot is responsible for self-separation

from other aircraft is called the SCA. Similar to Class C airspace, the SCA can be modified to integrate into the current National Airspace System (NAS) by tailoring it to be as small as possible, but large enough to allow a pilot to safely fly the approach and self-separate from other aircraft. The SCA described in this paper is a generic 15 nautical mile radius circle centered over the Final Approach Fix (FAF), and extended vertically from the surface to 3000' AGL (Figures 1 and 2). No work was done to identify the best SCA size or shape, and further research is required to optimize the SCA.

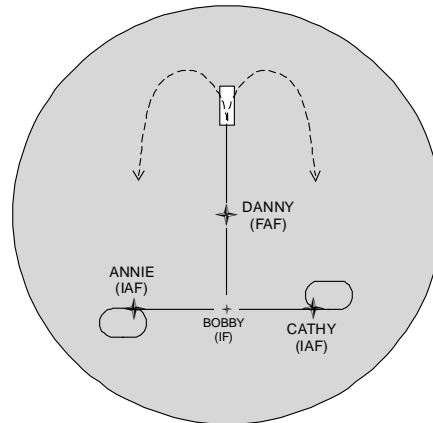


Figure 1. Plan view of the Self-Controlled Area (SCA)

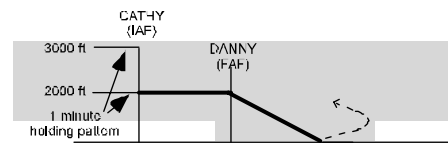


Figure 2. Profile view of the Self-Controlled Area

Airport Management Module (AMM)

The HVO concept uses a ground-based automation system called an Airport Management Module (AMM), which provides sequencing information to arriving pilots. Although typically located at the airport, the AMM is not an automated tower controller, but rather a system that issues sequence information based on predetermined rules using the aircraft's broadcasted flight information. These assignments are based on calculations involving aircraft speed, aircraft position, winds in the terminal area, and missed approach requirements. The AMM sequence assignment process also supports actions and decisions made by ATC by sequencing only those aircraft at the lowest ATC managed altitude above the SCA, tying the ATC and AMM sequences together (this gives the controller flexibility to resolve issues unknown to the AMM, like crossing airways, weather, etc.).

AMM Operating Assumptions

The AMM assumes the following applies in the SCA:

- 1) Pilots are responsible to maintain flight path separation from all aircraft, and the proper sequence and spacing with the leading aircraft.
- 2) The AMM only provides an arrival sequence, and does not monitor aircraft flight paths for conflicts, provide conflict resolution, or command pilots to descend or commence an approach.
- 3) Departing aircraft are not sequenced by the AMM. [NOTE: HVO does accommodate departures in a timely manner. See Departure section for more.]
- 4) HVO procedures provide a unique place for every arriving aircraft in the event of lost voice or datalink communication, whether entering the SCA, in holding at the IAF, on approach, or on missed approach.

AMM Entry Message Request and Format

When an aircraft is within 5 minutes of a 5 nautical mile ring around the IAF, onboard software allows the pilot to request an entry into the SCA from the AMM. This “5+5” request ring (shown as dotted circle in Figure 3 for IAF ANNIE) creates a “first come – first served” arrival sequence that compensates for different arrival speeds and winds aloft (faster aircraft have a larger circle while winds aloft shift the circle). Once the onboard software allows the pilot to request an entry, the AMM’s response to the pilot request is a “Vertical”, “Lateral”, or “Stand By” entry message. The entry message format consists of: entry type (“Vertical” or “Lateral”), IAF to proceed to (confirms the IAF requested by the pilot), aircraft to follow (given as registration number), and MAHF (opposite of preceding aircraft). A sample AMM entry message and subsequent pilot action would be:

- Message: “Entry: Vertical; IAF ANNIE; Follow N12345; GPS-03 MAHF CATHY”
- Pilot response: inform ATC of entry message from AMM, request descent into SCA, notify ATC when entering the SCA

AMM Vertical Entry Message Logic

The AMM’s default arrival procedure is the Vertical entry, where the pilot proceeds under traditional Instrument Flight Rules (IFR) control to the vicinity of the IAF at the lowest ATC managed altitude immediately above the SCA. In “the vicinity of the IAF” creates a known and predictable traffic flow from which the pilot would self-separate. For the vicinity of the IAF, the HVO concept selected a “Protected Holding Area” (FAA Order 7130.3A) for the IAF/MAHF holding depicted by the checkered magenta area around ANNIE in Figure 3. Once the aircraft is within the vicinity of the IAF and a Vertical entry

message from the AMM is received, the pilot determines the altitude below is clear of other traffic, notifies ATC and receives clearance to depart their airspace, and then descends through the top of the SCA to the lowest available altitude.

NOTE: A pilot receiving a Vertical entry must determine that there is no other traffic at 3000’ AGL; if there is, the pilot must wait. Likewise, a pilot receiving a Vertical entry with no other aircraft within the Vertical entry area and adequate spacing behind the aircraft to follow can immediately begin the approach; that pilot only enters holding if required to lose altitude (Vertical entries with holding shown in Figure 4).

