Low Visibility Operations/Surface Movement Guidance and Control System (LVO/SMGCS) Chart Usability: An Examination of Flightcrew Position Awareness in Homogeneous 300 ft/75 m RVR Conditions

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13. ABSTRACT (Maximum 200 words)
Two studies were conducted to identify best practices for the design of Low Visibility Operations/Surface Movement Guidance and Control System (LVO/SMGCS) paper charts and flightcrew use of them in extremely low visibility surface conditions. In the Chart Usability study, the researchers gathered information to understand the general usability of LVO/SMGCS charts on flightcrew position awareness. In the Airport Markings study, the researchers evaluated different airport marking designs, which may influence the use of LVO/SMGCS charts under those same conditions. For each study, 24 air transport pilots (twelve flightcrews) with Cat II or III qualifications performed taxi scenarios in a simulation of Memphis International Airport at runway visual range (RVR) 300 ft/75 m at night. The RVR and night-time conditions were chosen to represent worst-case conditions for LVO/SMGCS operations. In some scenarios, flightcrews were given difficult air traffic control (ATC) clearances that contained appropriate clearance instructions but did not necessarily follow strict ATC clearance protocol. The study was particularly interested in examining the accuracy of flightcrew actions under these conditions while using LVO/SMGCS taxi charts. The results of these studies showed that, under extreme low-visibility conditions, an 8.5 x 11 inch (21.59 x 27.94 cm) black-and-white paper LVO/SMGCS chart was sufficient for flightcrews to maintain position awareness. Additionally, flightcrews generally responded to air traffic control instructions properly and reported their locations correctly. The detailed results of the studies were used to generate a list of recommended best practices for LVO/SMGCS charts and airport markings.

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Low Visibility Operations; LVO; Surface Movement Guidance and Control System; SMGCS; Paper charts; Chart usability; Symbology; Airport markings

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
oz	ounces	28.35	grams	g
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
mL	milliliters	0.034	fluid ounces	fl oz
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
g	grams	0.035	ounces	oz
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in^2

***SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)**

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List of Abbreviations

Abbreviation	Term
AC	Advisory Circular
ANOVA	Analysis of Variance
ASDE-X	Airport Surface Detection Equipment – Model X
ATC	Air Traffic Control
ATP	Air Transport Pilot
ATIS	Automatic Terminal Information Service
CAT	Category
CDU	Control Display Unit
CPDLC	Controller-Pilot Data Link Communication
CRM	Crew Resource Management
EFB	Electronic Flight Bag
EICAS	Engine Indication and Crew Alerting System
EFVS	Enhanced Flight Vision System (ICAO/EASA says EVS for credit)
EV	Enhanced Vision
EVS	Enhanced Vision System [a U.S. term for a vision system that is primarily used for situation awareness, but not for operational credit under 14 CFR 91.175(l) and (m)]
FAA	Federal Aviation Administration
FMS	Flight Management System
GPM	Geographic Position Marking
HAT	Height Above Touchdown
HUD	Head-Up Display
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
LVO	Low Visibility Operations
LVO/SMGCS	New U.S. term for the Low Visibility Operations/Surface Movement Guidance and Control System program formally referred to as SMGCS
MCP	Mode Control Panel
NASA	National Aeronautics and Space Administration
NASA-TLX	NASA Task Load Index
ND	Navigation Display
PIC	Pilot in Command
PF	Pilot Flying
PM	Pilot Monitoring
RFD	Research Flight Deck
RVR	Runway Visual Range
SART	Situation Awareness Rating Technique
SMGCS	Surface Movement Guidance and Control System
SD	Standard Deviation
SME	Subject-Matter Expert

Executive Summary

This report describes two studies conducted to support the Federal Aviation Administration (FAA) in determining best practices for the design of Low Visibility Operations/Surface Movement Guidance and Control System (LVO/SMGCS) paper charts. These studies also evaluated flightcrew position awareness and actions during extremely low visibility conditions while complying with air traffic control (ATC) clearances of varying complexity. The U.S. Department of Transportation Volpe Center collaborated with the National Aeronautics and Space Administration (NASA) Langley Research Center to conduct this research. The first study focused on LVO/SMGCS chart usability, and the second study examined the design of airport markings, which may influence the content and use of LVO/SMGCS charts. LVO/SMGCS chart usability is ultimately verified by the accuracy of flightcrew position awareness and flightcrew actions in response to ATC clearances in low visibility conditions.

Twenty-four LVO/SMGCS qualified pilots (12 flightcrews) completed 10 taxi scenarios for a total of 120 scenario runs in night-time homogeneous runway visual range (RVR) 300 ft/75 m conditions using a simulation of Memphis International Airport (KMEM). KMEM signage, markings, and lighting, including LVO/SMGCS-specific information elements, were precisely replicated in the simulator with help from an FAA subject-matter expert. The RVR and night-time conditions represented worst-case conditions for current authorized international LVO/SMGCS operations. In Study 1 (Chart Usability), flightcrews completed six taxi scenarios (three departures and three arrivals) using LVO/SMGCS charts from each of three chart providers: two providers' charts were currently in use and one was an FAA prototype. All of the charts for the study were shown on an 8.5 x 11 inch (21.59 x 27.94 cm) page, regardless of their actual size. U.S. chart providers use 5.5 x 8.5 inch (13.97 x 21.59 cm) or 8.5 x 11 inch (21.59 x 27.94 cm) pages, whereas European chart providers use 8.27 x 11.69 inch (21 x 29.69 cm; A4) or 5.83 x 8.27 inch (14.85 x 21 cm; A5) pages. Each chart was used for one departure and one arrival. In Study 2 (Airport Markings), flightcrews completed four departure scenarios using FAA prototype LVO/SMGCS charts. Three of the scenarios were designed to examine differences in the design of airport-surface markings, specifically, the spacing of geographic position markings (GPMs) on the airport surface and the use of "enhanced" GPMs (which were larger than the current GPMs drawn on the airport surface) and "enhanced" taxiway identifiers (surface markings with an arrow pointing in the route direction). The fourth scenario was designed to observe flightcrew actions and situation awareness of other traffic aircraft in an off-nominal condition.

