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Small Aircraft Transportation System, Higher Volume Operations Concept: Off-Nominal Operations

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Nomenclature

ADS-B: Automatic Dependent Surveillance - Broadcast

AMM: Airport Management Module

APDLC: Airport-Pilot Data Link Communications

ATC: Air Traffic Control

ATIS: Automatic Terminal Information Service

AWOS: Automated Weather Observing System

CD&A: Conflict Detection and Alerting

CD&R: Conflict Detection and Resolution

CTAF: Common Traffic Advisory Frequency

D-ATIS: Digital ATIS

FAF: Final Approach Fix

GPS: Global Positioning System

HVO: Higher Volume Operations

IAF: Initial Approach Fix

IF: Intermediate Fix

IFR: Instrument Flight Rules

IMC: Instrument Meteorological Conditions

MAHF: Missed Approach Holding Fix

MFD: Multi-Function Display

NAS: National Airspace System

NNO: No New Operations

PA: Pilot-Advisor

PFD: Primary Flight Display

RNAV: Area Navigation

SATS: Small Aircraft Transportation System

SCA: Self-Controlled Area

TTA: Time To Approach

VFR: Visual Flight Rules

Abstract

This document expands the Small Aircraft Transportation System (SATS) Higher Volume Operations (HVO) concept to include off-nominal conditions. The general philosophy underlying the HVO concept is the establishment of a newly defined area of flight operations called a Self-Controlled Area (SCA). During periods of poor weather, a block of airspace would be established around designated airports where procedural separation is currently employed, i.e. airports with no tower and limited or no radar services available. Aircraft flying enroute to a SATS airport would be on a standard instrument flight rules flight clearance with Air Traffic Control providing separation services. Within the SCA, pilots would take responsibility for separation assurance between their aircraft and other similarly equipped aircraft. Previous work developed the procedures for normal HVO operations. This document provides details for a number of off-nominal and emergency procedures for situations that could be expected to occur in a future SCA.

1.0 Introduction

The intent of this document is to expand the Small Aircraft Transportation System (SATS) Higher Volume Operations (HVO) operational concept (refs. 1-4) to include a set of off-nominal operations, e.g., the failure of an airborne system normally required for a HVO operation. In this regard, this document will describe HVO procedures to address off-nominal operations, procedural deviations, equipment failures, and aircraft emergencies with a focus on safety and simplicity in the development of these procedures. In addition, because equipment design and equipment failure are highly interrelated with the development of off-nominal procedures, a specific equipment design will be discussed in this document.

A major underlying assumption in the development of this document was that only reasonable failures and operational errors (i.e., failures and errors that had a practical expectation for occurrence) would be addressed. Hence, while the list of off-nominal conditions in this paper is not complete, it does cover a wide range of cases. The major design goals for these procedures were to minimize procedure and equipment changes relative to the normal procedures that were defined in ref. 1 while minimizing the level of system criticality (ref. 5).

2.0 Background

2.1 Normal HVO Operations

The general philosophy underlying the SATS HVO operational concept is the establishment of a newly defined area of flight operations called a Self-Controlled Area (SCA). During periods of poor weather, a block of airspace would be established around designated airports where procedural separation is currently employed by Air Traffic Control (ATC), i.e. airports with no tower and limited or no radar services available. Aircraft flying enroute to a SATS airport would be on a standard instrument flight rules (IFR) clearance with ATC providing separation services. Within the SCA, pilots would take responsibility for separation assurance between their aircraft and other similarly equipped aircraft. Note, however, that while pilots would be required to take responsibility for self-separation within the SCA, they would not be required or allowed to take responsibility for establishing the sequence of their arrivals within the SCA. This concept would take advantage of a proposed ground-based automation system, called an Airport Management Module (AMM), which would provide sequencing information to pilots for safe and improved operations. The AMM would typically be located at the airport and would make these assignments based on calculations involving aircraft performance, aircraft position information, winds in the terminal area, missed approach requirements, and a set of predetermined operating rules for the SCA. This sequence assignment process supports actions and decisions made by ATC in that it sequences only those aircraft at the lowest altitude approaching the Initial Approach Fixes (IAFs), allowing ATC to control the sequence order of the arriving aircraft. This process allows the controller the flexibility to resolve issues unknown to the AMM (e.g., crossing airways, weather, and aircraft holding).

A plan view graphic depicting a generic SCA is shown in figure 1. The SCA would be similar in concept to a Class E surface area and is similar to the proposal by Conway and Consiglio in reference 2. The waypoints could be existing waypoints for a generic Global Positioning System (GPS) T approach. In this concept, the outboard IAFs on the T (e.g., ANNIE and CATHY) would be used for all arrivals. These fixes would also be used as the missed approach holding fixes (MAHF). During low traffic conditions, an arriving aircraft could fly directly to an IAF at the lowest appropriate IFR altitude and upon reaching the IAF, begin an approach operation. During periods of higher traffic conditions, the holding pattern in the SCA would be used to delay aircraft while they are waiting for appropriate aircraft-to-aircraft separation prior to initiating the approach and landing. Arriving aircraft would enter at the top of the IAF holding pattern and drop down in 1,000-foot increments as the altitude below becomes clear, until they reach the initial approach altitude. At that time, the aircraft would self-separate along the approach path for landing. The profile view in figure 2 shows one of these arrival fixes and helps illustrate the holding pattern above the IAF. Note also that the shape of the SCA is similar to a Class C airspace design, but offset on the approach-side of the airport. Additionally, the shape of the SCA may also be tailored to fit the geometry of local airspace constraints. The outrigger IAFs on the opposite T could be used as the departure fixes.

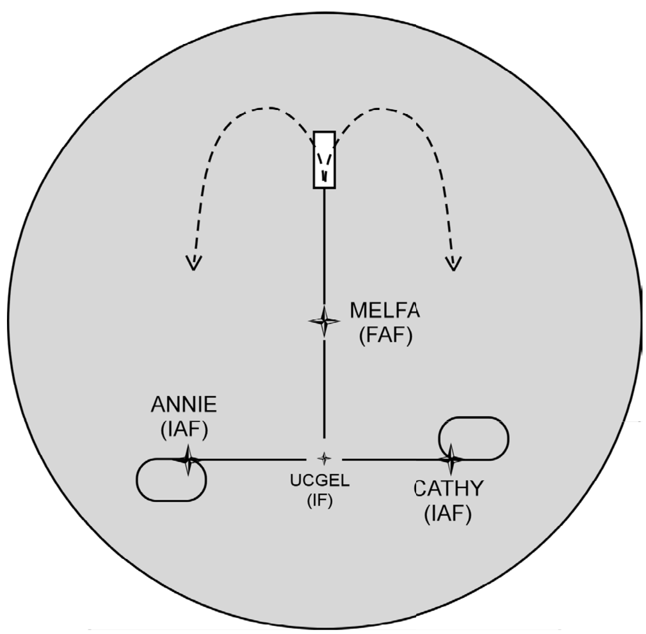

Figure 1. Plan view example of a Self-Controlled Area.

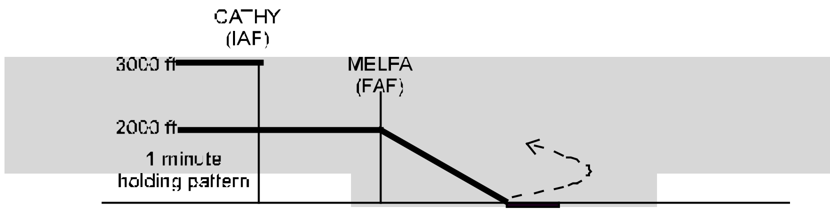

Figure 2. Profile view example of a Self-Controlled Area.