For a Vertical entry message to be generated and sent by the AMM, the following conditions must be met (satisfies requirement for procedural separation for both normal and off-nominal HVO procedures):

- 1) Less than two aircraft assigned to that IAF/MAHF (aircraft proceeding to, in holding at, on approach assigned to, or on missed approach to that fix).
- 2) The requested IAF is not assigned as the MAHF to another aircraft on missed approach.
- 3) The requested IAF is not assigned as the MAHF to another aircraft on the approach (inside the IF).
- 4) The requesting aircraft is less than 1000’ above the top of the SCA (integrates the AMM to ATC).
- 5) The requesting aircraft must be within the Vertical entry area of the IAF.
- 6) Simultaneous entries at an IAF are not permitted. If any preceding aircraft entering the SCA has been assigned this IAF, it must have already transitioned into (or beyond) the “Vertical” entry area (Protected Holding) of that IAF.

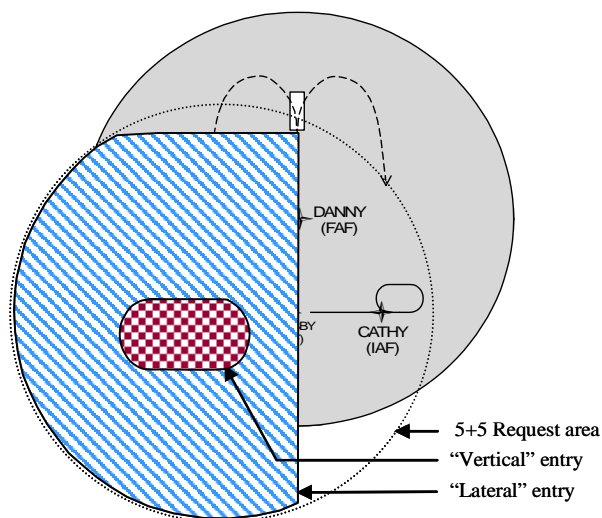


Figure 3. “Five plus Five” Request area, “Vertical” entry area, and “Lateral” entry areas for IAF ANNIE

AMM Lateral Entry Message Logic

If traffic conditions allow, the AMM issues a Lateral entry message that allows the aircraft to penetrate from the top or side of the SCA to expedite starting the approach. An ATC clearance to descend and depart ATC managed airspace is required as with a Vertical entry. If the Lateral conditions below are met, the pilot receives a Lateral entry message from the AMM (within the diagonal blue stripes in Figure 3).

In addition to the Vertical entry conditions, a Lateral entry (see Figure 3 and 4) requires:

- 1) Aircraft within 5 NM and 5 minutes of the IAF. (The “5+5” entry request ring uses aircraft ground speed to create a first-come, first-served arrival sequence based on estimated time of arrival at the appropriate IAF.)
- 2) The requesting aircraft is on the approach side of the airfield.
- 3) The requesting aircraft and IAF are on the same side of the extended runway centerline.
- 4) No other aircraft are assigned to that IAF/MAHF.

AMM Standby Message Logic

The AMM will issue the pilot a Standby message if:

- 1) The aircraft is within the vicinity of the IAF but Vertical entry criteria has not been met (e.g., two other aircraft assigned that IAF/MAHF, aircraft on approach with that assigned MAHF, etc.).
- 2) The aircraft is within the Lateral entry area but does not meet Lateral entry criteria (traffic, etc.).
- 3) The aircraft is within the “5 NM plus 5 minutes” request ring of the IAF with no other traffic in the SCA, but does not meet other entry requirements (e.g., too high above the SCA, etc.).

HVO Arrival Sequence

The arrival sequencing determined by the AMM in the HVO concept orders aircraft as they meet entry requirements. Rather than providing a constantly changing sequence number, the AMM indicates relative sequence by providing the pilot with the identification (“tail number”) of an aircraft to follow. Once the AMM entry message has been received, the pilot confirms via onboard traffic displays that he is sufficiently clear from other traffic already within the SCA, and then requests a descent out of ATC controller-managed airspace into the SCA. ATC approves the descent and advises the pilot that separation services are terminated. The pilot acknowledges and descends into the SCA to the lowest available altitude (see Figure 4).

Pilot Operating Procedures within the SCA

Pilots will use the following procedures within the SCA (see Figure 4 and Figure 5):

- 1) Pilots entering the SCA will descend to the lowest available altitude and continue descending when lower altitudes become available.
- 2) Pilots only hold at the IAF if required to maintain appropriate separation behind the preceding aircraft (for either Vertical or Lateral entries).
- 3) On a missed approach, pilots will fly to the lowest available altitude at their assigned MAHF.
- 4) Aircraft operating in the SCA must be able to climb at 300 feet per mile or better.
- 5) Pilots departing the SCA self-separate from arriving and departing traffic, fly the published departure procedure, and adhere to the ATC clearance to transition back into managed airspace.