The results indicated that an 8.5 x 11 inch (21.59 x 27.94 cm) black-and-white paper chart was sufficient for flightcrews to maintain positional awareness for LVO/SMGCS operations in extremely low visibility conditions. Flightcrews responded to ATC instructions properly and reported their locations correctly. The results also provided information to generate a list of best practices for the design of LVO/SMGCS paper charts addressing the following:

- *Finding Information.* Flightcrews were of the opinion that information may be difficult to find on LVO/SMGCS charts due to clutter, and that some symbols should be made more prominent (e.g., stop bars and the distinction between active and non-active runways and taxiways).
- *Reading Information.* Flightcrew feedback suggested that information may be difficult to read on LVO/SMGCS charts due to clutter, small size (of text or the chart itself), and low contrast between text and the chart background (e.g., black text on a gray taxiway).
- *LVO/SMGCS Operations and Procedures*. The results of these studies suggested that flightcrews may be unclear about the procedures for ILS hold lines and approach hold lines during LVO/SMGCS conditions. The results also suggested that similar naming conventions for GPMs and taxiway identifiers (e.g., GPM 9M versus taxiway M9) could potentially lead to confusion.

1. Introduction

The Federal Aviation Administration (FAA) is interested in identifying best practices for the design of Low Visibility Operations/Surface Movement Guidance and Control System (LVO/SMGCS) charts and evaluating the actions of LVO/SMGCS flightcrews in homogenous 300 ft/75 m RVR conditions. In support of this effort, the U.S. Department of Transportation's Volpe Center and the National Aeronautics and Space Administration (NASA) Langley Research Center collaborated to collect information regarding the usability of LVO/SMGCS paper charts. The goals of the research were to: (1) gain a better understanding of how pilots use their LVO/SMGCS charts to maneuver safely and efficiently, and (2) examine how changes to standard LVO/SMGCS airport markings might affect pilots' use of those charts on the airport surface to operate in low-visibility conditions.

The present research consisted of two studies conducted in simulated runway visual range (RVR) 300 ft/75 m at night, which represented worst-case scenario conditions for current internationally authorized LVO/SMGCS operations. These are the first studies sponsored by the FAA to examine flightcrew actions and use of paper charts in such conditions. The purpose of the Chart Usability study was to gather data on the usability of LVO/SMGCS charts to identify general human factors considerations and to understand flightcrew position awareness and compliance with air traffic control (ATC) clearances when using those charts. The purpose was not to compare performance across charts but rather to observe pilots using a variety of charts so that common human factors issues could be identified and understood. The Airport Markings study investigated the effect of variations in the spacing, size, and shape of geographic position markings (GPMs) and extra surface-painted taxiway identifiers on flightcrews' use of LVO/SMGCS charts.

These studies were conducted in a motion simulator replicating operations at Memphis International Airport (KMEM). The NASA Langley research team, with help from an FAA KMEM subject-matter expert (SME), designed the airport simulation to be a reproduction of the signage and markings at KMEM. In support of that effort, a joint NASA Langley and FAA team traveled to Memphis and filmed all the taxiways to get the simulator visuals as accurate as possible representing the KMEM surfaces, markings, and lighting as they were in 2010. Additionally, the luminance and color of the airport/pavement lights in the simulation was adjusted to be representative in appearance to the actual out-the-window view. The airport simulation was generated using source data from March 21, 2007, which was then corrected and updated with video information collected by the FAA and the NASA Langley team at KMEM in 2010. The simulation was conducted with simulator motion so that the motion cueing might help pilots to maintain taxi speeds that are typical of real-world operations (see Williams, Hooey, and Foyle, 2006).

Despite all efforts to accurately replicate the out-the-window conditions in the simulator, there are some limitations that should be noted as these were still simulation studies, not operational ones. First, some of the simulated taxi scenarios were intentionally designed to be somewhat unrealistic to better investigate specific aspects of the design of LVO/SMGCS charts, LVO procedures, and related flightcrew actions. For example, in some scenarios flightcrews were intentionally given long taxi instructions with several turns. That approach enabled the team to examine flightcrew responses and possible confusion when presented with complex instructions involving similar-sounding taxiway and GPM names such as

Mike 9 and 9 Mike. Flightcrews were also routed through areas that were designated as hot spots on the paper charts—areas with a high potential for, or history of, runway incursions. Some routes also included instrument landing system (ILS) hold lines and approach holds to gather information on whether flightcrews understand and correctly follow the procedures for ILS hold lines and approach holds in LVO/SMGCS conditions. It should be noted that the routes and scenarios used in this experiment were briefed to a KMEM Operations Duty Manager and found to be plausible and realistic for operations at that airport.

The realism of the studies was also somewhat constrained by the research flight deck (RFD) simulator used. Specifically, the simulator did not have a designated area for the flightcrew to place their charts which possibly prohibited flightcrews from easily taking notes and recording ATC clearances. This is a standard practice in commercial operations today to ensure disciplined and correct flightcrew actions under extremely variable flight and weather conditions. The LVO/SMGCS charts were bound into separate booklets (by provider) and flightcrews could not remove a chart from the booklet, also not in accordance with some operators' standard flight deck practices and discipline.

Since these studies were conducted within the context of LVO/SMGCS operations at a single airport, KMEM, the results may be limited in their applicability to other airports. The complexity of LVO/SMGCS operations varies from airport to airport due to factors such as runway configurations, taxiway configurations, and traffic levels. Each airport develops an LVO/SMGCS plan that describes operations at that airport and specific LVO/SMGCS procedures/restrictions to mitigate for these factors. Additionally, the design of LVO/SMGCS charts may be specific to an airport (e.g., with different symbols and naming conventions). The point here is that lessons learned specific to KMEM may not apply for airports as complex as Chicago O'Hare (KORD) or John F Kennedy (KJFK). The data gathered in these studies were intended to be an accurate reflection of KMEM operations and may not fully encompass the breadth of all LVO/SMGCS chart features proposed or currently in use. However, the results here are intended to provide an estimation of general chart usability and LVO/SMGCS operations.

