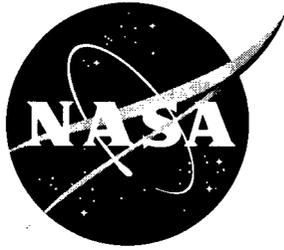# Small Aircraft Transportation System Simulation Analysis of the HVO and ERO Concepts

Gary D. Millsaps
Swales Aerospace, Hampton, Virginia

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INTRODUCTION

It is acknowledged that the aviation and aerospace industries are primary forces influencing the industrial development and economic well being of the United States and many countries around the world. For decades the US national air transportation system has been the model of success - safely and efficiently moving people, cargo, goods and services and generating countless benefits throughout the global community; however, the finite nature of the system and many of its components is becoming apparent.

Without measurable increases in the capacity of the national air transportation system, delays and service delivery failures will eventually become intolerable. Although the recent economic slowdown has lowered immediate travel demands, that trend is reversing and cargo movement remains high. Research data indicates a conservative 2.5-3.0% annual increase in aircraft operations nationwide through 2017. Such growth will place additional strains upon a system already experiencing capacity constraints.

The stakeholders of the system will continue to endure ever-increasing delays and abide lesser levels of service to many lower population density areas of the country unless more efficient uses of existing and new transportation resources are implemented. NASA's Small Aircraft Transportation System program (SATS) is one of several technologies under development that are aimed at using such resources more effectively.

As part of this development effort, this report is the first in a series outlining the findings and recommendations resulting from a comprehensive program of multi-level analyses and system engineering efforts undertaken by NASA Langley Research Center's Systems Analysis Branch (SAB). These efforts are guided by a commitment to provide systems-level analysis support for the SATS program. Subsequent efforts will build upon this early work to produce additional analyses and benefits studies needed to provide the technical and economic basis for national investment and policy decisions related to further development and potential deployment of a small aircraft transportation system.

This report primarily serves two purposes. First, it presents results attained from an *initial evaluation and analysis* of the Higher Volume Operations (HVO) and EnRoute Operations (ERO) concepts – both designated operational capabilities within the SATS Program's Concept of Operations (CONOPS) document. It further outlines areas of the concepts that would benefit from follow-on analyses and system engineering efforts. It is intended that these processes will aid continued maturation of the concepts and promote additional studies of their effects and influences in combination with other designated CONOPS currently under development.

In essence, it establishes a baseline of data upon which subsequent analyses and studies can be built and identifies performance characteristics the concept must exhibit in order to provide, at minimum, levels of safety and usage equal to or better than the current system.

SATS PROGRAM OVERVIEW

NASA leads a joint research & development program focused on maturing technologies needed for a successful small aircraft transportation program. To prove that the SATS concept will work in the evolving National Airspace System, NASA formed a public/private partnership with the Department of Transportation/Federal Aviation Administration (FAA), universities, service providers, and state & local aviation authorities. The partnership's initial focus is to demonstrate four new operating capabilities that will enable safe and affordable access to virtually any runway in the nation in most weather conditions. These new operating capabilities use on-board computing, advanced flight controls, advanced flight deck display formats, and evolving communication, navigation, surveillance and air traffic separation technologies.

The program's four primary objectives centered on operational capabilities are:

- **Higher Volume Operations at Non-Towered/Non-Radar Airports (HVO)**
  Enable simultaneous operations by multiple aircraft in non-positive controlled airspace at and around small non-towered airports in near all-weather conditions.

- **EnRoute Procedures and Systems for Integrated Airspace Operations (ERO)**
  Provide simulation and analytical assessments of concepts that integrate SATS equipped aircraft into the enroute air traffic system and controlled airspace.

- **Lower Landing Minimums at Minimally Equipped Landing Facilities (LLM)**
  Provide precision approach and landing guidance to small airports while avoiding land acquisition and approach lighting costs, as well as ground-based precision guidance systems e.g. ILS.

- **Increase Single-Pilot Crew Safety and Mission Reliability (SPS)**
  Increase single-pilot safety, precision, and mission completion.

Current NASA in-house research efforts are directed toward the HVO and ERO concepts. The results presented in this report are focused on these concepts however; the Systems Analysis Branch will conduct analysis and evaluations of other concepts as called for. Other consortium members have responsibility for detailed development of the remaining operational concepts.

HIGHER VOLUME OPERATIONS (HVO) CONCEPT[1]

The general philosophy underlying the Higher Volume Operations (HVO) concept is the establishment of a newly defined area of flight operations surrounding a newly designated HVO airport. The structure and configuration of the flight operations area (FOA) would be uniquely defined for each designated airport. The airspace would meet all current FAA airspace design criteria and comply with required standards for terrain avoidance, obstacle clearance, local traffic densities and noise abatement procedures. Inside this zone, free flight and self-separation between HVO equipped aircraft as well as flights conducted under traditional Instrument Flight Rules (IFR) are permitted in Instrument Meteorological Conditions (IMC). These HVO airports will be some of the non-towered, non-radar controlled airports that currently have limited or no operations in IMC.

Assuming an IFR arrival to an HVO airport in IMC (under ATC control), HVO equipped pilots will be permitted to request an HVO clearance and take responsibility for separation assurance from other HVO aircraft once inside the HVO FOA. Aircraft operating under IFR will also be permitted to land at an HVO airport with certain requirements, and under certain procedural guidelines. This is addressed in more detail in the section entitled mixed equipage.

What follows is a brief description of what HVO operations might look like in the year 2010, along with high-level concepts for operational procedures.

The following are the major assumptions made in the formulation of this concept of operations:

- The concept of an HVO Flight Operations Area is operationally feasible.

- All HVO aircraft have a minimum set of equipage, which is defined to include: an ADS-B transceiver, GPS, CDTI, data link and automated conflict detection.

- Within the HVO Flight Operations Area, HVO pilots must assume responsibility for self-separation.

- The HVO airport has an Airport Management Module for aircraft sequencing that exchanges data with HVO pilots and ATC.

- The HVO airport must have weather observing/reporting capability.

- These operations are conducted in IMC.

- In the enroute phase of flight, if the aircraft is operating under IFR it is assumed the aircraft is under positive ATC control.

- These operations are conducted under FAR Part 91 as much as possible.

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[1] Section Ref: **Small Aircraft Transportation System Program**, 2010 Concepts of Operations Document, NASA, July 2002

- There is no special provision required for separation from VFR traffic ("see and avoid" in effect per FAR Part 91.113).

- All approaches are approved, "published" approaches (they may be sent up from the ground from a pre-approved set but they are not dynamically calculated in the air).