As noted previously, the AMM would consist of a ground-based automation system, typically located at the airport. The AMM would not be an automation of the ATC function but would be more of a simple counter that issues sequence information based on a set of predetermined rules. The AMM would rely on aircraft position information provided through a ground-based Automatic Dependent Surveillance Broadcast (ADS-B) receiver to manage the operations within the SCA. Aircraft would be expected to contact the AMM via data link (Airport-Pilot Data Link Communications, APCLC) and request landing sequence information. The AMM would then provide either a notification of which airplane the pilot would follow (if there was an airplane in the sequence ahead of the pilot) or inform the pilot that he cannot initiate the operation (e.g., enter the SCA) and provide him with a notification of the delay to expect before the operation can begin. What is unique to this concept is that ATC has implicit control of the arrival sequencing. This implicit control occurs because the AMM only accepts vertical entries into the SCA from aircraft flying immediately above the SCA (i.e., at the lowest IFR altitude above the SCA vertical boundary). This design could provide ATC with a relatively low workload and seamless means for controlling IFR entries into the SCA. In this concept, ATC directs aircraft to the appropriate IAF; the AMM provides the aircraft with an approach sequence; and the pilot follows the sequence for the approach and landing.

In addition to its other calculations, the AMM must also assure that there would be available missed approach airspace for each aircraft arriving in the SCA. Since it must be assumed that every approach may result in a missed approach and since there would not be an active controller involved in SCA operations (who could respond in real time with unique missed approach instructions), each aircraft entering the SCA would be given specific missed approach information by the AMM as it enters the airspace. This technique would keep the ground-based automation relatively simple and less critical to the operational concept. However, it would mean that the total number of operations would be constrained by the number of unique missed approach locations that could exist within the SCA. For the SCA shown in figures 1 and 2, there are four missed approach holding options (two holding altitudes at each MAHF), therefore there are a total of four approach operations allowed at one time in this version of a SCA. Again, it is expected that this design would be modified for specific airport and airspace configurations. Also note, however, that designs with significantly more missed approach fixes may not significantly increase the number of allowable landing operations.

For the generic SCA shown in figures 1 and 2, there are four missed approach positions, two at ANNIE and two at CATHY. Therefore, there would be a total of four approach operations allowed at one time in the generic SCA. From this maximum of four operations, exclusive of departure operations, a set of implementation and operating rules were developed. The normal SCA operating rules are as follows:

- No more than four concurrent arrival operations are allowed in the SCA.

- Simultaneous entries are not allowed at a single IAF.

- Entry is granted only if no other aircraft on approach is assigned to that fix as their MAHF.

- Entries may not result in the assignment of more than two aircraft to a specific fix, with the assignment as either an IAF or as a MAHF.

- Vertical entries (descending into the SCA while in the arrival holding pattern) are only allowed at the IAFs from the lowest IFR altitude above the SCA.

- Upon entering the SCA at an IAF, aircraft are to go to the lowest available altitude and then continue to descend as altitudes below them become available.

- Alternating MAHFs are given to sequential aircraft (e.g., the first aircraft is given ANNIE, the second aircraft is given CATHY, the third aircraft is given ANNIE, etc.). Note that for operational efficiency reasons, if there were no other landing aircraft (i.e., aircraft with approach sequences) in the SCA, the first arriving aircraft would be assigned a "same-side" MAHF (e.g., if the arrival fix is ANNIE, the MAHF will be ANNIE). An example approach chart with ANNIE as the MAHF is given in figure 3.

- When proceeding to a holding fix on a missed approach, aircraft are to climb to the lowest available altitude (e.g., the first aircraft heading to ANNIE climbs to 2000 feet, the next aircraft going to ANNIE climbs to 3000 feet).

- Aircraft operating in the SCA must be able to climb at 300 feet per mile (required for obtaining the required vertical separation at a MAHF if the lower altitude is occupied).

It is also noteworthy that airports would only need to make relatively minimal infrastructure investments to increase their ability to sustain operations during periods of IMC. Airports would be expected to have weather reporting capability (e.g., Automated Weather Observing System - AWOS) and would need to install an AMM, a ground-based ADS-B receiver, and have a data link capability. AWOS input into the AMM may also be needed to assist the AMM to determine the appropriate instrument procedure (i.e., the appropriate landing direction).

For this operational concept to be viable, a link between the AMM and ATC would be required. This link would be necessary to enable ATC to terminate and subsequently re-enable HVO operations when necessary to accommodate non-HVO operations (e.g., normal IFR operations). This link would also be necessary to efficiently enable HVO departure operations that would transition into traditional IFR airspace. Additionally, if controllers had access to the SCA status information, this could facilitate air traffic management. For example, if controllers knew that the SCA was not currently accepting aircraft (because the SCA was full), and that there would be a 20-minute delay at the airport, they could begin planning for that delay in advance. This information could then be provided to arriving aircraft by ATC or possibly broadcast on ATIS-like transmission.

Since the SATS project is focused on achieving a realistic, operationally deployable system for the 2010 timeframe, this concept emphasized integration with the current and the planned near-term National Airspace System (NAS). As a result, the design approach focused on simplicity from both a procedural and systems requirements standpoint. It was further assumed that any additional ATC workload must be minimized and that enroute procedures would be as similar to today’s system as possible. This concept is based on a distributed decision-making environment that would provide pilots with the necessary procedures, airborne systems, traffic awareness, and aircraft sequence information to enable safe operations within the SCA while minimizing the requirements for ground support tools. Because this is a distributed decision-making environment, much of the decision-making responsibility would be left with the pilot, as it is today with visual flight rules (VFR) operations into non-towered airports. Finally, the overall philosophy in the development of the HVO operational procedures was to emphasize simplicity and operational safety as major aspects in the design. The details of these procedures for normal operations are provided in ref. 1.