This report describes the current research to examine LVO/SMGCS chart usability and airport markings. The methods for this research are described, starting with an overview of the two studies (1: Chart Usability and 2: Airport Markings), followed by a description of the participants, equipment, and research setup used for both studies. The methods section describes the procedures for each study, followed by the objective and subjective data collected from each study. Next the report describes the results of the Chart Usability study and then the Airport Markings study. Lastly, the report provides a summary of the results of the two studies, with recommendations.

2. Method

2.1 Studies Overview

The research described in this report consisted of two studies: the Chart Usability study and the Airport Markings study. In the Chart Usability study, flightcrews completed one departure and one arrival scenario using the LVO/SMGCS charts from each of three chart providers (two providers' charts were currently in use and one was an FAA prototype). The focus was not to compare charts, but rather, to examine chart usability with a variety of LVO/SMGCS charts. The Airport Markings study was completed after the Chart Usability study on the same day. In the Airport Markings study, flightcrews completed four departure scenarios using the FAA prototype LVO/SMGCS charts. The depiction of airport surface markings out-the-window was varied across the scenarios to examine how differences in airport surface markings affected flightcrew actions during LVO/SMGCS operations. The participants, equipment, and research setup was the same for both studies.

2.2 Participants

Twelve flightcrews (24 pilots) participated and were provided with travel reimbursement and a small stipend for their participation. Nineteen of the twenty-four selected pilots had previously conducted operations at KMEM.

Pilots were recruited by a NASA-contracted service provider according to the following set of participant-selection criteria:

- Held an airline-transport pilot (ATP) rating
- Were currently employed by a Part 121, Part 135, or Part 91(k) operator (all flightcrews were Part 121)
- Had glass cockpit experience, with preference given to those with a type rating in the simulated aircraft
- Pilot flying (PF) had at least 100 hours of experience with head-up-display (HUD), Pilot in Command (PIC) operations
- At least three flightcrews were to have had LVO/SMGCS experience, defined as having been a Category (CAT)-III qualified flightcrew member for more than five years. Of the 24 selected pilots, 21 met this requirement.
- Pilots were selected so that participating pilots had a mix of chart experience (ideally 1/3 Jeppesen, 1/3 Lido, and 1/3 FAA) in general . Chart experience was defined by the type of charts being used by the pilots in their present flying position. Note that the FAA does not currently produce LVO/SMGCS charts and no Part 121/135 operators use FAA charting products. Participating pilots who were chosen to represent "FAA chart users" were ones who had

significant FAA charting usage due to their having more than 5 years PIC, instrument-flight-rules rated service in the U.S. military (active duty or reserves) where FAA charting products are used.

- The pilots in this study were also recruited to participate in another study focused on Enhanced Vision System (EVS)/Enhanced Flight Vision Systems (EFVS) operations in an LVO/SMGCS environment (see Arthur, et al., 2013). Therefore, one of the participation criteria—that the PF must have EVS/EFVS experience, either military, general aviation, or commercial—was necessary to the EVS/EFVS study.

Pilots were paired in a flightcrew with another pilot from same employer, whenever possible, in an attempt to minimize inter-flightcrew conflicts in standard operating procedures and crew resource management. Note that pilots did not always take the same position that they would in actual operations (e.g., a Captain could serve as the First Officer/act as the pilot monitoring (PM) in the simulator). However, it should be noted that in simulator training pilots work in both the PF and PM positions throughout their airline career, and are required to be proficient in both seats.

Pilots' self-reported flight hours are summarized in Table 1.

Table 1. Summary of Pilot Flight Hours

Experience	Mean	Median	Range
Years Flying	33.25	34	15-48
Total Flight Hours	13,650	14,000	5,500-27,000
LVO/SMGCS Flight Hours (excluding simulator)	31.61	7.5	0-200 (2 pilots had 0 hours)
LVO/SMGCS Simulator Hours	87.82	35	1-600

Although pilots were selected so that there was an equal number of participants with Jeppesen, Lido, and FAA chart experience, current surface chart (i.e., airport diagram) use may be more representative of pilots' recent chart experience during surface operations. Table 2 summarizes pilots' current surface chart use, determined by the chart provider that pilots indicated they used currently for surface operations in general (i.e., not specific to LVO/SMGCS charts). Note that two pilots are counted twice; two of the pilots who currently used Jeppesen charts also indicated that they used other providers' charts currently (one pilot who also used Lido and one who also used FAA charts currently), but both pilots were more familiar with Jeppesen charts. All other pilots used only one chart provider currently.

Table 2. Summary of Pilots' Current Surface Chart Use

Chart Provider Used Currently	Number of Pilots
Jeppesen	17
Lido	8
FAA	1

2.3 Equipment and Research Setup

2.3.1 NASA Research Flight Deck Simulator

The research was conducted in the NASA Langley Research Center Research Flight Deck (RFD) simulator with motion (Figure 1). The full-motion RFD simulated a state-of-the-art NextGen transport aircraft. The flight deck had hydraulic-actuated sidestick controllers for the flight controls. Approaches and landings were conducted using an autoland/autopilot capability, so flightcrew performance would not be affected if flightcrews were not familiar with the use of sidestick controllers. A collimated out-the-window scene was produced by an Evans and Sutherland Image Generator graphics system, providing approximately 200 degrees horizontal by 40 degrees vertical field-of-view at 26 pixels per degree.

The cab was populated with flight instrumentation and pilot controls, including the overhead subsystem panels, to replicate standard aircraft systems. Surface maneuvering was effected through a standard tiller for the PF (left seat). The RFD was configured to mimic the instrument panel of current state-of-the-art aircraft, with four 10.5 inch (26.67 cm) vertical by 13.25 inch (33.66 cm) horizontal, 1280 x 1024 pixel resolution, color displays tiled across the instrument panel. Also, the RFD included a Mode Control Panel (MCP), Flight Management System (FMS), and Control Display Units (CDU). The simulator was also equipped with an Electronic Flight Bag (EFB), auxiliary displays above and on either side of the glareshield, and a HUD (as shown below in Figure 1), but these were not powered on or used during the studies. Unlike a real flight deck, the RFD did not have a designated area for the flightcrew to place their charts which possibly prohibited flightcrews from easily taking notes and recording ATC clearances.