- The goal of this concept of operations is to facilitate achieving the program target goal of safely allowing 10 simultaneous operations in non-radar airspace.

Departure Phase

Prior to departure, the pilot of the HVO aircraft will file either an HVO only, or an HVO/IFR/VFR combined flight plan. The combined plans will look something like today's VFR/IFR composite Flight Plan with minor variations. An HVO/IFR combined plan would include an HVO portion covering the areas occurring in HVO governed airspace. The IFR portion of the plan would include the en-route portion of the flight, where the aircraft would be under positive control. It would also be possible to file an HVO/VFR combined plan, where once outside the HVO governed airspace, the aircraft would fly under VFR. An HVO only plan would allow for HVO equipped aircraft to fly between overlapping HVO airports without entering ATC controlled airspace. Initially, a pilot would file the flight plan using any of the currently available traditional methods. However in the future, it is possible they will be able to do so via data-link from their aircraft.

In continuing preparation for departure, an HVO equipped aircraft would transmit a data-link message, containing several departure parameters, to an Airport Management Module (AMM) located at the departure airport. Initially, these parameters will include, but may not be limited to, the pilot's specific choice from a set of predefined Departure Fixes (DF), a Requested Time of Departure (RTD), and aircraft type and performance information. The Airport Module will process this request, and in coordination with any necessary Air Traffic Control authority, assign the requesting aircraft both a departure window, and a sequence position in departure/arrival queue. Once these assignments are made, the AMM data-links this information to the requesting aircraft.

The Airport Management Module will make this assignment based on an optimization routine that includes calculations using aircraft performance, wake turbulence requirements, other traffic, and winds in the terminal area. If the departure window, and forecast performance are adhered to, the sequence and departure window assignments will be a considerable aid to ensuring separation with other departing/arriving HVO equipped aircraft. It is important to remember that separation assurance inside the HVO FOA will be the responsibility of the pilot and that sequence numbers and arrival/departure windows assigned by the AMM are meant to significantly aid the pilot in this regard. This sequencing and provision of windows will also provide for an orderly and smooth flow or traffic into and out of the HVO FOA.

As the departing aircraft taxis to the active runway, the pilot will use a multi-function display to see his position and sequence relative to other local traffic. This display will show not only his aircraft, but also the position and sequence numbers of other HVO aircraft in the control zone. As he approaches the number one position for the active

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runway, the pilot will hold short until he is inside his departure window. If there is other traffic inside the HVO FOA, the pilot will notice his sequence number begin to count down as he approaches the active runway. Once he is inside the departure window, and his sequence number is upgraded to #1, he is cleared to taxi onto the active runway and commence his takeoff.

There may be occasions when an HVO aircraft would take-off but desire to stay in the HVO Control Zone near the airport (e.g. flying multiple approaches at the airport). In this case, the request to stay in the local area would be a part of the initial message to the AMM, and after takeoff, the HVO aircraft would be issued a new sequence number for his position in the traffic arrival/departure cue. After each approach, the aircraft would again be issued a new sequence number.

Once a departing aircraft is airborne, the pilot flies to his requested DF via a published departure procedure. Compliance with this standard procedure, coupled with his departure window, allows him to remain clear from other departing and arriving traffic.

Prior to reaching the DF, he contacts the local ATC sector controller who, because of early coordination from the AMM, is already aware of his impending departure from the HVO FOA and intent to transition into the en-route structure.

Based on the previously coordinated and approved departure window, the ATC controller is aware of the window of time in which the HVO aircraft will reach his requested DF.

Once radar contact is established, and the controller is ready to begin providing separation, the HVO pilot requests and receives their IFR clearance, relieving them of self-separation responsibilities.

There will be holding patterns established at each of the departure fixes. If there is an unusual event with respect to sequencing, or leaving the HVO FOA, an HVO equipped pilot will easily enter the holding pattern at his approved fix. They will use their CDTI to ensure no traffic at their selected holding altitude.

En Route Operations

After ATC established control over the aircraft, the en-route portion of the flight begins. In the year 2010, it is assumed that, this IFR portion of the HVO/IFR composite flight plan will be conducted under standard IFR in today's controlled airspace.

Approaching an HVO FOA, the ATC controller will issue descent clearances consistent with the planned arrival. While still outside the zone, the arriving aircraft will transmit a landing clearance request to the AMM at the arrival airport. This message will be the initial contact with the arrival airport's AMM. The AMM will respond by data-link message indicating the pilot's request has been received and communication has been established between the AMM and the arriving aircraft.

The AMM at the arrival airport would have access to the original flight plan data as part of the initial coordination process with ATC. Portions of this initial arrival request message sent to the AMM (outside the HVO FOA) from the requesting arriving aircraft

would confirm and update that original flight plan data. This arrival message will also contain, but may not be limited to the pilot's requested IAF, Estimated Time of Arrival (ETA), and information on aircraft performance.

For an HVO equipped aircraft to enter an HVO FOA and participate in HVO operations, the aircraft must have established contact with the AMM, be willing to self-separate from other HVO aircraft inside the HVO FOA and receive permission from ATC to enter the HVO FOA.

There will be holding patterns established at each of the arrival fixes, as well as each of the available IAFs. If there is an unusual event with respect to sequencing, or entering the HVO FOA, an HVO equipped pilot will easily enter the holding pattern at his approved fix.

Descent and Arrival

After the arriving aircraft is inside an HVO FOA, the HVO aircraft will request to be released from ATC control. Once released from ATC control, the pilot is required to self-separate from other HVO aircraft. Pilots will adhere to specified separation criteria defining legal separation of HVO aircraft. Pilots will also follow procedures providing easily anticipated maneuvers among self-separating aircraft within the HVO FOA and "rules of the road" to detect and resolve traffic conflict encounters. The self-separation task will be enabled in IMC by new "HVO" equipment; the location of other HVO traffic will be shown on a Cockpit Display of Traffic Information, or CDTI, in the cockpit of all HVO equipped aircraft. Other aids to the self-separation task include Conflict Detection, Conflict Resolution and Conflict Prevention advisory equipment based on the same data that would drive the CDTI and on the rules and separation criteria in effect.

Based on previously transmitted information and knowledge of the local traffic and weather, the AMM will select and assign a sequence number in the arrival/departure queue for the arriving aircraft. In addition to this sequence number, the module will assign an arrival window for the approved IAF, and transmit this information to the arriving aircraft via data-link. Like the module at the departure airport, the sequence number and arrival window will be calculated based on differentials in aircraft performance, time and distance from the arrival fix, winds, other traffic, as well as wake and turbulence requirements. In addition to aiding the pilot in his self-separation responsibilities, and providing for a smooth flow of traffic, *the receipt of and compliance to a sequence number and arrival window is required* to begin an instrument approach. Displays onboard the HVO aircraft will aid the pilot, by helping him comply with his assigned sequence.