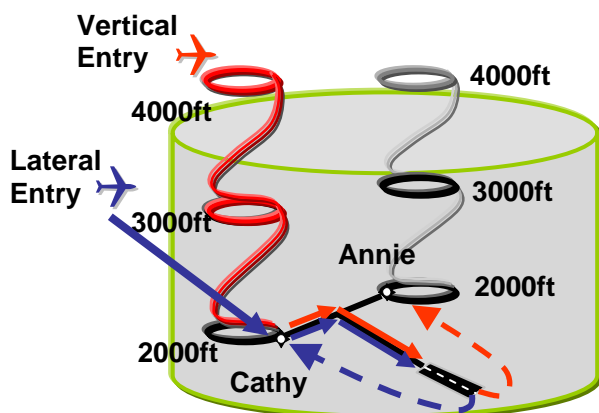


Figure 4. Pilot Operating Procedures

HVO Arrival Spacing

Pilots continue their descent until they arrive at the initial approach altitude. Before leaving holding and initiating the approach from the IAF, the pilot must determine if the preceding aircraft is sufficiently ahead to provide adequate spacing throughout the approach. SATS HVO aircraft create spacing by holding at the IAF until spacing with the lead aircraft meets specified criteria (dynamically computed by onboard algorithms, or a default that the previous aircraft has passed the FAF). A pilot arriving at the IAF with greater than the required spacing behind the preceding aircraft would immediately commence the approach; no turn in holding would be required although the pilot could elect to do so if other requirements dictated.

Most of NASA Langley Research Center simulator and flight experiments used onboard algorithms that continuously computed spacing required to generate a

minimum 3 NM spacing throughout the approach. During the approach, aircraft would continuously monitor the relative spacing between it and the preceding aircraft. If the following aircraft is predicted to get closer than the nominal spacing, onboard software issues alerts to reduce the approach speed. A comprehensive analysis of the spacing requirements on approach and missed approach was mathematically

modeled to verify the HVO concept met IFR safety standards and minimum spacing distance.⁸

With the runway in sight and in position to land, the pilot lands and exits the runway. If the pilot cannot land, the pilot follows the missed approach procedure given as part of the initial AMM entry message to the appropriate MAHF.

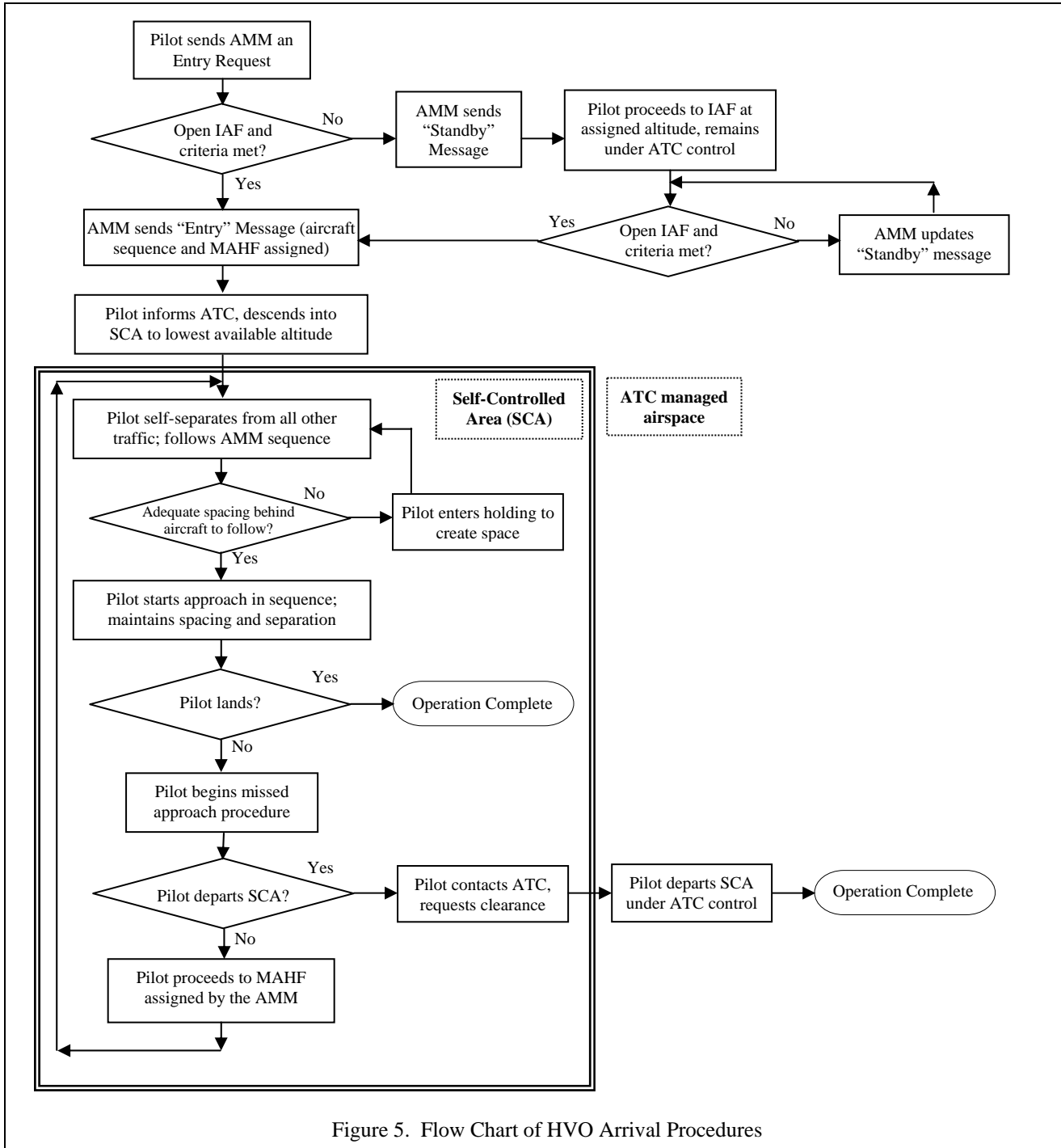


Figure 5. Flow Chart of HVO Arrival Procedures

HVO Separation

The HVO concept uses a 3-tiered approach to allow pilots to assume the responsibility for separation from appropriately equipped aircraft within the SCA.⁹