Figure 1. NASA Langley Research Flight Deck (RFD)

2.3.2 Aircraft Simulation

All scenarios were tailored for a typical mid-weight transport aircraft configuration and center of gravity (arrivals at 180,000 pounds (81,646.63 kg) gross weight and 10,000 pounds (4,535.92 kg) fuel, departures at 200,000 pounds (90,7018.47 kg) gross weight and 30,000 pounds (13,607.77 kg) fuel, with both at 25% center of gravity).

Aircraft performance was in accordance with the nominal NASA Langley simulation model. Uncertainties or errors in weight, center of gravity, and environmental conditions were not modeled. Performance data were provided to the flightcrew at the start of each run to verify required takeoff or landing performance and enable the setting of takeoff or landing reference speeds and aircraft configuration.

2.3.3 Airport Simulation

The studies were conducted using a research simulation of Memphis International Airport (KMEM). A Rockwell-Collins EP-1000 database was used to create the simulation of KMEM, including all airport runways, taxiways, LVO/SMGCS visual aids and markings, prominent airport buildings, obstructions, signs, and airport terrain and cultural features. The database had between 3.28 ft and 9.84 ft (1 and 3 meter) photo imagery with the underlying terrain data using 3 arc-seconds per post spacing resolution. The center of the database was located at the runway 36L threshold and extended to a radius of 243,000 feet/74,066.4 m (~40 nmi/74.08 km).

The KMEM EP-1000 database used to generate the airport simulation reflected source data from March 21, 2007. The information in the database was then updated and corrected with video information of KMEM in 2010. An FAA KMEM ATC subject-matter expert (SME) provided detailed information regarding the airport layout and appearance to ensure that the airport lights and markings were identical to what a pilot would observe out-the-window when taxiing at KMEM. The simulator also used the appropriate database information to emulate the accurate location and appropriate radio frequencies of navigation aids, to coincide with published charts.

One unique aspect of KMEM with respect to LVO/SMGCS operations is their numbering of GPMs. The use of GPMs are only required for Level 2 LVO/SMGCS, which at the time of this research study was for operations below RVR 600 ft/182.88 m. Only five airports in the U.S. have such operations at this time. KMEM uses odd and even numbers depending upon the direction of flow. At KMEM, the applicable GPMs on LVO/SMGCS routes taxiing north to south are odd numbered. When using LVO/SMGCS routes taxiing south to north, the applicable GPMs are even numbered. GPM numbering starts at 1 in the northeast corner of the airport, and increases to the largest number at the southwest corner. Furthermore, the GPM letter to the right of the number corresponds to the taxiway on which the GPM is located. Other airports do not use these same numbering conventions; in fact, there is no standard convention for numbering GPMs.[1]

[1] FAA AC 150/5340-1K provides guidance on GPM use and numbering. For example, GPMs must be in sequence. Taxiway letters after the number are optional.

2.3.4 Head and Eye Tracking Equipment

A ten-camera SmartEye Pro 9.0 oculometer system was installed in the RFD to collect eye tracking and head position data for both members of the flightcrew. Data were available for most scenarios; however head and eye tracking was occasionally disrupted (e.g., by the pilot shifting in his/her seat, when pilots were wearing glasses, etc.). Vector intersections with appropriate portions of the flight deck were used to derive head-up and head-down time for each pilot. The head box for eye tracking was approximately one cubic foot (0.30 cubic meters), centered on each pilot's Design Eye Reference Position. Tracking accuracy was approximately 2.0 degrees for head rotation and eye gaze.

2.3.5 Flight Deck Communication and Audio Effects

Pre-recorded ATC instructions were presented to the flightcrew aurally. A researcher was present in the control room to provide simulated ATC directives and information as needed, and intervene when required (e.g., if the flightcrew had a question regarding a clearance). The control room layout is discussed in detail in the report section 2.3.7. Additional pre-recorded voice communications were presented during each scenario to create "party-line" chatter and to promote realism. Pre-recorded Airport Terminal Information Service (ATIS) messages were also presented (aurally) based on the environmental conditions and airport status (e.g., LVO/SMGCS operations in use) for each scenario.

During flight operations, altitude call-outs were played over the flight deck speakers and included the callouts "approaching minimums" and "minimums" as well as "100," "50," "40," "30," "20," and "10" at the corresponding radar altitudes in feet, which are standard on this model of aircraft. Other flight deck aural cues (e.g., caution and warning tones, engine and airframe noise) were also in effect.

2.3.6 Head Down Flight Deck Displays

Four large form-factor panel displays presented traditional glass displays heads-down; from left to right on the flight deck, these displays were the PF primary flight display (PFD; Figure 2), the PF navigation display (ND) with Engine Indication and Crew Alerting System (EICAS; Figure 3), the PM ND (Figure 4), and the PM PFD (Figure 5). Each panel display (10.5 inch/26.67 cm vertical x 13.25 inch/33.66 cm horizontal), when viewed from 25 inches (63.5 cm), subtended an angular area of 24 degrees (vertical) by 30 degrees (horizontal). The flight deck also included overhead panels, MCP, FMS, and CDU.

Pilots used the auto-land capability for approaches and a tiller for surface maneuvering. Because the RFD was configured for general research purposes, the flight deck displays provided some capabilities that were not applicable or used for these LVO/SMGCS studies. Specifically, Controller-Pilot Datalink Communications (CPDLC) functionality would typically have been displayed on the lower left quadrant of both PFDs. However, because CPDLC was not used in this study, that area of the display was blank (as shown in Figure 2 and Figure 5). Similarly, the PM ND had an enhanced vision (EV) mode, which was not used for these studies.