With state of the art displays showing both navigational information, and the relative position of other traffic, the pilot easily flies from the arrival fix to his assigned IAF, avoiding other traffic, and arriving during his approved window. Arriving in this approved window makes the task of self-separation a relatively easy task during this critical phase of flight. After arriving at the IAF, he flies an approved instrument approach to the active runway and lands. Once off the runway, an automated message is data-linked to the arrival airport management module, which closes his flight plan.

In a case where the arriving aircraft was forced to execute a missed approach, the pilot flies the published missed approach procedure to a specified fix contained within the HVO FOA. While holding at this fix, the pilot continues to self-separate. The pilot transmits a message to the airport AMM, requesting a new sequence number and arrival window. Once this message is received and processed, the AMM data-links both the new sequence and arrival window, which restarts arrival sequence.

Mixed-Equipage

Up to this point in the discussion of the concept of operations it has been assumed all aircraft have some minimum equipment allowing these "HVO operations." Additionally, these operations are confined to within specially designated HVO control zones. Within an HVO FOA, HVO equipped aircraft have the ability to self-separate in IMC. This capability is enabled in part because pilots of HVO equipped aircraft have position information on other HVO aircraft in the area. They have the ability to provide separation between themselves and the other HVO aircraft with the use of their specialized equipment. However, not all aircraft flying into non-towered, non-radar airport environments will be equipped for HVO operations by 2010, so the issue of mixed equipage must be addressed.

The primary issue regarding traditionally equipped IFR aircraft operating in an HVO airport environment is the lack of surveillance of these aircraft by ATC and/or other aircraft (HVO and non-HVO), and the necessity of providing separation *assurance* between all aircraft in the airport environment in IMC. Although HVO aircraft will be able to separate themselves from each other, without proper procedures and possibly additional equipment, HVO aircraft will not be able to separate themselves from unequipped aircraft and vice-versa. In today's environment, for IFR operations in IMC at these types of airports, separation assurance is provided through a set of procedures that generally restrict operations to only one aircraft at a time in the airport environment.

While this is safe, it is not always very efficient. The HVO concept of operations that allows for multiple aircraft operating the airport area would generally be more efficient than today's system, but is only feasible when all aircraft are either HVO equipped or have a way to "see and avoid" each other as they inter-operate using different procedures.

Therefore, this concept of operations assumes that there will be two different sets of operations that can occur at an airport in IMC– HVO operations or today's procedural separation operations. While the airport can handle either type of operations at any time, these two different methods of separation assurance provision will not occur simultaneously. When there are HVO aircraft operating in the HVO FOA, HVO operations are in effect and traditional IFR operations are not permitted. When procedural separation is in effect, HVO operations are not permitted and all other aircraft must be excluded from the HVO FOA ("sterilization" of the airspace). The type of operation that occurs at the airport is dependent on the service requested by the pilot as the pilot approaches the HVO FOA.

When an aircraft approaches the HVO FOA, the AMM is notified of the aircraft's intent to land or transition the HVO FOA and the type of operation desired. If the aircraft approaching the airport is HVO equipped and desires HVO operations, sequencing

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commensurate with HVO operations is provided and no traditional IFR operations are allowed. This works if there is one HVO aircraft operating in the HVO FOA or multiple HVO aircraft operating in the HVO FOA. It is essentially the concept of operations described earlier. If, however, a non-HVO equipped aircraft approaches the airport, the pilot notifies ATC of his desire to land at that airport. This information is relayed from the controller to the AMM and the AMM incorporates this request into its departure/arrival queue. Once all HVO aircraft have landed or cleared the zone, the traditionally equipped aircraft is permitted into the HVO FOA. All other aircraft (either traditionally equipped IFR aircraft or HVO aircraft) are kept out of the zone. Once the aircraft has landed and notified ATC, the HVO FOA considered clear and other use requests, either a traditional or HVO operations, can be processed.

Non-Normal Operations

Some examples of non-normal operations might include the following:

Systems failures, loss of:

Communications

Navigation

Surveillance—Loss of ADS-B, TIS-B signals if used

Weather Information

Displays—If pilot loses CDTI and longitudinal separation guidance information or display

Automation—Automated warning in airport surveillance automation system alerts all aircraft and controller

In the case of any of the above circumstances, procedures and technologies would be in place to allow for a graceful degradation to safely transition to less than HVO allowed levels of operation.

Rare-Normal Operations

Some examples of Rare-Normal Operations are:

Wind shear

Pilot errors:

A pilot/aircraft fails to maintain separation distance and/or violates his Arrival Window during operations. Once again, procedures and technologies would be in place to allow for a graceful degradation to safely transition to other than standard HVO procedures.

For example, if an aircraft were too early for an assigned Arrival Window but continued on their approach, the aircraft on which they were encroaching would be able to see this and take appropriate action if necessary for safety. Similarly, if an aircraft was late for their arrival window yet chose to continue the approach, then the following aircraft, would be responsible for maintaining appropriate separation distance, as right of way rules dictate that the aircraft lower on the approach has priority. However, the aircraft in violation of its clearance window may have to address this incompliance, just as with non-compliance with an ATC clearance in traditional positive control.

Once on published approach, as today, a guidance deviation in excess of full scale requires execution of a missed approach procedure.

Rules of the road would be in place to assure the safety of other than normal operations.

Controller errors:

Procedures very much like the established procedures would be in place

Hazardous weather:

Hazardous weather (thunderstorms or icing conditions in excess of aircraft certification levels) on the approach profile may require deviations or missed approaches. Hazardous weather graphics are available via data-link to the airplane and could be displayed in the cockpit. Pilot would be responsible for deviations and their compliance with Terminal approach procedure guidelines (TERPS), and for maintaining separation from traffic during deviation.

HVO Airspace Configurations Studied

As previously stated, under IMC conditions, aircraft operating into un-towered airports having no radar separation services are assured appropriate separation via procedural separation operations by ATC. This simply means one IFR aircraft is allowed to proceed into the airspace surrounding an un-towered airport, execute the published approach and either closeout the IFR flight plan after landing or otherwise report clear of the airspace prior to another aircraft proceeding into the area. One of the rudimentary ideas being pursued within the Higher Volume Operations concept is that of providing a capability for self-separation operations between multiple "SATS capable" aircraft operating within defined airspace under all weather conditions. This operational capability would be available within a newly defined airspace – the HVO Flight Operations Area.