- 1) Procedural Separation. Pilots flying today follow procedures to ensure separation between aircraft, for example in the event of lost two-way radio communication (FAR 91.185). A central tenet of the HVO concept is that the procedures must provide procedural separation of aircraft at all times. The HVO research team maintains that when aircraft are flying in Instrument Meteorological Conditions (IMC) in uncontrolled airspace, it is imperative that all aircraft have a specific location (e.g., clearance limit fix) in the event of lost two-way communication. This requirement heavily influenced the development of the AMM entry message logic described earlier, and is a major factor in flow inefficiencies for arriving aircraft (spacing varies from 3 to 8 NM).
- 2) Procedure Support. The HVO team developed an onboard Pilot Advisor (PA) as a second-tier system that takes inputs from an Altitude Determination Tool, a Spacing Tool, and a Conformance Monitor to provide procedural support for the pilot. The PA selects and displays the highest priority message on a display to provide assistance and guidance to the pilot (white text in top right of Figure 12), such as:
 - When the next lowest altitude is available to the pilot (OPEN: 2000)
 - When the approach can be started from the appropriate IAF and the required spacing maintained (TTA: 1+22)
 - Monitors pilot flight path conformance to the instrument approach (MONITRO ALT)
- 3) Conflict Detection and Alerting (CD&A). The third-tier is onboard algorithms that constantly monitor the conformance of ownship and other aircraft to HVO procedures, determines potential conflicts, and issues alerts as required.

HVO Missed Approach

An aircraft entering the SCA with no aircraft to follow will be given a MAHF that is the same as the aircraft's original IAF. Aircraft following other aircraft will be assigned the MAHF point opposite of the preceding aircraft as part of their SCA entry message. Since approach spacing must consider the potential loss of separation while two aircraft are on a common path, alternating missed approach paths reduces the distance along which the second aircraft must maintain the required IFR spacing (3 NM spacing must only be

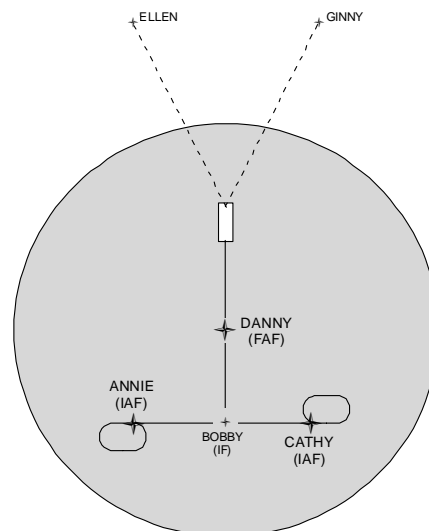
maintained from the IAF to the Missed Approach Point (MAP). This becomes especially noticeable when there is a performance difference between two aircraft, as in a faster aircraft following a slower aircraft.

Just as with an instrument approach today, if a missed approach is required, pilots may begin a climb to the missed approach altitude at any point along the instrument approach path prior to the MAP, but may only turn to the MAHF after crossing the MAP. Aircraft on a missed approach climb to the lowest available holding altitude, simplifying the transition to begin another approach.

Should only one missed approach path or IAF/MAHF be available (weather, airspace constraints, terrain, etc), the HVO concept and the AMM logic still functions but with larger spacing requirements and therefore slower rates of operation. Without the ability to alternate missed approach paths, the pilot must now maintain IFR spacing from not only the IAF to the MAP, but also from the MAP back to the IAF/MAHF. A faster aircraft following a slower aircraft would need to increase the time gap between aircraft by delaying their start of the approach (more time in holding at the IAF).

HVO Departure Sequence and Spacing

Prior to departing a SATS airfield, pilots file a standard IFR flight plan and receive a clearance, potentially including Release and Clearance Void times.¹⁰ When ready for takeoff, the pilot ready for a takeoff would determine that it is still within the ATC clearance window, that there are no aircraft past the FAF or on the runway, and there is sufficient spacing behind the previous departure (3 NM to opposite departure fix, 10 NM to same fix as shown in Figures 6 and 7). Onboard displays and software aid the pilot in making this determination. HVO employs two departure paths which reduce the spacing requirement.



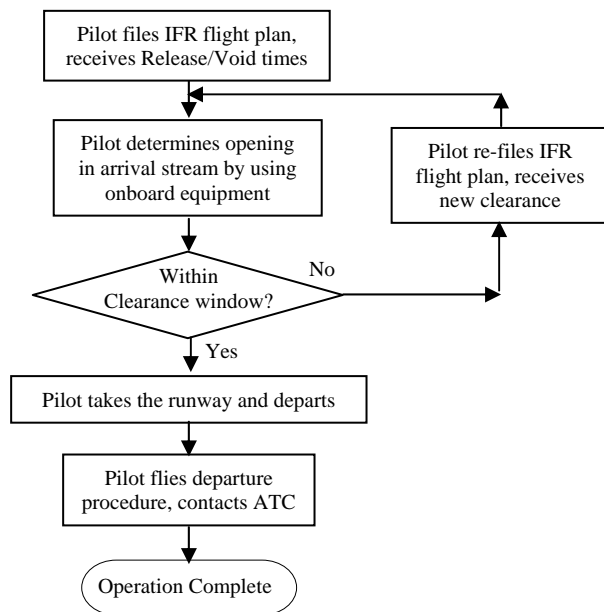


Figure 7. Flow Chart of HVO Departure Procedures

In an early version of the HVO concept, the AMM sequenced departures as well as arrivals. However, it was determined during concept development that gaps in the arrival flow caused by procedural requirements and pilot variances would create enough space for departures without the AMM having to sequence them. Removing the requirement to schedule departures significantly reduced the complexity of the AMM.