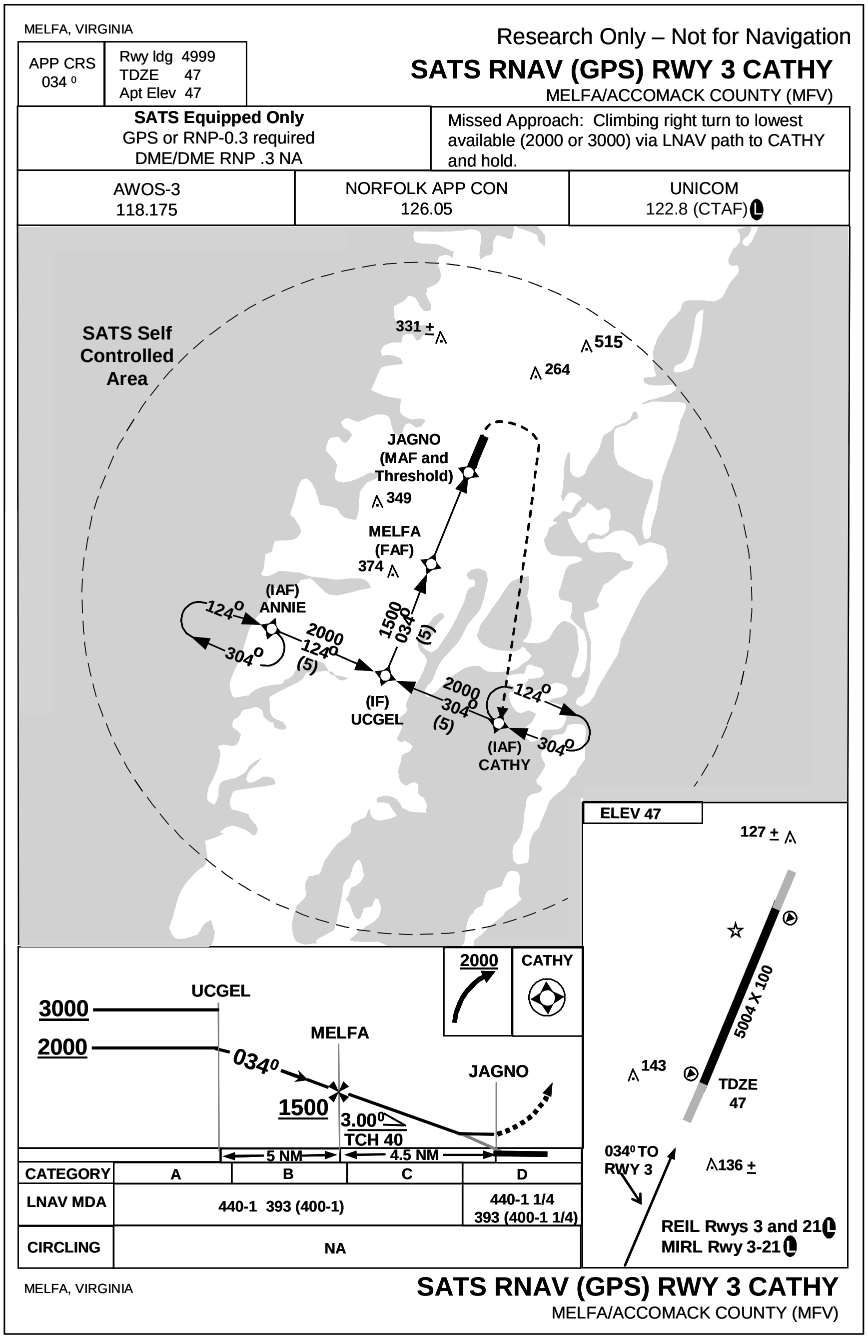

Figure 3. Example approach chart.

2.2 Conflict Detection and Alerting

As noted in the development of the normal operational procedures for the SCA, an explicit design decision was made in that neither conflict detection and alerting (CD&A) nor conflict detection and resolution (CD&R) would be required as a primary means for aircraft separation in conducting HVO. That is, the HVO procedures, with the supporting AMM design and relatively simple flight displays, would provide the primary means for aircraft-to-aircraft separation within the SCA. It was assumed, however, that either CD&A or CD&R would be required as a secondary means for operational safety. Given this, the inherent nature of off-nominal situations will probably require an onboard conflict detection system to obtain an operationally viable level of safety.

2.3 Prototype Aircraft Multi-Function Display

The underlying functionality and display formats of a modern multi-function display (MFD), representative of a current-generation GPS moving map display, were assumed as the implementation basis for the SATS HVO concept. A basic map-page layout for this generic MFD is shown in figure 4. Major functions and display items assumed for the map portion of the MFD are:

- A track-up, moving map display that includes both geographic and navigation information.

- Aircraft-centered and aircraft-offset formats.

- Adjustable map range scales.

- Programmable bezel buttons.

- Feature-select knobs.

Figure 4. Generic MFD map layout.

In addition to the navigation map information, the MFD would provide traffic information (ref. 6), HVO-specific alerting information, and Airport-Pilot Data Link Communications (APDLC) messages. APDLC messages could provide AMM messages as well as general airport information, such as Digital Automatic Terminal Information Service (D-ATIS). Note that APDLC is a two-way, addressed data link that would function in a manner similar to a CPDLC system (ref. 7).

The MFD would also include a pilot procedure tool, unique to the HVO concept. This tool, called the Pilot-Advisor (PA), would provide an automated HVO-specific checklist to the pilot relative to the current state of the aircraft and other surrounding traffic. Effectively, the PA, would provide prompts in the PA window to the pilot regarding the next appropriate procedural step for the current HVO procedure. The PA window would only display one message at a time, with that message being the oldest message with the highest priority. Table 1 lists the proposed messages, with priority level 1 as a higher priority than priority level 0. For example, the "Monitor Path" (blue, priority level 1) takes precedence and would overwrite the "OPEN: 2000" message (black, priority 0). The message text color would be consistent with alerting standards (ref. 8). The prototype messages for the PA information, displayed in the PA window on the MFD, are provided in Table 1. Unlike the SATS HVO requirement for CD&A or CD&R, the HVO concept does not require the use of a PA, although preliminary tests with subject pilots have found it to be highly desirable.

Alerting information, provided in an alert window on the MFD map, along with any appropriate audio cues, would also be provided via the MFD. Alerting information would include the following:

- The availability of any new broadcast message: e.g., AWOS, D-ATIS, or AMM broadcast data.

- The reception of any new AMM instruction addressed to the aircraft, e.g., entry notification.

- A new PA message.

- Traffic conflict messages.

This MFD implementation, along with the PA tool, is but one possible means for providing an airborne capability to support the HVO concept.

Table 1. Pilot-Advisor (PA) Messages

Message definition	Example message	Priority level
The pilot is entering the SCA without an entry notification	NO SEQUENCE EXIT SCA	1
The pilot is entering the SCA at the wrong IAF.	WRONG IAF	1
"Open altitude" informs the pilot of the next altitude that is required for the current procedure and indicate that no other HVO aircraft is occupying that altitude. This message example informs the pilot that the 3000 ft altitude slot is open (available).	OPEN: 3000	0
The pilot has climbed or descended beyond the open (available) altitude. This message would be displayed on the second line of the PA window as a modifier to the instruction displayed on the first line.	OPEN: 3000 MONITOR ALT	1
If an operation is pending but has not occurred after a predetermined time due to an unexpected delay by the pilot, a "proceed now" prompt will be added to the PA message. This message will also be associated with an alert.	OPEN: 2000 PROCEED NOW	1
Time-To-Approach (TTA) defines when the aircraft may leave the IAF with the appropriate spacing behind the aircraft it will be following. The example is 1 minute, 32 seconds before approach initiation.	TTA: 1:32	0
This message shows the pilot that the approach may be initiated.	OPEN: APPR	0
This message shows that the separation distance from the pilot's aircraft to the preceding approach aircraft is below the nominal value (for either an approach or a departure) and that the pilot should reduce speed.	TOO CLOSE REDUCE SPD	1
The pilot is flying faster than the nominal approach speed.	TOO FAST CHECK SPEED	1
The pilot is flying slower than the nominal approach speed. This message is inhibited if a "too close" message has been issued.	TOO SLOW CHECK SPEED	1
The pilot is flying off of the approach path.	MONITOR PATH	1
The pilot is the second aircraft conducting a missed approach to a common MAHF, and he is overtaking the preceding missed approach aircraft. An expedited climb to 3000 ft is required in this example; this information would be shown on the second line of the message window.	OPEN: 3000 CLIMB NOW	1
The pilot is going to the wrong MAHF.	WRONG MAHF	1
This message shows that a departure may be initiated. It is displayed when the pilot is ready for takeoff and there is sufficient separation between both arriving and departing HVO aircraft for an HVO departure operation to be performed.	OPEN: DEPART	0
The pilot is flying the wrong departure procedure.	WRONG DP	1

3.0 Off-Nominal Operations

The development of off-nominal operations created a set of procedures somewhat similar to today's procedures. It was recognized that procedures cannot be written for every possible scenario, and that voice communication will sometimes be essential in safely concluding an off-nominal operation. Development of these proposed off-nominal operations still require a safety fault tree analysis and experiments to validate them. This papers offers one possible implementation, i.e., using a Multi-Function Display and a Pilot Advisor. However, other implementation schemes are possible, and the Pilot Advisor functionality is not a requirement of HVO.

3.1 Off-Nominal Categories

The off-nominal conditions that were identified for inclusion into the HVO procedures were classified into four categories: routine off-nominal operations, procedural deviations, equipment malfunctions, and aircraft emergency procedures.

The routine off-nominal conditions that were identified included:

- A pilot cancellation of an approach request.
- A change of landing approach direction.
- A pilot cancellation of a departure request.
- Leading aircraft conducting a circle-to-land operation.