In the current analyses, the HVO airspace configuration generally follows FAA established guidelines for airspace design and configuration. In accordance with the currently expected modes of operation for SATS capable aircraft, the HVO airspace configuration is, in essence, an adjunct to the established Terminal Arrival Area (TAA) airspace. (Fig. 1)
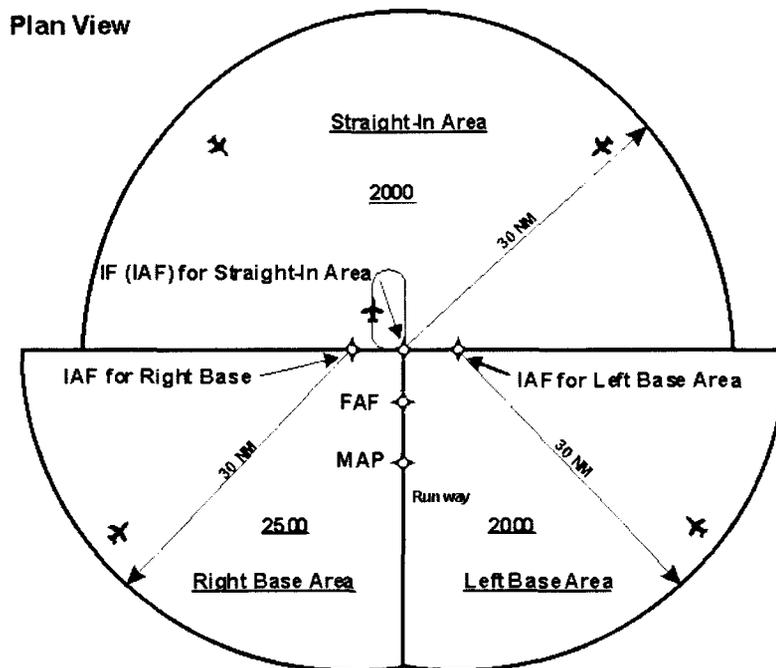
Terminal Arrival Area (TAA)

Figure 1

The objective of the TAA is to provide a seamless transition from the enroute flight structure to the terminal environment for arriving aircraft equipped with flight management system (FMS) and/or Global Positioning system (GPS) navigational equipment. The TAA provides a very efficient method for routing air traffic into the terminal environment with little required air traffic control interface, and with minimal altitudes depicted that provide standard obstacle clearances

compatible with the approach procedure(s) available for use. The first-order configurations for the HVO airspace have ranged from a simple cylindrical shape to those of a more complicated design. One of the primary analysis goals in this series is confirmation of the basic assumption that the HVO Flight Operations Area is indeed operationally feasible. Toward that end, the HVO airspace in this analysis was limited to a circumscribed area in the following diameters: 20nm, 24nm, 30nm, 40nm, and 60nm. Alternative designs will be evaluated in subsequent studies. HVO airspace heights ranged from 3000 to 6000 feet above ground level (AGL) measured in 1000 foot increments. (Fig. 2)

Conforming to the ideal of using current FAA established procedures where appropriate; the "Basic T" approach is used as the standard approach path design for the TAA airspace configuration. (Fig. 2) The standard TAA contains three areas defined by the Basic T approach segment centerline extensions. The arc boundaries of each area are equivalent in function to a feeder fix. When crossing the boundary inbound or when released by ATC within the area, an aircraft is expected to proceed directly to the Initial Approach Fix (IAF) – ideally the closest IAF in range to its current position. It is currently envisioned that the HVO airspace boundary will likely define a smaller circumferential area and thus be contained within the TAA boundary and therefore will by default, be used in the same capacity.
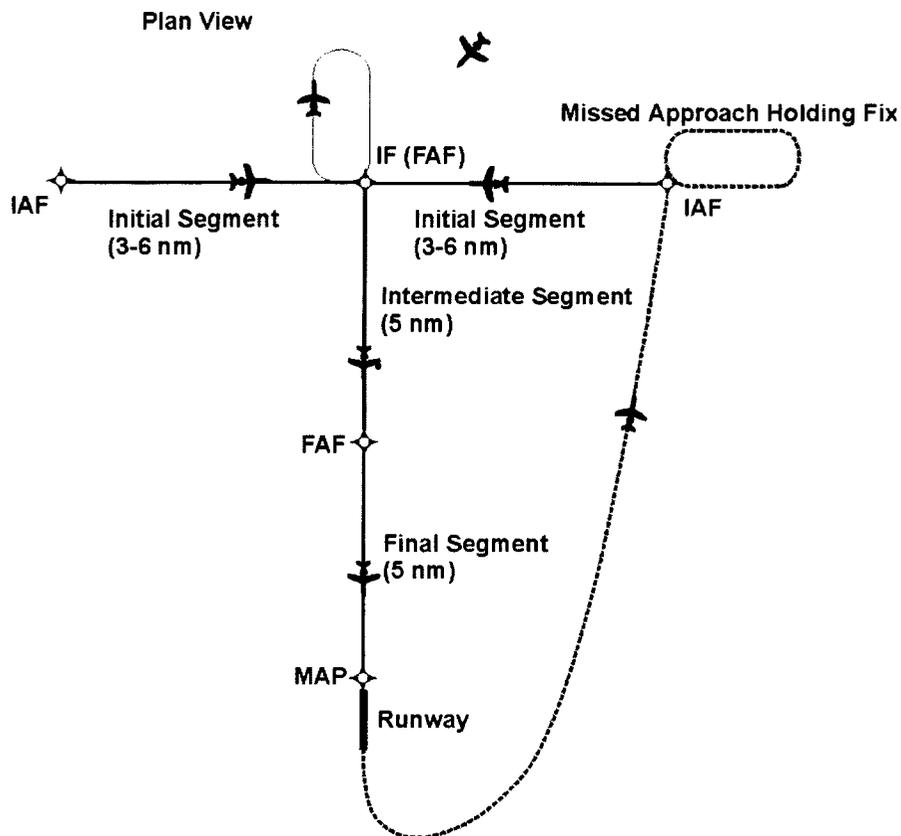
Typical "T" Approach Path