Gaps in the theoretical maximum arrival flow (3 NM between aircraft over runway threshold) are generated for several reasons, to include:

- 1) Speed differential of aircraft (slow behind fast).
- 2) Pilots not commencing approach at earliest time possible (flight path geometry, pilot not ready, etc).
- 3) AMM logic closing an IAF to new entries due to other aircraft on the approach or missed approach.

HVO Minimum Equipment Requirements

Key to the HVO concept is the ability to transmit and receive GPS quality information, the ability to display that information, onboard software to support the pilot, and two-way datalink with the AMM. Here is an initial list of required equipment:

- Aircraft: IFR approach-certified GPS receiver, ADS-B transmission and reception of aircraft information, AMM messaging data link, a cockpit display of traffic information (CDTI), and onboard conflict detection and alerting capability. Also desirable is a Pilot Advisor providing HVO altitude, spacing and conformance information.
- Airports: weather reporting, an AMM, a ground based ADS-B transceiver, and data link capability.

Mixed Equipage Operations

HVO aircraft can separate from other HVO aircraft in the SCA, but can not separate themselves from aircraft not transmitting flight data. In order to retain the level of safety that procedural separation provides (both in today's procedures and the proposed HVO concept), it is necessary to separate non-equipped aircraft from SATS aircraft during HVO, that is all HVO aircraft must land prior to a non-equipped aircraft departing ATC's airspace, or all non-equipped aircraft must land prior to a HVO aircraft entering the SCA. Although not as efficient as HVO, this procedure does produce a faster rate of flight operations than today's procedures. For example, assume six aircraft arrive at an airport at approximately the same time but only the three first aircraft are equipped for HVO. The non-equipped aircraft still reap the benefits that HVO aircraft provide by having approximately 20 fewer minutes in holding than they would otherwise (10 minute savings between the first and second aircraft, another 10 minute savings between the second and third aircraft, therefore fourth aircraft can start approach at least 20 minutes earlier).

Experiment and Study Results

This section of the paper provides a summary of the studies, simulations, and flight experiments done in support of the HVO Concept. Included are formal method studies to ensure a complete accounting for all states and transitions between those states, batch studies to determine throughput, conflict detection and alerting studies for appropriate algorithms and warning criteria, and human-in-the-loop simulation and flight experiments to determine the safety and usability from a subject pilot's and subject controller's perspective.

Formal Methods Studies

Early in the development of HVO, a Formal Methods analysis was conducted utilizing non-deterministic, asynchronous mathematical models of the operational concept. This study found that the procedure was safe for all nominal operations, e.g., no procedural deadlocks (all aircraft in the SCA eventually land or depart), no loss of separation, and there always is an available altitude for aircraft on missed approach.¹¹ Several concept changes were incorporated based on that research, the most important being modifications to missed approach procedures.¹²

Throughput Batch Studies

Using the simulation batch mode, multiple runs were investigated for both today's procedures (Baseline) and the HVO concept (SATS), using an equal number of arriving and departing aircraft per hour from multiple

points with varying approach speeds. Initial studies indicate the HVO concept results in a four-fold increase in the rate of flight operations.¹³ Figure 8 shows 8 operations per hour (4 arrivals and 4 departures) using today's procedures results in a 5 minute average delay, while HVO procedures can support 26 operations with the same average delay. This batch study closely correlates with the results of the linked NASA – FAA simulation experiment described on the next page.

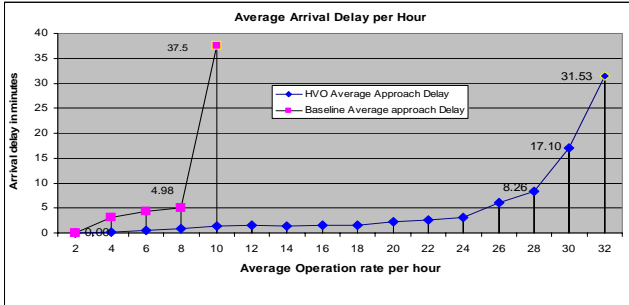


Figure 8. Throughput Study Results

Conflict Detection Studies

HVO uses a concept whereby an aircraft that is within the containment volume of an instrument approach to the declared destination would include as part of its ADS-B message that it is in conformance. This allows proximate aircraft to use state plus intent algorithms in determining traffic conflicts between aircraft (Aircraft #2 and #3 can infer that Aircraft #1 will make a right turn onto final in Figure 9 since it is in conformance). Should the aircraft's position or flight path not be within the containment volume, the transmitted data field in the ADS-B message would state that aircraft is not in conformance. At that time, all other aircraft would revert to state-based algorithms of that aircraft's flight path (linear projection of that aircraft's current position) to determine if there is a potential conflict between the two aircraft (Aircraft #2 and #3 in Figure 9 are not in conformance, Aircraft #1 uses state-based CDA to determine their potential for conflict).¹⁴