The procedural deviations that were identified included:

- An aircraft returning to an incorrect MAHF.
- A loss of aircraft-to-aircraft spacing on approach.
- The inability to use an assigned IAF or MAHF.

The equipment malfunctions that were identified included:

- The loss of aircraft state data output on an arriving SATS aircraft.
- The loss of aircraft state data output on a departing SATS aircraft.
- The loss of aircraft state data input on an arriving SATS aircraft.
- The loss of aircraft state data input on a departing SATS aircraft.
- The loss of the AMM.
- The loss of AMM reception by a single aircraft.
- The loss of voice radio communication capability.

<u>The emergency conditions that were identified included the following:</u>

- A priority-landing request from an aircraft with an approach sequence.

- A priority-landing request from a departing aircraft.

Examples of each of these two emergency conditions are shown in figures 5 and 6. Figure 5 is an example of a priority-landing request from an aircraft holding for an approach at ANNIE at 3000 ft. In this figure, the aircraft at the highest altitude has made a priority request and will follow the aircraft on final approach, landing ahead of the aircraft holding at the lower altitudes. Figure 6 is an example of a priority-landing request from a departing aircraft. This condition would occur if an aircraft conducting an HVO departure needed an unplanned, immediate return to the airport. In this figure, the departing aircraft (the right-most aircraft) has made the landing request and will land before the two aircraft on the farther holding patterns.

The procedures that were developed to support these identified conditions are provided in the subsequent sections.

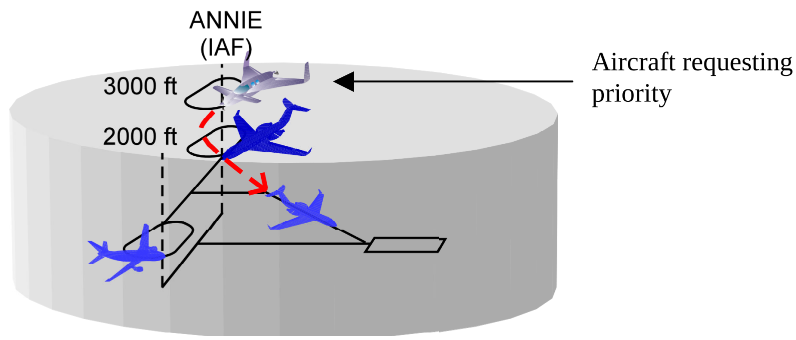

Figure 5. Example of a priority-landing request.

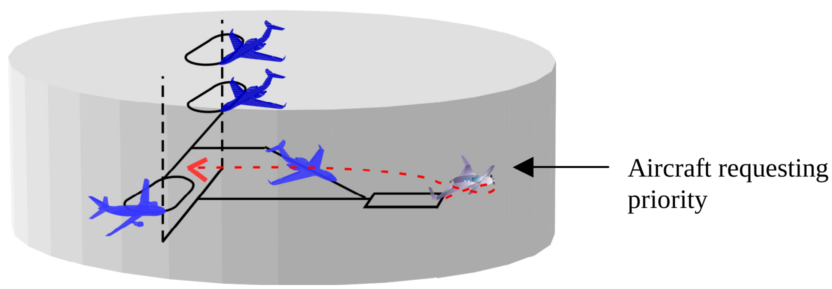

Figure 6. Example of priority landing request from a departing aircraft.

3.2 Implementation Considerations

The addition of off-nominal operations in this document, and the development of their operational procedures have, not surprisingly, led to some increase in the overall complexity of the concept required to support these operations. However, as in the development of the normal operational procedures, these new procedures were based, whenever possible, on similar existing procedures for VFR operations or non-radar, IFR operations. Also, with regard to VFR operations, it is worthwhile to reiterate that the normal operational procedures (ref. 1) allow for mixed operations of both SATS and VFR aircraft, where these operations are expected to be accommodated in a manner similar to today's mix of IFR and VFR aircraft, i.e., the pilot is responsible to see and avoid other traffic (ref. 9).

Also as noted previously, off-nominal operations, especially the detection of equipment failures, will require system-to-system periodic checks and some data retention outside of the AMM. As such, the following requirements were identified to support the off-nominal procedures.

- Changes to the SCA state data information (performed in two phases)

  1. System-to-system (e.g., AMM to the aircraft via the APDLC) information exchange would require confirmation from the receiver back to the sender.

  2. A confirmation process within the aircraft would be required between the aircraft systems and pilot (e.g., the pilot alerted to a change responds with activation of a confirmation/accept button on the MFD).

- Periodic AMM status messages to all participating HVO aircraft.

- Periodic ADS-B reception messages from the AMM to participating HVO aircraft (after the AMM has received an ADS-B message from the aircraft, it would periodically reply with a message back to the aircraft noting that the aircraft's ADS-B message has been received). This message is necessary to alert aircraft to a loss of their ADS-B output or APDLC input capabilities, and is also required prior to conducting a departure operation.

- Prior to takeoff, departing HVO aircraft would require the reception of both an AMM normal-operation status message and an ADS-B reception message from the AMM.

- Current SCA status information (e.g., the number of operations and aircraft identification) would be sent from the AMM.

- Each participating aircraft would retain sequence data from the AMM on all surrounding SCA traffic. This information would be used by the pilots in situations when a reversion to pilot-to-pilot procedural separation is required due to the loss of aircraft state data information. These situations would be analogous to ATC situations upon the loss of ATC radar information.

- Periodic AMM normal-operation status messages would be sent to ATC (e.g., the number of operations and aircraft identification).

It is also important to note that while ADS-B would be the primary means for the dissemination of aircraft state data, the APDLC could be used to provide a secondary means for data exchange. Therefore, failures such as the loss of state data transmission are procedurally addressed only if all means of transmission have failed.

This document only covers procedures unique to SATS HVO. Pilots are expected to use traditional procedures in managing situations that are not unique to HVO. Furthermore, today's requirement for the use of voice communication and airmanship in handling emergencies will still be required in HVO.

Also note that any situation that would require closing the airport, e.g., a single-runway airport with the runway closed due to an accident, would require all approach aircraft to conduct a procedure similar to *Initiating a Departure from a Missed Approach*, described in reference 1.

3.3 Routine Off-Nominal Procedures

3.3.1 Pilot Cancellation of an Approach Request

It is envisioned that this procedure would be used when weather conditions within the SCA would be marginal VFR with the instrument approach operation transitioning to a visual approach. For a pilot to cancel an HVO approach, VFR conditions to the airport must exist (although the aircraft may remain on an IFR flight plan).

Canceling aircraft:

1. The pilot would select the "cancel approach" feature on the MFD.

2. The MFD would send the cancellation request to the AMM.

3. The AMM would mark the aircraft as a non-participating aircraft (e.g., it is assumed that the aircraft has transitioned to VFR).

4. The AMM would send the cancellation notice to the canceling aircraft.

5. The MFD would notify the pilot that his cancellation request was received by the AMM.

6. If the canceling aircraft has not received an approach sequence (i.e., it was outside the SCA with a standby notification), the AMM would delete the aircraft from its request queue.

7. If the aircraft had received an approach sequence:

   - The canceling pilot would announce the cancellation over the Common Traffic Advisory Frequency (CTAF).

   - The AMM would remove the canceling aircraft from the approach sequence.

   - The AMM would re-sequence the aircraft that followed the aircraft canceling HVO.

   - The AMM would send the new sequence information to all HVO aircraft.

Other HVO aircraft:

1. The MFD would identify the canceling aircraft as a non-participating aircraft.

2. If the aircraft had an approach sequence that has been changed (i.e., re-sequenced by the AMM), the MFD would notify the SATS pilot to the changes in the approach information (e.g., new leading aircraft and/or MAHF).

3. The MFD would inhibit all continuing-operations PA messages (e.g., OPEN 3000, OPEN APPROACH) until the pilot of the re-sequenced aircraft acknowledged the re-sequence. This acknowledgement could occur via a button-press on the MFD.