Figure 2. Pilot Flying (PF) Primary Flight Display (PFD)

Figure 3. Pilot Flying (PF) Navigation Display (ND)

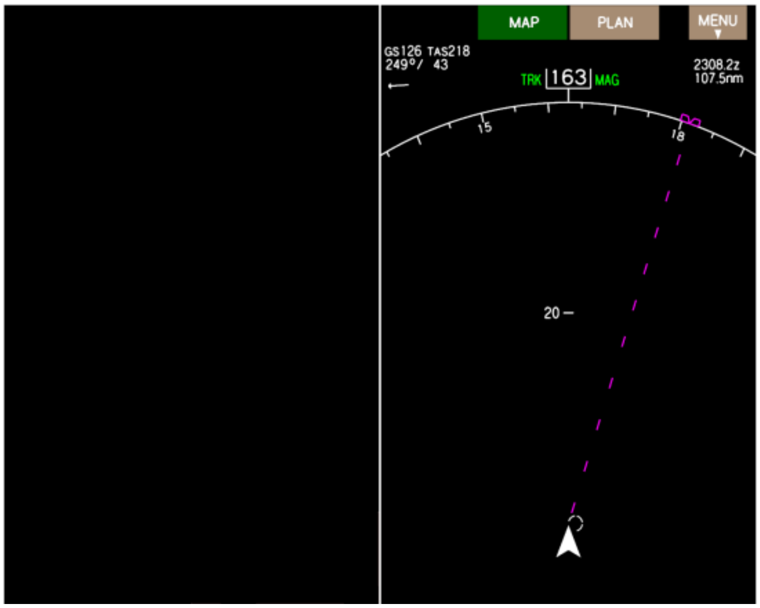


Figure 4. Pilot Monitoring (PM) Navigation Display (ND)

Figure 5. Pilot Monitoring (PM) Primary Flight Display (PFD)

2.3.7 Control Room

NASA Langley and the Volpe Center researchers monitored the research studies from a control room, which was remotely located from the simulator. Activities included loading the research scenarios and providing live ATC communications as needed (e.g., when pilots deviated from the scripted scenarios). The layout of the control room is depicted in Figure 6.

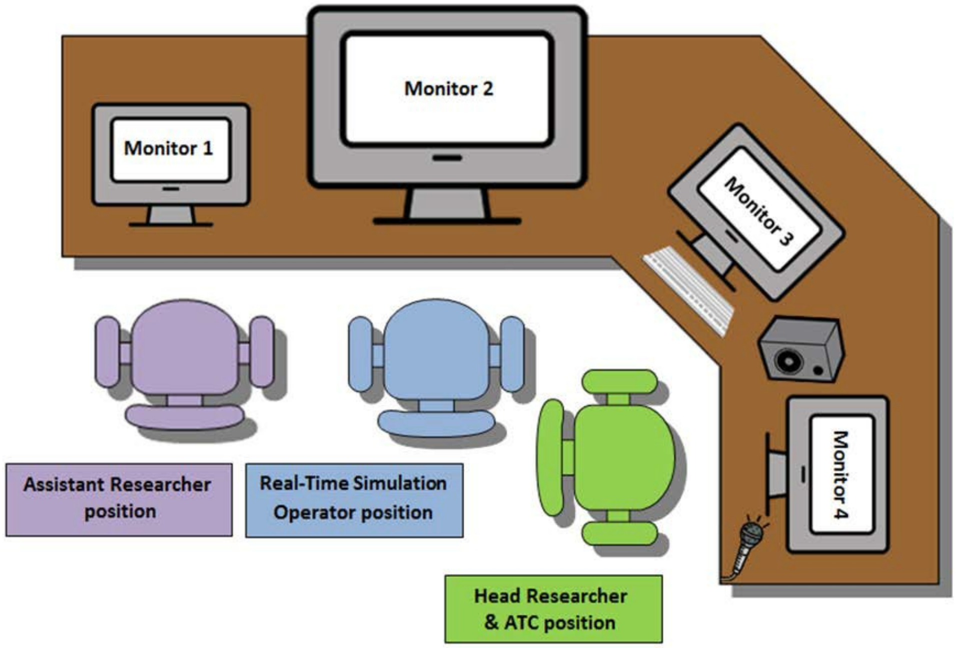


Figure 6. Control Room Layout

Information regarding the simulation was displayed on four computer monitors:

- Monitor 1 showed streaming video of one of two video feeds: (1) motion platform (default video), or (2) the interior of the simulator cab. The video of the simulator cab interior was recorded from behind the flightcrew and showed the two crewmembers and the researcher in the cab.
- Monitor 2 showed streaming video from three video feeds: (1) flight deck displays, (2) out-the-window view, and (3) the interior of the simulator cab (same feed shown on Monitor 1). The flight deck video showed both pilots' PFD and ND, and the HUD. Note that flightcrews were not provided with the HUD on the flight deck.
- Monitor 3 displayed the real-time simulator operator graphical user interface. The simulator operator used this interface to load the scenarios and to put the simulator in and out of motion.
- Monitor 4 provided information to the researchers regarding ownship aircraft's position on the airport surface in real time via a moving map display. Note that flightcrews were not provided with a moving map display on the flight deck.

A separate researcher sat in the simulator jumpseat to ensure the simulator was configured correctly and brief the flightcrew prior to each scenario (see Procedure). During data collection the researcher silently observed and took notes. The researcher also provided the post-scenario questionnaires to the flightcrew in the simulator following each scenario.

2.3.8 LVO/SMGCS Charts

LVO/SMGCS charts from two commercial providers and an FAA prototype chart were shown in this study. It is important to note that the FAA does not produce LVO/SMGCS taxi charts, but has developed the model for a prototype chart for the purpose of the study to evaluate aspects of LVO/SMGCS chart design, including the presentation of lead-in notes, detailed hot spot pages, and ILS and approach hold line depictions on the charts. Appendix A provides an example of the FAA prototype taxi chart and Appendix B provides an example of the lead-in notes and the depiction of the detailed hot spots, which were provided on a separate page from the taxi chart.

All LVO/SMGCS charts presented in these studies were printed on 8.5 x 11 inch (21.59 x 27.94 cm) paper; note however that the commercial chart providers used in this study produce expanded-size LVO/SMGCS charts for some airports if the airport layout requires a larger size to see the details. The charts were printed in the colors intended by the chart provider (two providers' charts were black-and-white/grayscale and one of the providers' charts had color elements). The charts were bound into separate booklets for each provider. Each booklet contained arrival and departure charts, different runway combinations, and LVO/SMGCS taxi charts for different visibility levels. Pilots used all three providers' LVO/SMGCS charts in the Chart Usability study and only the FAA prototype charts in the Airport Markings study.