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Figure 2

In order to provide an HVO airspace area that could supply the highest level of safety and maximum maneuverability, determining the optimum location of the HVO FOA within the TAA boundary is of paramount importance. Three airspace alignments were studied in this initial analysis; a cylindrical airspace centered at the initial approach fix (IAF), a cylindrical airspace centered at the final approach fix (FAF), and a cylindrical airspace centered at the approach runway threshold. Figure 3 displays the second listed option.
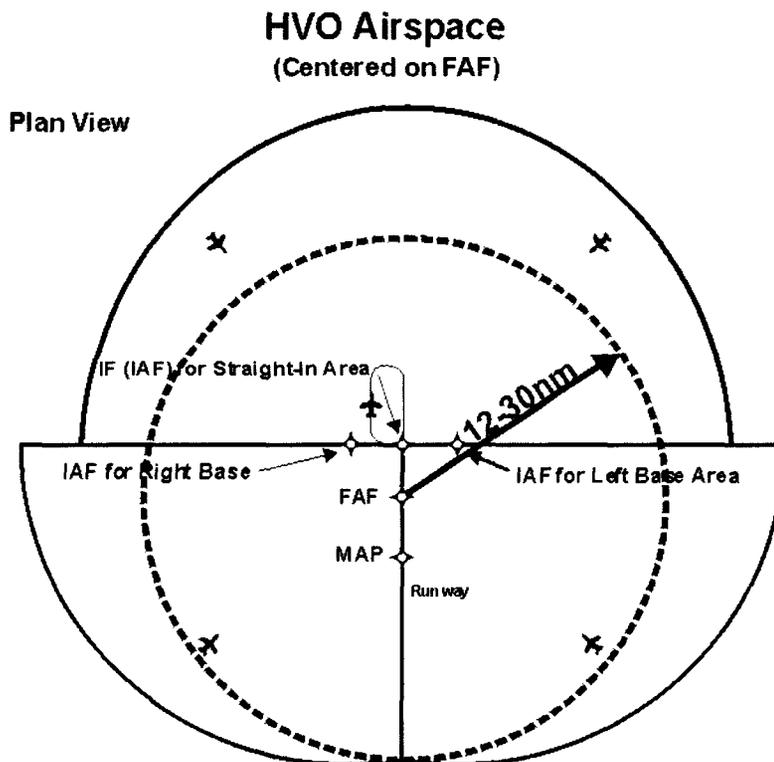
HVO Airspace
(Centered on FAF)

Plan View

IF (IAF) for Straight-In Area

IAF for Right Base

IAF for Left Base Area

FAF

MAP

Runway

12.30nm

Figure 3

Rather than attempt to model a "sterile" HVO FOA, it was determined early in the analysis process to overlay an HVO area at an existing airport taking into account all of the currently existing airspace structures at the candidate facility and the potential influences. In accord with the Langley Airborne Systems Competency group and their concept development efforts, Melfa/Accomack County Airport, Virginia (MFV) is the model airport for all of the initial simulation scenarios. MFV is a small general aviation airport with a single 5000-foot runway capable of supporting "SATS aircraft" and their attendant operations. Located on the outer peninsula of the Chesapeake Bay area of Virginia, it lies approximately 60 miles northeast of Norfolk International Airport and is a good example of an un-towered, non-positive controlled GA airport. MFV is a valid candidate model for the HVO concept simulations as it has a published RNAV approach to Runway 3 (using the "Basic T" approach path) and is within close range of a network of established airways servicing the mid-Atlantic coastal areas of the US. It also has several Restricted Airspace areas (RA), Military Operations Areas (MOA), and a number of general and military aviation facilities in close proximity. The MFV airport proper

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lies just outside of Norfolk TRACON (ORF) airspace however the initial and intermediate segments of the approach path are within the ORF TRACON boundary. Figure 4 shows the MFV facility (including the HVO FOA) and its surrounding airspace as depicted in the current series of simulations.

MELFA/ACCOMACK COUNTY AIRPORT (MFV)
HVO Airspace

Figure 4

ENROUTE OPERATIONS CONCEPT[2]

During IMC and under radar coverage, en route operations conform to air traffic control guidance, rules and procedures. Separation will be maintained by ATC. SATS aircraft will operate and interface with ATC in the same manner as every other IFR aircraft. This includes the capability to fly direct-to (free flight) routes or to conform to standard airway routes. Navigation via GPS WAAS is anticipated to provide the necessary accuracy, reliability, and availability of service. During VMC, SATS aircraft will comply with the existing procedures for see-and-avoid to maintain separation from other traffic.

With enabling sensors and algorithms, SATS aircraft will monitor other transponder-equipped aircraft positions on a situation display and have the capability to automatically resolve conflicts and maintain separation with other aircraft, weather obstacles, airspace boundaries, terrain, and man-made obstructions. SATS aircraft will have the capability to automatically data link their updated positions in-flight to ATC in order to update their flight plans, and to predict traffic flow density and impact on adjacent sectors and terminal areas. Such real-time information will facilitate greater accuracy in optimizing terminal airspace and en route traffic flows. SATS aircraft will have the capability to relay position and flight plan information to ATC from other SATS aircraft transitioning to radar coverage and controlled airspace (airborne internet mode).

Real-time weather information gathered from on-board SATS aircraft sensors will relay environmental data to the NWS for a more accurate NAS weather composite. SATS aircraft traversing en route over a general aviation airport with a data link transceiver and a digital interface to the NAS-wide Information Center (NIS) will be able to send and receive updated flight plans, PIS, TIS and CIS information for destination and alternate airports. This service should encourage free- flight operations among general aviation airports catering to SATS aircraft, thereby reducing disruptions to NAS traffic flow in more congested terminal areas and airspace sectors. It is expected that many general aviation airports, particularly along the east coast, will accommodate traffic that operates adjacent to existing sectors and TRACONs. The NIS will be better able to calculate traffic flow projections and dynamic traffic density for sectors and TRACONs by having up-to-date traffic positions and flight plans of SATS aircraft via these general aviation airport digital interfaces to the NIS.

In addition, an advanced processor and network system on the SATS aircraft will blend all static and dynamic information pertaining to aircraft system's health and status. A special computer performs knowledge-based intelligent processing to oversee A TC instructions and pilot conformance to flight path and flight plan, as well as collaborate directly with ATC and other SATS aircraft via digital data link.

Mixed Equipage Operations

During VMC, standard see-and-avoid flight rules will be followed for traffic separation assurance. During IMC, SATS vehicles will receive ADS-B position and intent information and Mode-C transponder position information through enabling technology sensors and algorithms. The Mode-C yields much less accurate position information, but will nonetheless alert the pilot of traffic and provide general bearing, altitude, and range information. Position, orientation, and path of traffic will appear on a traffic situation display in the cockpit. Resolution of data will depend on the source and will be so noted on the display.