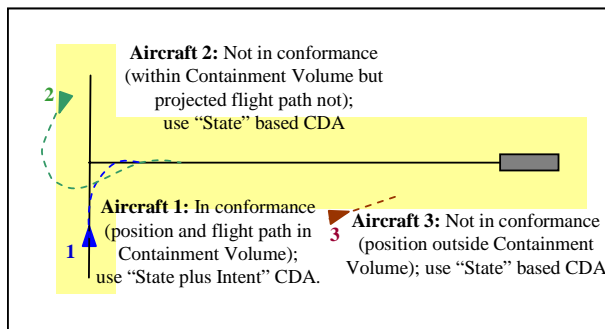


Figure 9. Conflict Detection Geometries

One study of the HVO procedures and state-based versus state plus intent CDA indicated a significant

decrease in false alarms (alert or alarm issued without subsequent violation by the aircraft) with the state plus inferred intent CDA algorithms compared to state only CDA.¹⁵ Figure 10 shows “D” as the diameter around the aircraft, T_c the look ahead time for a caution, and T_w the look ahead time for a warning.

Configuration	CD&A	False Alarm Ratio
1 $D = 3, H = 750, T_c = 120, T_w = 30$	Hybrid	49%
	State	69%
2 $D = 3, H = 750, T_c = 45, T_w = 20$	Hybrid	32%
	State	58%
3 $D = 1, H = 300, T_c = 120, T_w = 30$	Hybrid	30%
	State	61%
4 $D = 1, H = 300, T_c = 45, T_w = 20$	Hybrid	10%
	State	59%
5 $D = 0.35, H = 400, T_c = 35, T_w = 20$	Hybrid	0%
	State	0%

Figure 10. Conflict Detection False Alarm Rates

Simulation Experiments

Four simulation experiments using pilot and controller subjects were conducted at NASA Langley's Air Traffic Operations Laboratory (ATOL) and FAA Technical Center's Target Generation Facility (TGF).

HVO-2 (Normal Operations)

The primary objective of this experiment was to validate the HVO Concept of Operations. Fifteen low-time instrument rated pilots flew two replicates of ten scenarios (five scenarios using today's procedures (Baseline) and the same five scenarios using HVO procedures) to answer these two questions:

- “Can pilots safely and proficiently fly an airplane while performing HVO procedures?”
- “Do pilots perceive that workload while performing the HVO procedures is no greater than flying in today's system?”

The first four scenarios for both Baseline and HVO operations consisted of the pilot flying in various phases of flight with virtual traffic, and the fifth scenario in both procedure types replaced the virtual traffic with the other three subject pilots to create a live, linked simulation.

Results indicate little difference in pilot performance for altitude control in either simulation. However, the pilots performed statistically better relative to airspeed and lateral deviation using HVO procedures.¹⁶ Based on FTE analysis and workload assessments, the experiment showed pilots can safely and proficiently fly the HVO procedures with no increase in workload.

HVO-3a (Pilot Advisor)

In January 2005, the NASA HVO research team conducted an experiment with 16 evaluation pilots. The ATOL was used over a two day period to evaluate four groups of four subjects, all low-time instrument rated pilots. These pilots were run through a series of scenarios to determine the requirement for a PA that provided information on altitudes available for the pilot, conformance to the selected flight path, and conflict detection. Results from the pilot surveys indicate that, although not required, the PA was highly desired for the use in HVO procedures. Furthermore, pilot workload was less and situation awareness higher using the PA than without a PA.¹⁷

HVO-3b (Off-Nominal Operations)

Immediately after the Pilot Advisor study there was a simulation experiment to examine two of the HVO procedures developed to address off-nominal operations (runway changes, change in arrival sequence, etc) and equipment malfunctions (radio failure, etc.).¹⁸ The same pilots were presented various off-nominal scenarios. The subjective workload assessments given by the pilots indicated there was no difference in the pilot workload from a normal HVO procedure, and the tested off-nominal HVO procedures.¹⁹ In other words, the use of data-linked displays offset the additional cognitive requirements to safely fly HVO procedures.

Air Traffic Controller Experiments

The principle objective of this simulation was to determine the viability of the SATS HVO concept from an Air Traffic controllers point of view. Using the FAA's William J. Hughes Technical Center Target Generation Facility (TGF), controllers were brought in from Washington Air Route Traffic Control Center and from Philadelphia Terminal Radar Approach Control facilities. Three simulation experiments were conducted: 1) the Terminal Sector, 2) the En Route Sector, and 3) Linked En Route Sector (controllers at FAA Technical Center linked live to pilots at NASA Langley). Twelve current controllers participated (four in each phase), and each controlled four scenarios that replicated today's procedures, HVO procedures, today's traffic load, and predicted traffic load in 2010.

In all three simulations, the controllers were able to hand off aircraft quicker (much faster arrival rate) with the HVO concept compared to today's procedures, and generally had decreased workload (Figure 11). (In the linked experiment, controllers and pilots regularly landed all six HVO aircraft within 35 minutes, but using today's procedures only landed three aircraft after 55 minutes.) The HVO concept was generally well received by the subject controllers. The two primary areas identified for further research were tailoring the

size and shape of the SCA to meet airspace constraints, and the handling of non-equipped aircraft.²⁰ This FAA report also includes suggested phraseology for the transition from managed to non-managed airspace.