2.4 Procedure

Participants were recruited for a two-day research project at NASA Langley; one day was dedicated to the LVO/SMGCS studies described in this report, and another day focused on EVS/EFVS research (see Arthur et al., 2013). The day which flightcrews completed the LVO/SMGCS studies was counterbalanced across flightcrews. That is, half of the flightcrews completed the LVO/SMGCS studies on day 1 and the EVS/EFVS study on day 2. The other half of the flightcrews completed the EVS/EFVS study on day 1 and the LVO/SMGCS studies on day 2. A statistical examination of the data indicated that the day on which flightcrews completed the LVO/SMGCS studies had no influence on flightcrew performance.

The schedule of events for the LVO/SMGCS studies is provided in Table 3 and described in the following sections. The Chart Usability study lasted approximately five hours and the Airport Markings study lasted approximately two hours. Participants always completed the LVO/SMGCS chart usability study first.

Table 3. Schedule of Events

Time	Event	Location
0730	Briefing	Pilot Briefing Room
0800	Oculometer Calibration	RFD
0830	Training Scenarios (2)	RFD
0900	Chart Usability (Study 1) Test Scenarios (2)	RFD
1020	Break	
1030	Chart Usability (Study 1) Test Scenarios (2)	RFD
1150	Lunch	NASA Cafeteria
1230	Chart Usability (Study 1) Test Scenarios (2)	RFD

Time	Event	Location
1350	Break	
1400	Airport Markings (Study 2) Test Scenarios (2)	RFD
1520	Break	
1530	Airport Markings (Study 2) Test Scenarios (2)	RFD
1630	Debrief	Pilot Briefing Room

2.4.1 Briefing

As the schedule in Table 3 shows, flightcrews started the day with a briefing about taxi operations, LVO/SMGCS, and low-visibility surface procedures. The briefing also provided a general outline of the studies and general information about the simulation facility, simulated aircraft, simulated airspace, navigation and communications procedures, and procedures unique to the research scenarios. The briefing also included review of the FAA-provided lead-in notes and detailed hot spot pages for KMEM. After the briefing, participants filled out a biographical questionnaire which gathered detailed information about each pilot's flight experience, age, gender, overall flight time in a cross section of aircraft, flight time in the simulated aircraft or comparable aircraft, time spent in the military, experience with LVO/SMGCS, EVS/EFVS experience, and any experience flying into and out of the KMEM. The biographical questionnaire is included as Appendix C. The participants also completed an Informed Consent Form prior to simulator training.

2.4.2 Training Scenarios

After the initial briefing, flightcrews entered the RFD for oculometer calibration and then training, as shown in the schedule in Table 3. Flightcrews completed two training scenarios to familiarize themselves with the simulator and its displays and controls. The training scenarios were intended to provide pilots with the opportunity to work with their new crewmember. The purpose of the training was not to practice LVO/SMGCS procedures.

The training scenarios included one departure and one arrival in an area of KMEM that was not used in any of the research scenarios. The training scenarios were flown in daytime visual meteorological conditions with an RVR greater than 1800 ft/550 m. The training was led by a NASA Langley researcher who was a qualified ATP-rated pilot with commercial and military experience. During the training scenarios, flightcrews used the commercial charts from the provider that they were most familiar with (both crewmembers in each flightcrew were familiar with the same chart providers).

2.4.3 Study 1: Chart Usability

After completing the training scenarios, flightcrews began the Chart Usability study (Study 1). The objective of the Chart Usability study was to identify best practices for the design of LVO/SMGCS charts through observations of pilot interactions with those charts in simulated worst-case scenario LVO/SMGCS conditions (night-time, homogeneous RVR 300 ft/75 m), and to gather data on flightcrew position awareness and compliance with ATC clearances. The researcher emphasized that, at all times, the flightcrew must remain safe; and if they felt unsafe conditions existed, they should immediately execute the necessary precautions, just as if they were carrying passengers in Part 121 operations.

2.4.3.1 Scenarios

Participants performed six taxi scenarios using LVO/SMGCS charts from three different chart providers; one of which was an FAA prototype LVO/SMGCS chart that was not currently in use and was therefore new to all participants. The purpose of this study was not to compare charts but rather to observe and gain a better understanding of flightcrews' use of LVO/SMGCS taxi charts. The scenarios presented to pilots varied in realism in terms of taxi instructions and taxi routes. Some scenarios were intentionally designed to include confusing ATC instructions and taxi routes through complex areas to examine flightcrews' use of LVO/SMGCS taxi charts and understanding of LVO/SMGCS procedures as well as compliance with ATC clearances in worst case situations.

Flightcrews completed one departure scenario and one arrival scenario with each chart provider. Before conducting each scenario, the flightcrew was given a pre-scenario briefing in the simulator cab by the same researcher who conducted the initial briefing and training. The pre-scenario briefing included information regarding the initial aircraft position (and configuration, if airborne); the specific LVO/SMGCS operations in effect (by runway); and the appropriate frequencies for Ground, Tower, and ATIS.

Before beginning the departure scenario, the researcher helped the flightcrew to pre-program route information in the flight management computer and gave the flightcrew the preliminary departure clearance. Departure scenarios began at designated locations away from the departure runway. During the departure scenarios, flightcrews listened to ATIS and contacted ATC Ground for the taxi clearance before starting to taxi. Departure scenarios ended near the departure runway.

Arrival scenarios began 1,000 ft (304.8 m) height above touchdown (HAT) on the ILS path. Before conducting each arrival scenario, the flightcrew ensured that the aircraft was configured for landing and completed the landing checklist, and the researcher provided the flightcrew with a terminal and gate area for parking. The researcher then verified that the simulator configuration was correct and then provided the flightcrew with the charts that they were to use during the scenario. During the arrival scenarios, flightcrews called ATC Tower for the landing clearance. Landings were completed using autoland. When flightcrews exited the runway, they reported their position to ATC Ground and received their taxi clearance. Arrival scenarios ended at specific locations along the cleared route.

During all scenarios (departures and arrivals), ATC asked flightcrews to hold and report their position at specified locations in order to gather data on flightcrews' position awareness. The order of the scenarios and the chart used were counterbalanced across participants to minimize learning/training effects.