[2] Section Ref: **Small Aircraft Transportation System Program**, 2010 Concepts of Operations Document, NASA, July 2002

Separation assurance algorithms will calculate separation zones based on the target and source of its position data. Less resolvable position targets will result in larger separation distances. Collaborated results of detected Mode-C aircraft by multiple SATS aircraft via data link may improve resolution of position information that can be shared by all SATS aircraft in the airspace.

When not under radar-controlled airspace, self-separation will be provided by the SATS aircraft's algorithms; however, any deviation from ATC instructions will be reported to ATC. While under ATC radar control, the SATS aircraft self-separation algorithms will provide an added margin of safety; however, the SATS aircraft will conform to ATC separation instructions unless an ATC human error is encountered.

The on-board SATS computer will monitor dynamic and static aircraft systems to continuously assess aircraft health parameters. With predictive algorithms, some aircraft system failures can be averted through timely maintenance actions or by modifying the use of aircraft systems while in flight. The potential for encountering in-flight emergencies due to system failures may be significantly reduced in this manner.

Non-Normal Operations

SATS aircraft will conform to standard flight rules and procedures for in-flight emergencies and CNS avionics failures. During en route operations, ATC will provide direct assistance if voice communication is functional. ATC may use data link communication for guidance and instructions if only voice communication has failed. A TC will be able to monitor Mode-S transponders of SATS aircraft for position and ensure safe separation from other aircraft.

The on-board SATS computer will monitor dynamic and static aircraft systems to continuously assess aircraft health parameters. With predictive algorithms, some aircraft system failures can be averted through timely maintenance actions or by modifying the use of aircraft systems while in flight. The potential for encountering in-flight emergencies due to system failures may be significantly reduced in this manner.

Rare-Normal Operations

SATS aircraft will have data link access to digital weather information and forecasts. In addition, SATS aircraft will collect weather sensor data in flight and distribute the data to the NWS. Adverse weather objects in the enroute environment will be observable both in the cockpit and by ATC. ATC will be responsible for separation from known weather phenomena. Sensors on the SATS aircraft will also observe lightning strike incidents in localized severe weather cells that may not be observable by ATC. Convective weather at lower enroute altitudes may be detected by AWOS at general aviation airports and reported to NWS to create weather composites. Higher altitude clear air turbulence (CAT) will be more difficult to detect in advance, but SATS aircraft encountering CAT will automatically report incidents of turbulence to the NWS and ATC.

ATC guidance instructions for separation from other traffic, weather obstacles, terrain, man-made obstructions, and airspace boundaries will be automatically input into the SATS aircraft flight management system. Monitoring of ATC instructions with on-board sensors and databases

will confirm separation assurance and thereby reduce the potential for ATC human errors to propagate into incidents or accidents. During VMC, the pilot will still be required to have situational awareness through see-and-avoid flight rules.
SATS aircraft enhanced vision sensors will improve the pilot's ability to locate non-transponding aircraft when outside of primary radar coverage in VMC ATC controlled airspace.

Similarly, the on-board SATS computers will monitor pilot flight performance in regard to conformance to flight path, altitude and separation from system-identified obstructions including airspace boundaries, other traffic, and weather. The SATS computer in anticipation of flight plan maneuvers will automatically generate checklists. Certain actions will be performed by the computer to relieve cockpit workload, such as checking destination weather for the future ETA, identifying other alternate airports with acceptable minima, and modifying flight plans for review and submission by the pilot. Another example may include checking the status of special use airspace for a more direct route and modifying the flight plan appropriately. These capabilities will serve to assess pilot flight performance (to increase separation area buffer as a consequence of fatigue or aircraft handling difficulty, but not for reporting to ATC), anticipate next-step actions, perform redundant duties, and thereby reduce the potential for pilot-induced errors.

ENROUTE OPERATIONS STUDIED

For purposes of this initial analysis series, the scope of enroute operations studied was narrowed to that portion of the enroute environment that directly feeds into the arrival stream into the SATS HVO airspace. The flight scenarios built for simulation used all of the various flight navigation modes normally occurring within the current NAS.

The airspace surrounding the Melfa/Accomack County Airport is serviced via several victor airways and jet routes. Additionally, there are numerous GPS waypoints available for use in approach and entry into the MFV TAA for aircraft navigating via GPS. These routes also serve the previously noted Restricted Areas (RA), Military Operations Areas (MOA) and the Norfolk Approach Control (ORF) airspace areas adjacent to the MFV TAA.

A matrix showing relevant information about the simulated aircraft and their flight modes is shown in Figure 5 and described in the **Analysis Methodologies** section.

ANALYSIS TOOLS

Recently, the Systems Analysis Branch embarked on an aggressive program of acquiring numerous computer-based simulations and modeling systems. SAB now has a well-balanced suite of tools available for performing analytical studies at varying levels of fidelity. This tool suite includes a series of mathematical methods models and several airport/airspace simulation systems. One of the primary simulation systems being used is the Reorganized ATC Mathematical Simulator (RAMS Plus©) simulation system. Although a relative unknown system in the US, RAMS Plus© has a broad and well-developed user base in Europe and has acquired a strong succession of validation through the work of EuroControl and its member agencies. It is well suited for airport/airspace centric studies and the results and recommendations presented in this report are largely based on results obtained with the RAMS Plus© system.

RAMS PLUS© SYSTEM DESCRIPTION[3]

RAMS Plus© is a fast-time discrete-event simulation software package providing functionality for the study and analysis of airspace structures, Air Traffic Control systems and future Air Traffic Management (ATM) concepts. The objective of RAMS Plus© is to model a wide range of ATC concepts, producing analytical results in a short period of time, allowing more time for comparative analysis while reducing the time for data preparation. The results of this simulation modeling offer insights to ATM planning and organizational proposals, from high-level macro-views to in-depth micro-view scenarios. RAMS Plus© features include an integrated editor and display tool, rapid data development, real and stochastic traffic generation, 4D flight profile calculation, 4D sectorization, 4D spatial conflict detection, AI rulebase conflict resolution, 4D resolution maneuvering, workload assignment and monitoring, airport runway queuing, aircraft holdstacks, airspace routing, free-flight and RVSM zones, and graphic animation.

The model is capable of simulating a wide range of ATM functions, which can be applied to carry out studies from a variety of different viewpoints.

Route Planning: Traffic display and edit facilities, coupled with conflict detection mechanisms allow high level route planning "top-down" ATC simulations.

Re-sectorization: Graphical sector manipulation facilities offer a simple and effective manner to investigations of the effect of re-sectorization/route re-organization on airspace.