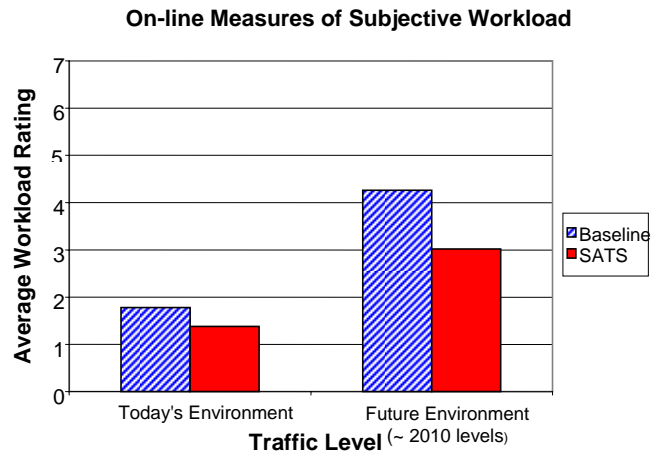


Figure 11. Philadelphia Controller Results

Flight Experiments

Flight experiments were also conducted at NASA Langley with a Cirrus SR-22. Other flight experiments were conducted by Southeast SATSLab and North Carolina and Upper Great Plains SATSLab.²¹

HVO-1 (Self-Separation and Sequencing)

From November 2003 through January 2004, NASA Langley examined whether pilots could hand fly an aircraft using a CDTI to self-separate and sequence their own aircraft from other similarly equipped aircraft. Six general aviation low-time pilots (less than 350 hours) flew scenarios to evaluate if they could maintain separation and spacing behind the preceding aircraft, and maintain the proper landing sequence.

Analysis of the results indicates there was no difference in the pilot's flight path deviation or airspeed, nor did the pilots report an increase in workload. Even more significantly, during the 48 test runs, no pilot violated the separation requirements or landed out of sequence.²²

HVO-2 (Normal Operations)

From July through October 2004, NASA Langley conducted flight experiments to validate results of the Normal Operations simulation experiment in a Cirrus SR-22. The twelve subject pilots in this experiment had participated in the Normal Operations simulation experiment, and flew two replicates of six different approach scenarios. The flight experiment used the same procedures, software and displays, and approach scenarios as the simulation experiment.

The display shown in Figure 12 was used in both the simulation and flight experiments. It shows a pilot entering the terminal area from the bottom of the screen, with traffic to follow indicated by the double cyan chevron symbol on the right side of the display. The twelve evaluation pilots reported lower workload and higher situation awareness. The Flight Technical Error (FTE) results for lateral, vertical, and airspeed deviation were comparable for HVO procedures versus today's procedures, despite having the additional requirements to separate, space, and sequence their own aircraft while in IMC. Furthermore, there were no violations of separation and spacing requirements, nor did any pilot land in an improper sequence.²³



Figure 12. HVO-2 MFD (white own-ship, traffic to follow double-cyan chevron, green “Entry” message, solid line instrument approach, dotted line missed approach)

Future Research

Normal and Non-Nominal Procedures

More research in HVO procedures by a broad spectrum of experts is required. More efficient operations can be realized by analyzing the parameters used to allow entrance into the SCA, and adjusting them within the constraints established by procedural safety.

Conflict Detection and Alerting

Research is required to determine the acceptable rate of false alarms, and the appropriate containment volume and look-ahead time in a terminal area. It may be possible that state based alerting algorithms would be sufficient in this operating environment, however the intent based approach seems to offer a much more viable, robust, and accurate approach.

Mixed Equipage Operations

During the SATS2005 Technical Demonstration held at Danville, VA, most of the six SATS aircraft were able to see non-participating aircraft on their certified Garmin cockpit displays. The information on non-SATS equipped aircraft came from the FAA's SAFEFLIGHT 21 system that sends radar data to the FAA Technical Center in Atlantic City, NJ, then retransmits the information in a TIS-B format that the Garmin UAT can read. These new technologies may afford possibilities for mixed equipage operations.

Other Implementation Issues

- Altitudes or IAF/MAHF constraints. Airspace requirements, overlaying instrument approaches to other airfields, terrain, and weather all create situations where the full, generic HVO concept cannot be implemented. Initial experiment results indicate even when there is only one IAF and one altitude at that IAF, that pilot and controller workload is less and the rate of operations slightly higher than today's procedures.
- Optimize the SCA. The size of the SCA would be significantly reduced if there was no requirement that the missed approach path remain within the SCA, however it is believed that ATC workload would be substantial.
- Optimized instrument approach designs. Further research should examine other configurations and how to handle circling approaches.
- Airspace activation. How will the SCA be turned on or off, and who will activate it?
- Runway selection. How will the AMM receive this information, who will notify the pilots?
- Controller visibility into the SCA. If traffic within the SCA is visible to the controller, it may require competing cognitive processing and imply controller responsibility for separation. However lack of visibility may lessen the controller's situation awareness or reduce efficiency.
- Multiple runway operations. Research has not yet been conducted into multiple runways, either parallel or crossing.
- Safety and Hazard Analysis. A safety and hazard analysis of the HVO concept needs to be conducted by the FAA.
- Equipment. What will be the minimum equipment and level of complexity for a pilot and an aircraft needed in order to fly and operate within the SCA?
- Training. A training program and requirements for both pilots and controllers needs to be set.