2.4.3.2 *Post-Scenario Questionnaires & Interview*

After completing one arrival and one departure scenario with LVO/SMGCS charts from a chart provider, flightcrews completed the following (in order):

1. *Chart Usability Questionnaire.* This paper-based questionnaire collected both crewmembers' feedback concerning the presentation of information on the LVO/SMGCS charts used during the scenarios performed. Pilots were not allowed to look at the charts or discuss their responses with each other while they completed the questionnaire. The questions were intended to be general across all chart providers, with the exception of two questions that specifically addressed features in the design of the FAA prototype LVO/SMGCS chart. The chart usability questionnaire is provided in Appendix D.
2. *Symbol Identification Questionnaire.* This paper-based questionnaire examined the perceived representativeness of a subset of LVO/SMGCS symbol shapes and gathered both crewmembers' opinions on the perceived usefulness of those symbol shapes during taxi operations. The symbol shapes shown on the questionnaire were specific to the LVO/SMGCS chart provider that pilots had just used. For example, after performing two taxi scenarios using the FAA prototype chart, pilots completed the questionnaire containing symbol shapes from the FAA prototype chart. The symbol shapes on the questionnaire were shown without context (i.e., the symbol was shown in isolation). Pilots were asked to write what they thought the symbol represented and provide a rating of usefulness for each symbol. Figure 7 presents a sample question; the full questionnaire is provided in Appendix E. Pilots were not permitted to look at the charts while filling out this questionnaire, and they were asked not to discuss their responses with their crewmember.

Symbol	What does the symbol mean?	Very useful	Somewhat useful	Not useful
27 271°	Identifies runway location	✓		

Figure 7. Example Symbol Identification Question

3. *Workload & Situational Awareness Ratings.* Both crewmembers' perceived workload was measured using the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988), which asked pilots to rate their perceived mental demand, physical demand, temporal demand, performance, effort, and frustration level. The NASA-TLX was shown to pilots on paper, but each pilot responded verbally to the researcher. Pilots were allowed to look at the charts while they answered this questionnaire. Both crewmembers also completed the Situation Awareness Rating Technique (SART), which was used to measure situation awareness (Taylor, 1990).
4. *Interviews.* Once pilots completed the paper questionnaires, a researcher conducted interviews with the flightcrew to gather more feedback regarding their experience taxiing with the LVO/SMGCS charts. The list of questions is provided in Table 4. The interview questions were the same for all chart providers with the exception of two questions which addressed features specific to the FAA prototype LVO/SMGCS chart (see questions 7 and 8 in Table 4). Interviews were conducted with each flightcrew in the simulator cab. The researcher read each interview question out loud to the flightcrew, and the two crewmembers responded in whichever order

they wished. As a consequence of the interview format, pilots' opinions expressed in the interviews may not have been independent from the opinion of their crewmember. In some cases, one crewmember might answer the interview question and the other crewmember would simply agree. When the interview was complete, flightcrews were given a 15 minute break.

The above process was repeated by each crew for the remaining two chart providers.

Table 4. Chart Usability Interview Questions

Interview Questions	
1.	a. Is there any information you would like to add to the chart? For example, is there other information you think should be shown on the chart? If so, why? b. Is there any information you would like to delete from the chart? [If so, what is this information and why would you like to delete it?] c. Were there any symbols that you did not recognize on the chart? If yes, which ones? What did you interpret these symbols to mean? d. Are there any symbols you would like to change? [If yes, what are these symbols and how/why would you like them to change or not be presented?]
2.	What do you consider to be the most effective feature(s) of the LVO/SMGCS chart in supporting your position awareness in low visibility conditions? Why?
3.	Were there any properties of the chart that could potentially reduce safety?
4.	Was the presentation of the information on the LVO/SMGCS chart sufficient for you to find the information you needed? Consider effects of clutter on findability.
5.	Was the presentation of the information on the LVO/SMGCS chart sufficient for you to read the information you needed? Consider size, use of fonts, and color on readability.
6.	Did you have difficulty finding information on the LVO/SMGCS chart? If yes, what information?
7.	Was it helpful to show the ILS hold lines on the LVO/SMGCS chart? The detailed hot spots chart? [FAA chart only]
8.	Do the Memphis charts lead-in notes help or hinder you in getting a better understanding of specific LVO/SMGCS equipage and procedures information for the Memphis LVO/SMGCS taxi charts? [FAA chart only]
9.	Did the main LVO/SMGCS taxi chart legend section help or hinder you in familiarizing yourself with the LVO/SMGCS taxi charts? How?

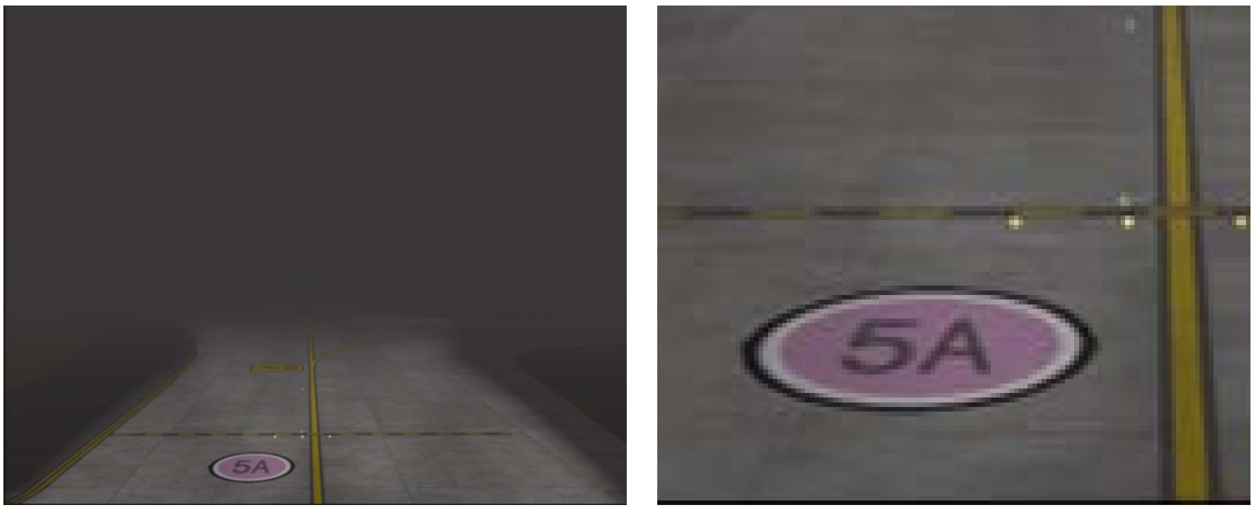
2.4.4 Study 2: Airport Markings

After completing Study 1 (Chart Usability), flightcrews were given a 15 minute break before beginning Study 2 (Airport Markings). The main objective of Study 2 was to examine variations in the design of airport markings, which may influence how flightcrews use LVO/SMGCS charts. The following airport marking characteristics were examined in this study:

- The distance between GPMs, which was examined by observing flightcrew actions during two scenarios that varied in the number of GPMs along approximately 5,000 ft (1,524 m) of taxiway. During one of the scenarios, flightcrews taxied down a stretch of taxiway with no

GPMs for 5,000 ft (1,524 m). During the other scenario, flightcrews taxied down a taxiway with three extra GPMs shown out-the-window and on the charts.