Note that for this and all other procedures that require an information exchange (e.g., cancellation request or re-sequence data) between the pilot and the onboard system, an acknowledgement by the pilot would be required. As noted previously, this acknowledgement could occur via a button-press on the MFD. Similarly, an information exchange between the onboard system and the AMM would also require an underlying (system-to-system) data exchange confirmation (e.g., an acknowledgement). This acknowledgement could occur via a data link "handshake" between the two systems.

3.3.2 Change of Approach Direction

The determination of the active runway should probably be a function of ATC, which may require ATC support tools, better than a D-ATIS or AWOS, in supporting this determination. Additionally, pilots should be able to provide feedback and input into the decision regarding the selection of the approach direction and the active runway. Further research may be required to agree upon an appropriate means for providing this determination.

It should be noted that normal changes of runway landing direction should be managed prior to aircraft being assigned approach sequences. That is, ATC should inhibit arrivals until all ongoing SCA operations have been completed, holding the new arrivals above the SCA until all current SCA operations have been completed. Also note that the SCA approach direction may not need to change if circle-to-land operations are used. Assuming that a change to the instrument approach direction must take place while aircraft are conducting SCA operations, the following should occur:

1. The AMM should inhibit all new SCA operations and set the SCA status to no new operations (NNO).

2. The AMM should notify ATC that the SCA is in an inhibit status.

3. The AMM would notify ATC regarding the configuration change and identify all active HVO aircraft.

4. All landing aircraft should either land or conduct a missed approach operation.

5. Missed approach aircraft should contact ATC to obtain a clearance to the MAHF at the lowest IFR altitude above the SCA.

6. At the completion of all HVO approach operations, which would occur when all aircraft have either landed or are no longer actively conducting SATS operations, the AMM would reconfigure the SCA for the new landing direction.

7. Once all of these actions have occurred, ATC may allow the AMM to resume SCA operations.

3.3.3 Pilot Cancellation of a Departure Request

If a pilot cancels an SCA departure request, the following should occur:

1. PA alerting would be inhibited for the canceling aircraft.

2. All other aircraft would continue with their normal operations.

3.3.4 Leading Aircraft Conducting a Circle-to-Land

This situation would occur if the leading aircraft plans to conduct a circle-to-land operation. For this situation, the following procedure should be used:

1. The pilot of the circle-to-land aircraft would select this function on the MFD.

2. The MFD of the circle-to-land aircraft would send the circle-to-land information to include the intended landing runway to all HVO aircraft.

3. Based on the received circle-to-land intent information, the following aircraft would have an additional distance or time interval added to the nominal spacing value for the approach spacing. Further development of this operation may be required.

3.4 Procedural Deviations

3.4.1 Aircraft Returning to an Incorrect Missed Approach Holding Fix

This procedure addresses the problem of an HVO pilot attempting to fly an incorrect missed approach procedure for the instrument approach. Note that for a pilot to turn toward the wrong MAHF, the pilot would have already made the following errors: performed the incorrect missed approach procedure; ignored the MAHF identified in the MFD “to waypoint” data block; ignored the missed approach procedure depicted on the moving map display of the MFD (and any associated primary flight guidance information on the Primary Flight Display - PFD); and ignored the PA alert for an incorrect missed approach procedure.

In the event that an aircraft does accidentally attempt to return to the wrong MAHF, the following procedure should be performed once the pilot recognizes the error (e.g., observes the correct MAHF name on the MFD):

1. The pilot should make a call over CTAF announcing the problem.

2. The pilot should contact ATC as soon as possible and announce the problem

3. Due to the potential loss of separation with other aircraft on the instrument approach, this aircraft must not attempt to return to the assigned MAHF. The pilot should continue climbing along the errant missed approach path to an altitude above the SCA.

4. The pilot should contact ATC and request an IFR clearance from ATC. If possible, this clearance should be obtained prior to departing the SCA.

3.4.2 Loss of Aircraft-To-Aircraft Spacing on Approach

An aircraft that is predicted to lose aircraft-to-aircraft spacing while on the approach and subsequently receives a loss-of-separation alert should do the following:

1. Begin an immediate climb to its missed approach altitude.

2. Fly the lateral path of the approach and subsequent missed approach.

3. Fly the planned approach speeds (to maintain conformance for other SCA aircraft), where these speeds are either standard speeds for the aircraft or pre-selected by the pilot.

3.4.3 Unable to Use an Assigned IAF or MAHF

This condition may occur because of severe weather at the IAF or MAHF.

If this situation occurs while still in ATC managed airspace, the pilot should coordinate with ATC to proceed to the other IAF or divert to another airport.

If within the SCA, the pilot should climb above the SCA in the safest possible manner, avoiding obstacles, other aircraft, and the severe weather. During the climb, the pilot should notify ATC of the situation, noting that contacting ATC is a priority since the aircraft could be entering controlled airspace without a clearance.

3.5 Equipment Malfunction Procedures

3.5.1 Loss of ADS-B Output on an Arriving SATS Aircraft

This situation would occur if an HVO aircraft had lost the capability to transmit its state data information via ADS-B. If this situation exists, the following should occur:

Aircraft Without an Arrival Sequence:

Part of the arrival sequencing process that the AMM performs is the confirmation of ADS-B state data output from the requesting aircraft. If the aircraft has not already been issued an arrival sequence, the AMM would attempt to confirm the aircraft's ADS-B transmit capability (and all other output capabilities) prior to the sequence notification. If there is no ADS-B output, the aircraft would be notified of this condition and it would be denied an approach sequence.

Aircraft With an Arrival Sequence and with APDLC Output:

If the aircraft has an approach sequence and subsequently loses its ADS-B output but still has APDLC capability, the following should occur:

1. The AMM, noting the loss of the ADS-B signal from an aircraft, would inhibit all new SCA operations and would set the SCA status message to no-new-operations (NNO).

2. The AMM would notify ATC that the SCA is in an inhibit status.

3. The AMM, noting the loss of an ADS-B signal from an aircraft, would send that aircraft a "lost ADS-B output" message that could be displayed as an alert message on the MFD. The problem aircraft would then begin (or continue) transmitting its position data over the APDLC. This APDLC message would be broadcast to all aircraft in the SCA.
4. The AMM would resume normal operations after the problem aircraft has landed and would also set the SCA status appropriately.

Aircraft With an Arrival Sequence and without APDLC Output:

If the aircraft has an approach sequence and subsequently loses both its ADS-B output and its APDLC capability, the following should occur:

1. The AMM, noting the loss of an ADS-B signal from an aircraft (and all other output capability), would inhibit all new SCA operations and set the SCA status message to no-new-operations (NNO).

2. The AMM would notify ATC that the SCA is in an inhibit status.

3. The AMM would send all aircraft a "lost signal" message via the APDLC, identifying the aircraft that had lost its transmission capability.

4. All aircraft that were conducting approach operations would revert to procedural separation using CTAF and continue the approach operations using their original sequence assignments.

5. Departure operations would be inhibited until the aircraft with the problem lands.

6. A notification to the AMM that the problem aircraft has landed or has departed the SCA would be accomplished via a ground-based message from ATC.

3.5.2 Loss of ADS-B or APDLC Output on a Departing SATS Aircraft

Prior to conducting an SCA departure operation, aircraft would perform an ADS-B and APDLC check with the AMM. It is envisioned that if a successful link check could not be performed, the PA would inform the pilot that an HVO departure was not possible. In this instance, this departing aircraft would be required to revert to unequipped operations (ref. 1).