Free-Flight Routing: Graphical dragging of navigation aids offers a simple and fast method to re-route all flights using the navigation aid, thus simulating re-routing and free-flight routing.

Future Capacity: Actual and forecast traffic samples of varying density and composition may be generated to study the effectiveness of the proposed ATC refinements on the future capacity of the ATC system.

High-Density Conflict Areas: The spatial conflict detection functionality can be used to determine macro-level areas that contain a high-density of separation conflicts.

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[3] Section Ref: **RAMS Plus© User Manual & Data Manual**, Version 4.07, ISA Software, December 2002

Conflict Resolution: Rulebased conflict resolution system allows each type of control area to be effectively and accurately modeled without the need for extensive re-engineering of the simulation software (e.g., Tower, TMA, Enroute, Planning, Oceanic, Flow Management etc.).
Sector Workload: Sector working positions may be varied, to study the variation and distribution of workload given different tasks to perform (e.g. executive [tactical] and planning [support] control positions, coordinator positions, assistant and flight data positions, multi / single sector working practices etc.).
Future ATC Procedures: Future aspects of ATC procedures may be investigated (e.g. RVSM, Direct routing, ADS-B, FMS type Air/Ground communication etc.) by modeling the theoretical behavior of the new system and studying the effects on other aspects of the ATM environment.

By carrying out comparative analyses between different simulated scenarios the effects of proposed changes can be expressed in terms of:

>   Distribution of workload over centers, sectors, and individual control positions,

>   Traffic loads within each sector/center overall and per route, level band, point, classified according to cruise, climb and descent,

>   Penalties imposed upon traffic resulting from imposing ATFM measures, flight level changes, enroute/ground delays, and arrival holding.

Although RAMS Plus provides an extensive list of output data, the scenarios reported herein are purposefully limited in nature to narrowly define the analysis and establish a starting point for further concept development and subsequent analysis.

ANALYSIS METHODOLOGY

As stated, this series of analysis represents an *initial evaluation* of the operational feasibility of the HVO and ERO concepts of the SATS program. It is not intended to represent all of the analysis necessary to establish the HVO and ERO concepts as definitively feasible – it is a first step in that direction. In that light, it is important to first establish that the basic components of the system can fulfill the necessary requirements in support of the over-lying structure of the system total. The scenarios built for this analysis reflect this ideal in that they are somewhat simplistic by design but are discrete enough to allow identification of potential failure points within the current concept parameters.

The analysis was designed as a multi-iterative series of simulations. It has been posited by numerical analyses that the HVO concept could improve air traffic throughput at non-towered un-controlled airports; therefore, the metrics of value for this analysis were designed to be more of a qualitative rather than quantitative nature. No baseline scenario outside of a strict separation standard value proved useful as a measure against which subsequent comparisons could be made. This analysis was better served by an open-ended approach to study the base-level mechanics of the system with some degree of fidelity. The input matrices include key elements derived from the current operations at a GA airport like MFV with the addition of the base system components identified in the HVO concept of operations. An introduction of variance was necessary to capture the measurable changes created by the design alternatives inherent within the concept. The matrices are listed in a following section.

Operational Assumptions

Another necessary undertaking is the development of a set of base assumptions necessary to establish a core environment within which the analysis is performed. Development of the inputs is tied directly to the assumptions made. For purposes of this analysis, the assumptions are simple and hard-coded so no undue influence is rendered into the simulation scenarios. The basic assumptions list follows:

1) All aircraft perform according to their optimum performance characteristics.
2) All arriving aircraft utilize the published RNAV Runway 3 Approach to MFV. *Note: No procedure turns are required for this approach.*
3) All departing aircraft use Runway 3 and leave the HVO airspace (no local pattern work).
4) All aircraft enter the scenario either as a departure from a simulation-modeled airport or established on an approved inbound flight plan and route.
5) All aircraft fly their assigned routes of flight with no variance due to equipment failure, pilot mistakes, or weather diversions.
6) There are no communications failures or delays.
7) Weather conditions are IMC for all scenarios.
8) Current ATC separation standards are maintained throughout all airspace not defined as HVO airspace. In HVO airspace, a static 5nm lateral and longitudinal separation standard is in effect for all aircraft.
9) Aircraft are metered into the arrival environment for MFV per FAA standards and operating practices.

10) The HVO airspace is "active" for every scenario – no ATC controlled aircraft enter the HVO FOA.

Additional Scenario Settings

Several other settings were standardized across each scenario run. For example, three traffic schedules were developed; two being randomized and one flight schedule developed using intentionally controlled time entry points to emulate an ATC metered inbound stream to the HVO FOA. All three flight schedules remained constant across all scenario runs. Using the variation in speed versus time, the simulation captured the results of differing aircraft arriving at the HVO boundary at varying times.

RAMS Plus© implements the ATC controller function as an "actor" within the system; applying separation values according to dynamic or statically set values in an assigned rulebase. A single actor was assigned to provide *limited* ATC services within the HVO - emulating the very basic sequencing services that would be provided by the Airport Management Module (AMM) as described in the HVO conops. For purposes of this analysis, the runway-sequencing rule was statically set for this actor to handle all aircraft within the HVO airspace. However, the time at which the actor (AMM) applied the sequencing was altered between three values. Due to a current limitation in the RAMS Plus rulebase, no dynamic sequencing occurs in the simulations; furthermore, the sequencing must be applied either at some identifiable airspace entry point (a boundary or fix) or a specified distance from the runway. Note: this distance is a radial boundary distance from the runway threshold without regard to what flight segment the aircraft is executing. The three sequencing points used for this analysis were: at handoff (HVO entry), at 15 nm from the runway threshold, and at 10 nm from the runway threshold. This does not present a problem in this analysis series but work continues to upgrade the rulebase with more flexible alternatives.

The rulebase for conflict mitigation was dynamically applied based on aircraft position, phase of flight and intent. A standard 5 nm lateral and longitudinal separation value was equally applied to all aircraft in all phases of flight within the HVO.