Summary

The ability to operate multiple aircraft in poor weather at virtually any airport, offers a unique opportunity for significant air transportation growth and a major improvement in passenger convenience. This is accomplished by establishing an area around an airport within which the pilot is responsible for separation, sequencing, and spacing, using data-linked flight data from other aircraft. Improved situation awareness provided by modern displays allows pilots to assume self-spacing and self-separation responsibilities. This augmentation of existing flight procedures combined with the use of new information and cockpit display technologies for a distributed responsibility for separation is the core of the HVO concept.

The SATS HVO concept emphasizes integration with current and near-term NAS operations, procedural simplicity, and minimal workload change for pilots and controllers. The SCA described is a starting point for additional designs and analysis, no attempt was made to optimize the size or shape of the proposed airspace.

HVO investigations have demonstrated that a four-fold increase in the rate of flight operations is possible at small airports without ATC services during poor weather. This capability to overcome the limitation of one-aircraft-in one-aircraft-out operations during poor weather removes a major obstacle to operations at under-utilized small airports.

References

- 1 Transportation Secretary Mineta, speech to the Aero Club of Washington D.C., Jan 27, 2004
- 2 Dr. Bruce Holmes, "A Vision for 21st Century Transportation Alternatives", NASA, May 2002
- 3 Viken, S., and Brooks, F., "Demonstration of Four Operating Capabilities to Enable A Small Aircraft Transportation System", 24th DASC, Oct 2005
- 4 Conway, S., and Consiglio, M., "A Method of Separation Assurance for Instrument Flight Procedures at Non-Radar Airports", AIAA GNC, Aug 2002
- 5 Jones, K., Williams, D., Consiglio, M., Adams, C., and Abbott, T., "IFR Operations at Non-Towered, Non-Radar Airports: Can We Do Better Than One-At-A-Time?", AIAA 2003-2874, ATIO 2003
- 6 Baxley, B., Williams, D., Consiglio, M., Adams, C., and Abbott, T., "The SATS HVO Off-Nominal Operations", AIAA 2005-7461, September 2005
- 7 Abbott, T., Consiglio, M., Baxley, B., Williams, D., Jones, K., and Adams, C., "Small Aircraft Transportation System, Higher Volume Operations Concept", NASA/TP in preparation, September 2005
- 8 Munoz, C., and Dowek, G., "Formal Verification of Spacing Properties of an Air Traffic Management Concept", NETCA Workshop, July 2005
- 9 Consiglio, M., Carreno, V., Williams, D., Munoz, C., and Abbott, T., "Conflict Prevention and Separation Assurance in the Small Aircraft Transportation System (SATS) Higher Volume Operations (HVO) Concept of Operations", AIAA-2005-7463, Sept 2005
- 10 FAA, Aeronautical Information Manual. 5-2-4, 2005
- 11 Munoz, C., Dowek, G., and Carreno, V., "Modeling and Verification of an Air Traffic Concept of Operations", ISSTA 2004, July 2004
- 12 Dowek, G., Munoz, C., and Carreno, V., "Abstract Model of the SATS Concept of Operations: Initial Results and Recommendations", NASA/TM-2004-213006
- 13 Consiglio, M., and Williams, D., "Preliminary Validation of the SATS HVO Concept" 24th ICAS, October 2004
- 14 Consiglio, M., "SATS HVO Conflict Detection and Alerting Functional Requirements Draft Document", NASA Langley, Dec 2003
- 15 Consiglio, M., Munoz, C., and Carreno, V., "Conflict Detection and Alerting in a Self Controlled Terminal Airspace", 24th ICAS, Yokohama, Japan
- 16 Williams, D., Consiglio, M., Murdoch, J., and Adams, C., "Flight Technical Error Analysis of the SATS HVO Simulation and Flight Experiments" 24th DASC, October 2005
- 17 Adams, C., Consiglio, M., and Conway, S., "The Pilot Advisor: Assessing the Need for a Procedural Advisory Tool", 24th DASC, October 2005
- 18 Abbott, T., Consiglio, M., Baxley, B., Williams, D., and Adams C., "SATS HVO Concept: Off-Nominal Operations", NASA/TM in press, August 2005
- 19 Consiglio, M., Conway, S., and Adams, C., "SATS HVO Procedures for Priority Landings and Mixed VFR/IFR Operations at Non-Towered, Non-Radar Airports" 24th DASC, October 2005
- 20 Magyarits, S., Racine, N., and Hadley, J., "Air Traffic Control Feasibility Assessment of Small Aircraft Transportation System (SATS) Higher Volume Operations (HVO)", DOT/FAA/CT-05/26, May 2005
- 21 Kelly, W., Valasek, J., Wilt, D., Deaton, J., Alter, K., and Davis, R., "The Design and Evaluation of a Traffic Situation Display for a SATS Self Controlled Area", 24th DASC, Oct 2005
- 22 Murdoch, J., Ramiscal, E., McNabb, J., and Bussink, F., "Flight Experiment Investigation of General Aviation Self-Separation and Sequencing Tasks", NASA/TP-2005-231539, May 2005
- 23 Williams, Consiglio, Murdoch, Adams, "Flight Technical Error Analysis of the SATS HVO Simulation and Flight Experiments" 24th DASC, October 2005