3.5.3 Loss of ADS-B Input on an Arriving SATS Aircraft

This situation would occur if an HVO aircraft had lost the capability to receive ADS-B information from other SCA aircraft. If this situation takes place, the following should occur:

Aircraft Without an Arrival Sequence:

Part of the arrival sequencing process that the AMM performs is the confirmation of ADS-B state data input to the requesting aircraft. If the aircraft has not already been issued an arrival sequence, the AMM would attempt to confirm the aircraft's ADS-B reception capability (and all other input capabilities) prior to the sequence notification. If there were no ADS-B inputs, the aircraft would be denied an approach sequence.

Aircraft With an Arrival Sequence but with APDLC Input:

If the aircraft has an approach sequence and subsequently lost its ADS-B reception capability but still had APDLC capability, the following should occur.

1. The aircraft with the equipment problem would notify the AMM of the loss of ADS-B reception.

2. If all SCA aircraft were not already broadcasting their position data via APDLC, the AMM would request this transmission of state data via APDLC from all participating aircraft.

3. The aircraft with the equipment problem would use the APDLC-received state data as necessary.

Aircraft With an Arrival Sequence and without APDLC Input:

If the aircraft has an approach sequence and subsequently loses its ADS-B input and its APDLC capability, the following should occur.

1. The aircraft with the equipment failure would notify the AMM of the loss of ADS-B reception capability. Lack of a periodic status message via APDLC from an aircraft could also cause the AMM to initiate this event.

2. The AMM would inhibit all new SCA operations and set the SCA status message to no-new-operations (NNO).

3. The AMM would notify ATC that the SCA is in an inhibit status.

4. The AMM would send all aircraft an “unable to receive” message via the APDLC, identifying the aircraft that had lost its reception capability.

5. All aircraft conducting approach operations would revert to procedural separation using CTAF and continue the approach operations using their original sequencing assignments.

6. The AMM would resume normal operations after the problem aircraft has landed and would set the SCA status appropriately.

3.5.4 Loss of ADS-B or APDLC Input on a Departing SATS Aircraft

Part of the departure process that the AMM performs is the confirmation of ADS-B state data input to the requesting aircraft. The AMM would attempt to confirm the aircraft’s ADS-B reception capability (and all other input capabilities). If this confirmation fails, this aircraft would be required to revert to unequipped operations.

3.5.5 Loss of AMM Output

The AMM would send a periodic operational status message to ATC and to all proximate aircraft via the APDLC. Loss of this operational status message would indicate a failure of the AMM. Upon loss of the AMM status signal, the following should occur:

1. By default, the SCA would be inhibited from accepting any new arrival or departure operations.

2. ATC would be informed of an AMM failure though the loss of the periodic status message from the AMM.

3. ATC should then restrict any new SCA entries and departures.

4. The aircraft would identify the AMM failure through the loss of the AMM status message.

5. The MFD would provide a notification to the pilot that the AMM has failed.

6. Pilots with an assigned arrival sequence would use CTAF to corroborate their landing sequence.

7. Each pilot would close his flight plan after landing, which is both a standard ATC normal procedure (ref. 9) and an HVO procedure. This would provide ATC a means for correlating the landing aircraft with the previously retained information that identified the current SCA traffic aircraft.

8. At the completion of all HVO operations, the airport would revert to non-HVO operations.

3.5.6 Loss of AMM Reception by a Single Aircraft

As noted previously, the AMM would send a periodic operational status message to all proximate aircraft via the APDLC and to ATC. Loss of this operational status message could indicate an APDLC receiver failure on the SATS aircraft. Upon loss of the AMM status signal the following should occur:

1. To confirm that the problem is single aircraft specific, the pilot of the aircraft without AMM reception would announce the loss of the AMM data via CTAF. If more than one aircraft has lost AMM reception, then the previous procedure (Loss of AMM Output) would be used.

2. The pilots would use CTAF to corroborate their landing sequence.

3. The aircraft would land in their original sequencing order.

3.5.7 Loss of Voice Communications

HVO procedures were developed for the situations when aircraft have lost their voice-radio communication capability. Following normal HVO procedures assures pilots of the ability to self separate within the SCA and land according to the AMM generated sequence. For aircraft in ATC airspace, traditional procedures (ref. 9) would be used in conjunction with the HVO arrival procedures.

Arriving Aircraft Outside of the SCA:

1. As noted previously, ATC would use traditional lost communication procedures.

2. With the exception of the lost-communications aircraft, the AMM would inhibit all new operations and set the SCA status message to no-new-operations (NNO).

3. The lost-communications aircraft would be provided with a normal, non-priority approach sequence via APDLC, assuming that all other entry constraints were met (Sec. 2.1).

4. The lost-communications aircraft should descend to the altitude immediately above the SCA at a time appropriate for traditional lost-communications procedures.

5. ATC would enable the AMM for new HVO operations after the lost communications aircraft has landed.

6. The AMM would then resume normal operations.

Arriving Aircraft Inside of the SCA:

If the aircraft had an approach sequence and subsequently lost its voice communications capability, normal operations would be continued. Voice-communication loss should not be a critical issue since the communication radio is only used as a secondary means for situation awareness and for redundancy in other off-nominal procedures. The communication radio should be required to initiate a SATS operation, i.e., it is part of the minimum equipment requirement. A loss of voice communications does mean a loss of the CTAF environment, so transitions to VFR follow existing procedures (ref. 8).

Departing Aircraft:

Aircraft that have lost their voice communication capability and are not airborne may not conduct an HVO departure. Airborne aircraft would use traditional IFR lost-communication procedures (ref. 9).

3.6 Emergency Procedures

3.6.1 Priority Landing Request from an Aircraft with an Approach Sequence

This procedure would typically be used for an aircraft that is experiencing an emergency situation and must land immediately. This capability is valid only for aircraft that have an approach sequence assigned or are in a position where they would be eligible for an SCA entry notification (e.g., at the lowest available altitude over an SCA IAF). If they are not eligible for an SCA entry, they must coordinate with ATC since they are still under ATC control. Pilots within the SCA that have an emergency that precludes them from flying the complete instrument approach (engine or icing problems requiring an immediate landing) can still use the procedures in this section. Although terrain clearance cannot be assured in IMC when deviating from a certified approach (e.g., the pilot must proceed direct present position to the airport due to the emergency), the procedures below ensure all other pilots in the vicinity have awareness of the emergency and that the emergency aircraft has landing priority.

Requesting Aircraft:

For the aircraft requesting landing priority, the following procedure should be used:

1. The pilot would announce the emergency and his intent over CTAF.

2. The pilot would select the “emergency landing” feature on the MFD.

3. The MFD would send the priority request to the AMM.

4. The AMM would inhibit all new SCA operations and set the SCA status to NNO.

5. The AMM would notify ATC that the SCA is in an inhibit status.

6. The AMM would send the identity of the priority aircraft to all HVO aircraft.

7. The MFD would inhibit all continuing-operations PA messages (e.g., open altitude, open approach) on the requesting aircraft.

8. As soon as possible, the priority aircraft would begin the approach, procedurally spacing with respect to prior approach aircraft. If the approach spacing interval becomes too close, the pilot of the priority aircraft has the responsibility to request the preceding aircraft to perform a missed approach. Note that the requesting aircraft will not be assigned an approach sequence. If the aircraft was initially at the higher altitude at the IAF than the approach altitude, this aircraft would only begin a normal descent (e.g., 500 foot-per-minute descent rate) after crossing the IAF inbound on the approach.

Other SCA Aircraft:

1. The aircraft symbol on the MFD for the priority aircraft would be highlighted.

2. Arriving aircraft that are already on the approach would continue with the approach procedure. If the emergency aircraft requests that the approach path needs to be immediately cleared for the emergency operation, these aircraft could execute an early missed-approach climb.

3. If the priority aircraft was already on the approach or was the first aircraft in holding at an IAF (e.g., the next aircraft to initiate the approach), the AMM would not re-sequence the other aircraft. Otherwise, the AMM would re-sequence the aircraft waiting for an approach in their original order, excluding the priority aircraft.