One aircraft per simulation run was induced to perform a missed approach and forced to re-enter the approach path and require re-sequencing. *None of the simulated flights performed a missed approach based on loss of separation.*

Primary Input Matrices

HVO & ERO Configurations

HVO Diameter	HVO Location	HVO Height	Sequence Points
20nm, 24nm 30nm, 40nm 60nm	IAF, FAF, R/W	3-6000 ft	HVO Entry, 15 nm, 10nm

Aircraft Fleet Mix & Flight Plan Dynamics

Acft Type	# Of Type	ARR/DEP/ENRoute	VICtor/JET/GPS
BE35/36	2	1-ARR, 1-DEP	1-VIC, 1-GPS
TB21	2	2-ARR	2-GPS
BE58	2	1-ARR, 1-DEP	2-VIC
BE200	4	3-ARR, 1-ENR	4-VIC
LR35/55	3	1-ARR, 1-DEP, 1-ENR	3-JET
G3/G4	3	2-ARR, 1-DEP	2-JET, 1-GPS

CONCLUSIONS

Key Findings

An initial analysis of the mechanics of the proposed HVO and ERO operational concepts has identified areas in the concept definition needing further development and analysis and led to the following conclusions:

As currently tested and within the parameters listed below, the HVO Flight Operations Area is a viable concept. This determination is valid for an HVO FOA established at a representative airport like MFV and provided a lengthy list of critical assumptions remains intact. Analysis shows the HVO FOA is feasible if it is at least 30 nm in diameter and preferably centered on the Final Approach Fix. Although in many cases the HVO airspace will be uniquely defined for each SATS capable airport, in this instance, the 30 nm diameter ensures adequate clearance for aircraft entering and maneuvering within the airspace maintaining the established separation standard of 5nm between aircraft and between aircraft and the HVO boundary. It also provides the clearance necessary for the protected airspace designated around any holdstacks located coincidentally with any of the three IAFs configured in the Basic T approach path. This airspace size and location also provides adequate clearance for missed approach aircraft to make the transition from arrival to departure mode successfully while remaining within the HVO airspace boundary, and provide enough maneuvering room to preclude separation violations between aircraft inbound to the IAF and the missed-approach aircraft. Although larger airspace areas were evaluated, no appreciable gain in efficiency or capacity was noted. The smaller diameter footprint has appreciably less intrusiveness on adjacent airspace areas, as does the FAF centric location versus the IAF location.

Note: Operational considerations of the adjacent airspace areas were not evaluated for this report but are scheduled for inclusion in the next analysis series.

With appropriate metering of inbound aircraft, the HVO FOA met the goal of allowing ten aircraft operations per hour with no appreciable delay or capacity constraints. Within the strictures listed above, the HVO airspace simulated for MFV exhibited a throughput of 12 aircraft within an hour and 12 minutes of simulation time incurring no separation violations or holdstack operations. *ATC metering was a strong determinate factor to this flow rate.* This result endured a total of 1 minute 36 seconds delay. This delay was experienced by the singular aircraft executing the missed approach and was mitigated through acceptable speed reductions inbound to the IAF and along the initial and intermediate approach segments prior to the FAF. With randomized inbound flow, the results still affirmed a 10 aircraft per hour throughput rate but departure hold queuing and holdstack use increased appreciably (3x).

To provide the greatest flexibility, separation assurance and operational efficiency, the Airport Management Module must be capable of dynamic sequencing. The differing operational characteristics of the most likely aircraft to be determined "SATS capable" combined with variant operational influences will require a dynamic response mechanism to attain peak efficiency in the HVO FOA operation. Example influences include piloting habits, distance from boundary to IAF, separation assurance maneuvers performed inbound to the IAF, etc. Initial analyses showed that establishing the sequence at the HVO boundary with no subsequent updating induced several questionable instances of holding pattern usage prior to establishment on the approach. Appropriate separation along the approach path and minimal holding was attained when the sequence was firmly established for each aircraft prior to the IAF but inside the HVO boundary. *This will need additional study in subsequent analyses, capturing more fully developed operational procedures to accurately establish and analyze the relevant factors.*

No determination was found for the EnRoute Operations concept. The limited amount of Enroute Operations included in this series of analysis was not extensive enough to provide the data from which any valid conclusions could be drawn.

RECOMMENDATIONS

It is recommended that a continuing series of analyses and simulations be performed with incremental increases in complexity and fidelity. The following recommendations are suggested for continuing concept maturation:

Development of a converging set of operational parameters metered through an active program of system engineering and analysis is strongly recommended. Several fundamental procedures to be used by aircraft using the HVO FOA remain vague and problematic. Establish an initial set of comprehensive operational parameters defining the transition and clearance methodologies for aircraft using the HVO FOA and subject those parameters to analysis. The existing assumption list is too broadly defined to establish a feasible set of influence variables necessary for valid analytic conclusions. *This is a critical issue for this concept analysis.*

Continue the simulation-based analysis of the HVO FOA implementation at MFV with the inclusion of a full air traffic schedule for ORF and the surrounding airports. This will provide a high fidelity measure of the operational relationships and potential constraints extant in the inter-operability of the HVO FOA and adjacent airspace areas. Additionally, impacts of the realignment of approach airspace from the ORF TRACON control authority to the HVO FOA will be captured and evaluated. *This is a critical issue for concept analysis.*

Research additional HVO airspace design alternatives. The MFV airport/airspace complex is one of many GA airport configurations; therefore alternative HVO airspace configurations should be reviewed.

Select other candidate airports with differing airfield/airspace configurations for analysis to apply a broader set of evaluation parameters. Further validation of the feasibility of the HVO FOA concept can be procured through additional analyses of alternative airspace designs.

As concept maturation occurs and technologies are identified for inclusion within the HVO and ERO concepts, introduce them into the analyses matrix for evaluation of applicability and potential benefits. Where benefits appear promising, the concepts should be included in the analysis program.

Monitor other technology development efforts for potential inclusion of those ideas and initiatives into the SATS concept analysis. Establish and maintain a close working relationship with other SATS concept development teams to ensure full utilization of potentially beneficial ideas. There are always new technologies and ideas under development - many may prove beneficial toward attaining the goals and objectives outlined in the SATS program.

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Gary D. Millsaps

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Swales Aerospace
28 Research Drive
Hampton, VA 23666

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13. ABSTRACT (Maximum 200 words)
An analysis was conducted to evaluate the Higher Volume Operations (HVO) and EnRoute Operations (ERO) concepts of the Small Aircraft Transportation System program for feasibility, safety and efficiency. These concepts are two of the four primary operational capabilities being developed for implementation of the SATS program in the National Airspace System (NAS). The simulation engine used for the analysis was the RAMS Plus air traffic simulator developed by ISA Software from a licensed core program developed by EUROControl. RAMS Plus is a fast-time discrete-event simulation software package providing functionality for the study and analysis of airspace structures, Air Traffic Control systems and future Air Traffic Management concepts. This report outlines the results obtained from an initial analysis of the concepts and offers recommendations for further analysis as part of the concept maturation process.

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