4. The AMM would send the new sequence information to all HVO aircraft.

5. The MFD would notify the appropriate pilots of their re-sequence assignments.

6. The MFD would inhibit all continuing-operations PA messages (e.g., open altitude, open approach) until the pilot of the re-sequenced aircraft acknowledged the re-sequence.

7. The MFD would inhibit all approach-operations PA messages (e.g., open approach) until the priority aircraft has crossed the runway threshold.

8. Once the priority aircraft has crossed the runway threshold, normal operations would be resumed.

An example of this procedure is shown in figure 5.

3.6.2 Priority Landing Request from a Departing Aircraft

This procedure was designed to support a departing aircraft that is unable to continue the departure operation and must return for an instrument approach to the airport.

Requesting Aircraft:

Note that the first 7 steps of this procedure are the same as for *Priority Landing Request from an Aircraft with an Approach Sequence*.

1. The pilot would announce the emergency and his intent over CTAF.

2. The pilot would select the "emergency landing" feature on the MFD.

3. The MFD would send the priority request via APDLC to the AMM.

4. The AMM would inhibit all new SCA operations and would set the SCA status to no-new-operations (NNO).

5. The AMM would notify ATC that the SCA is in an inhibit status.

6. The AMM would send the identity of the priority aircraft to all HVO aircraft.

7. The MFD would inhibit all continuing-operations PA messages (e.g., open altitude, open approach).

8. As soon as possible, the priority aircraft would proceed to either IAF, at the lowest altitude, and begin the approach, procedurally spacing with respect to prior approach aircraft (if any). Note that this aircraft would not be assigned an approach sequence. 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.

Other SCA Aircraft:

1. The aircraft symbol on the MFD for the priority aircraft would be highlighted.

2. Arriving aircraft that are already on the approach would continue with the approach procedure. If the emergency aircraft needs the approach path immediately cleared, the pilot of the emergency aircraft would request that the preceding aircraft execute an early missed-approach.

3. Arrival aircraft that are holding at the IAF (i.e., not already on the approach) and are at the lowest altitude would be re-sequenced, if necessary, such that they would leave the IAF for the approach as soon as possible (i.e., the intent is to make a clear approach path for the emergency aircraft). These aircraft should make every attempt to expedite their approach operations.

4. For arrival aircraft that are holding at the IAF (i.e., not already on the approach) and are not at the lowest altitude, the following should occur:

   - These aircraft would be re-sequenced, as required, for the approach.

   - If the aircraft has an approach sequence that has been changed (i.e., re-sequenced), the MFD would notify the SATS pilot to the changes in the approach information (e.g., new leading aircraft or MAHF).

- These aircraft would be given a STANDBY notification by the AMM.

- The MFD would notify the appropriate pilots of their standby assignment.

- The MFD would inhibit all continuing-operations PA messages (e.g., open altitude, open approach) until the pilot of the re-sequenced aircraft acknowledges the re-sequence.

- The MFD would inhibit all continuing-operations PA messages (e.g., open altitude, open approach) until the emergency aircraft lands.

5. Normal operations would be resumed once the priority aircraft has landed.

An example of this procedure is shown in figures 7-10, with the chosen example portraying the worst approach sequencing situation prior to start of this procedure. The start of this procedure is shown in figure 7, with an aircraft on the approach and three other aircraft waiting to begin the approach. The approach sequence numbers are shown in this figure for these aircraft.

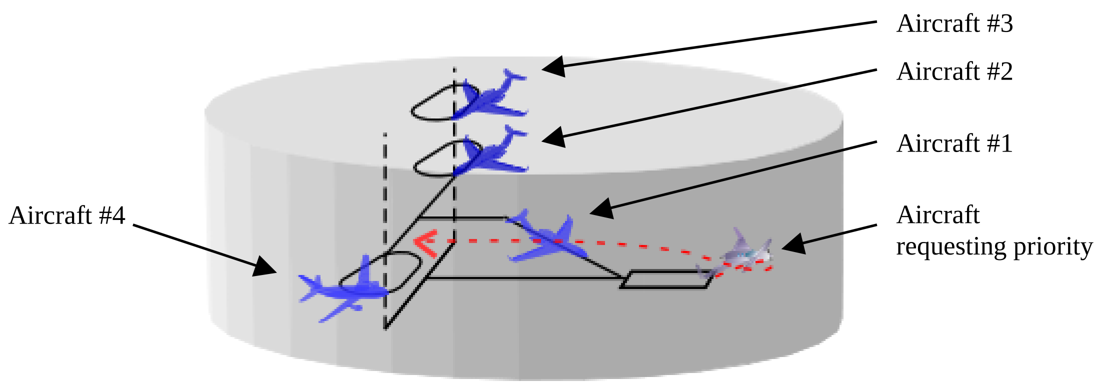

Figure 7. Example of a priority landing request from a departing aircraft: initial situation.

Figure 8 portrays the situation immediately after the departing aircraft makes the priority request. At this point, the AMM would have re-sequenced and issued the new sequence numbers and, where appropriate, STANDBY notifications. Note that the action by the AMM has affected all of the holding aircraft.

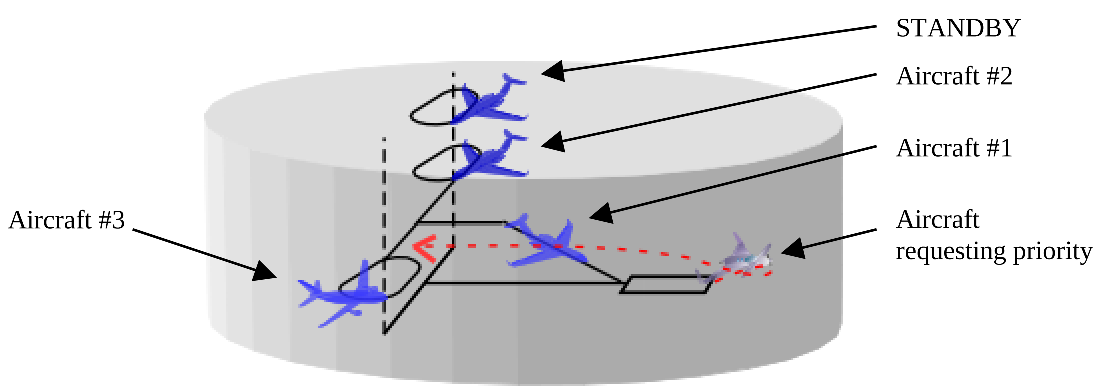

Figure 8. Example of a priority landing request from a departing aircraft: after re-sequence.

Figure 9 shows the situation as the second aircraft begins its approach. Note that the standard HVO airborne tools, using the AMM sequencing information, have provided the information to the second aircraft that it is safe to initiate its approach. Also note that the first aircraft has landed.

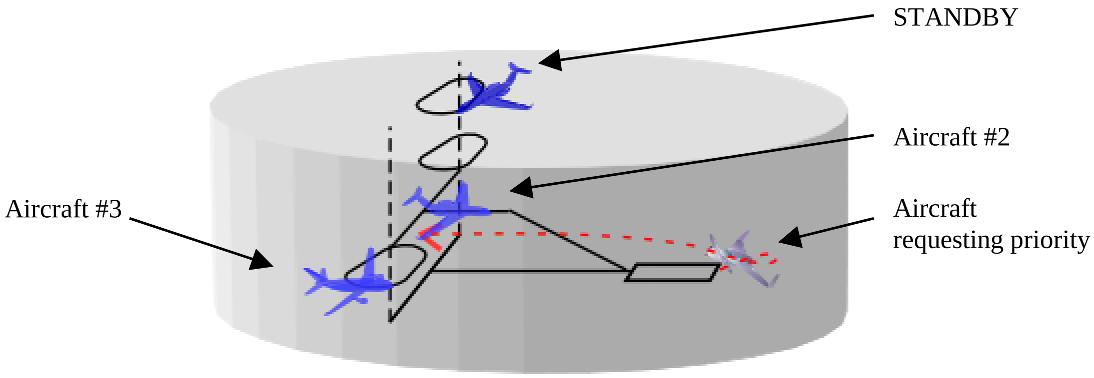

Figure 9. Example of a priority landing request from a departing aircraft: aircraft #2 begins approach.

Figure 10 shows the situation after the third aircraft begins its approach, again using its onboard tools to determine when to begin the approach. Figure 11 is a plan-view graphic of the situation shown in figure 10.

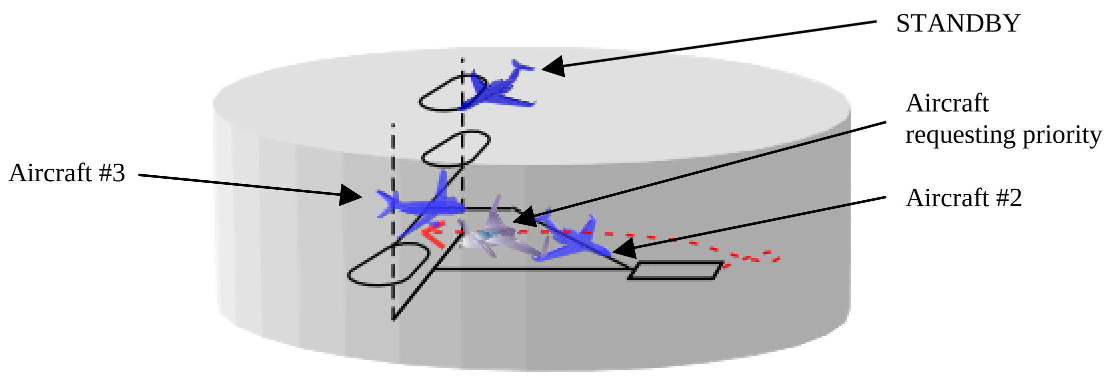

Figure 10. Example of a priority landing request from a departing aircraft: aircraft #3 begins approach.

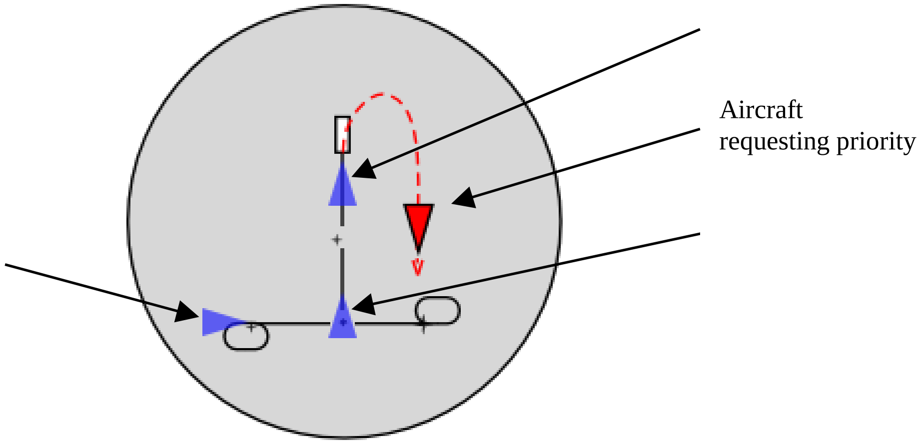

Figure 11. Plan-view of the situation of figure 10.

Figure 12 shows the situation as the priority aircraft begins its approach. Note that while the standard HVO airborne tools have provided the information to the third aircraft to initiate its approach, the pilot of the priority aircraft, because of the emergency situation, will initiate the approach as soon as possible. Also note that 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.

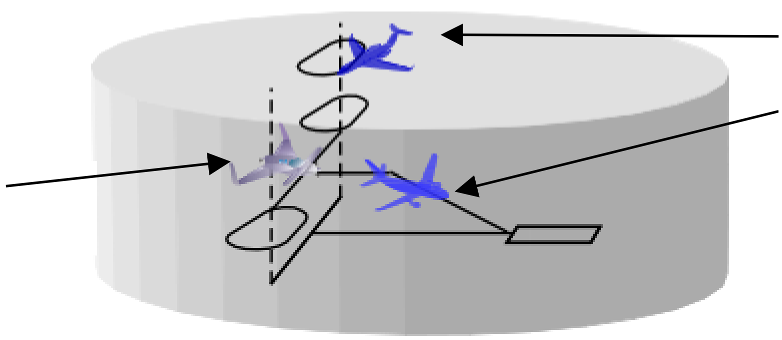

Figure 12. Example of a priority landing request from a departing aircraft: priority aircraft begins approach.

Once the priority aircraft has landed, the STANDBY aircraft will be allowed to resume approach operations. Also note that all normal operations would be resumed once the priority aircraft has landed.

4.0 Summary

The ability to operate multiple small aircraft, in near all weather conditions, at virtually any small airport offers a unique opportunity for revolutionary transportation growth and passenger convenience. A previous paper (ref. 1) presented a concept for aircraft operating at airports where operations are currently restricted to the inefficiency of a “one-in/one-out” procedure. This new concept would allow for simultaneous operations by multiple aircraft in this non-radar “terminal” airspace around small non-towered airports. Aircraft operating in this airspace would need special avionics to participate that would probably include near-term technologies, such as ADS-B and a communications data link, and appropriate self-separation tools. This concept would also require a new, relatively simple ground-based automation system, typically located at the airport, that would provide appropriate sequencing information to the arriving aircraft.

The effort described in this paper expands the SATS HVO operational concept to include off-nominal situations that could be expected to occur in a future SATS environment. The situations that were examined were segregated into four categories: routine, such as a change of landing approach direction; procedural deviations, such as flying to the wrong MAHF; equipment malfunctions, such as a loss of an aircraft's communication system; and emergency situations, such as a priority request for an emergency landing. SATS operational procedures were developed to accommodate these off-nominal situations and were described in this paper. Potential pilot and ATC workload issues were also considered in the development of these new procedures. With respect to potential problems relating to pilot workload, airborne display concepts were also defined to assist the pilot during these off-nominal situations. An effort was also made to minimize the impact on ATC following an off-nominal event in the SCA. Additionally, since both equipment requirements and equipment malfunctions are closely interrelated in off nominal situations, a candidate implementation scheme was also presented.

In keeping with the SATS goal of achieving a realistic, operationally deployable system for the 2010 timeframe, the development of these new operational procedures to support off-nominal situations again emphasized simplicity in the design. The development focus was 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. A significant design effort was also expended to minimize equipment requirements and changes to today's operating rules. The operational concepts and procedures described in this paper were intended to be a starting point for additional designs and analyses. Operational concepts such as the one proposed in the fundamental SATS HVO concept documents and expanded here could enhance the opportunity for point-to-point air taxi or charter operations into smaller airports, providing greater convenience to the traveling public.

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14. ABSTRACT
This document expands the Small Aircraft Transportation System, (SATS) Higher Volume Operations (HVO) concept to include off-nominal conditions. The general philosophy underlying the HVO concept is the establishment of a newly defined area of flight operations called a Self-Controlled Area (SCA). During periods of poor weather, a block of airspace would be established around designated non-towered, non-radar airports. Aircraft flying enroute to a SATS airport would be on a standard instrument flight rules flight clearance with Air Traffic Control providing separation services. Within the SCA, pilots would take responsibility for separation assurance between their aircraft and other similarly equipped aircraft. Previous work developed the procedures for normal HVO operations. This document provides details for off-nominal and emergency procedures for situations that could be expected to occur in a future SCA.

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