- Enhancements to GPM size and shape were examined by observing flightcrew actions during a scenario which showed “enhanced” GPMs out-the-window and comparing those flightcrew actions to a scenario that showed “traditional” GPMs. An example of an “enhanced” GPM is shown in Figure 8. “Enhanced” GPMs were larger than standard GPMs (18 x 12.5 ft/5.49 x 3.81 m) and were oval; compared to standard 9-ft (2.74 m) circular GPMs. Note that the depiction of GPMs on the charts was not changed to reflect the size and shape of the “enhanced” GPMs.



Simulator View **Enlarged View**

The image on the left shows a flightcrew’s out-the-window view of an “enhanced” geographic position marking (GPM) from the simulator at night in homogeneous RVR 300 ft/75 m conditions. The image on the right shows an enlarged view of the same “enhanced” GPM.

Figure 8. Example of an "Enhanced" Geographic Position Marking (GPM)

- The depiction of surface-painted taxiway identifiers was examined by observing flightcrew actions during a scenario which supplemented taxiway signs with “enhanced” taxiway identifiers on the airport surface. An example of an “enhanced” taxiway identifier is shown in Figure 9. The “enhanced” taxiway identifiers were depicted as a yellow box encompassing the taxiway identifier and an arrow pointing in the direction of the taxiway. Note that the depiction of taxiway identifiers was not changed on the charts; that is, the charts depicted standard taxiway identifiers, not “enhanced” taxiway identifiers.

Simulator View **Enlarged View**

The image on the left shows a flightcrew's out-the-window view of an "enhanced" taxiway marking from the simulator at night in homogeneous RVR 300 ft/75 m conditions. The image on the right shows an enlarged view of the same "enhanced" taxiway marking.

Figure 9. Example of an "Enhanced" Taxiway Marking

2.4.4.1 Scenarios

Participants used FAA prototype LVO/SMGCS charts, bound in a booklet, to complete four departure scenarios at night in homogeneous RVR 300 ft/75 m at KMEM. Before each scenario, the flightcrew received a pre-scenario briefing, similar to those given during Study 1 (Chart Usability), that reviewed initial aircraft position, pertinent instructions about LVO/SMGCS operations in effect, and ATC frequencies. The researcher also helped the flightcrew to pre-program the simulator as needed. The departure scenarios began at designated locations away from the departure runway. Before beginning the scenarios, flightcrews listened to ATIS and contacted ATC Ground for the taxi clearance. During the scenarios, ATC asked flightcrews to hold and report their position at specified locations in order to gather data on flightcrews' position awareness. The scenarios ended near the departure runway.

The order of the scenarios was counterbalanced across flightcrews to minimize the effects of learning. After each scenario, flightcrews completed the NASA-TLX (workload) and SART (situation awareness). According to the schedule in Table 3, flightcrews were given a 15 minute break after the first two scenarios, and then completed the remaining two scenarios.

The first three scenarios were considered "nominal," that is, pilots taxied in accordance with ATC clearance protocols and there were no unexpected events. The fourth scenario was considered "off-nominal" to observe flightcrew actions in LVO/SMGCS conditions when positional cues are absent or incorrect. In this scenario, the flightcrew (in the ownship aircraft) was behind a traffic aircraft on the same route. The flightcrew of the ownship aircraft could not see the traffic aircraft ahead of them, but they could hear the flightcrew of the traffic aircraft over the radio frequency. As both aircraft were taxiing along the same route, ATC announced a failure of the Airport Surface Detection Equipment (ASDE-X) and asked all airport surface traffic to hold their positions. The flightcrew of the ownship aircraft heard ATC ask the leading traffic aircraft to report their position, at which time the traffic aircraft replied that they were uncertain of their exact location. The flightcrew of the traffic aircraft then said that they thought they were somewhere between taxiways D and L. When the flightcrew of ownship aircraft examined the KMEM LVO/SMGCS chart, they should have seen that the location reported by the flightcrew of the traffic aircraft would put the traffic aircraft well south of the ownship aircraft. However, the traffic aircraft was in fact much closer to the ownship aircraft (that is, the flightcrew of the traffic aircraft reported the wrong position). The ownship aircraft was subsequently cleared to continue taxiing. The researchers were interested in observing how the flightcrew of the ownship aircraft stayed oriented during this off-nominal event, and whether they detected the conflict with the traffic aircraft.

2.4.4.2 Post-Study Questionnaire & Interview

After completing all four scenarios, flightcrews completed the following (in order):

1. *Airport Markings Questionnaire.* This paper-based questionnaire collected crewmembers' feedback concerning the presentation of airport markings seen out-the-window during the scenarios. The questionnaire is provided in Appendix F.
2. *Interviews.* Interviews were conducted to gather flightcrews' feedback regarding their use of the FAA prototype LVO/SMGCS charts and their opinions and perceptions of the airport markings. The list of interview questions is provided in Table 5.

Table 5. Airport Markings Interview Questions

Interview Questions
1. Did you notice a difference in the presentation of the GPM markings on the airport surface? For example spacing, size? If yes, which did you prefer?
2. Did you notice the taxiway markings painted on the airport pavement? If yes, did this help/hinder your position awareness?
3. Were any of the taxiway/runway markings confusing as to pilot responsibility?
4. What is your understanding of how approach hold lines apply during taxi operations?

2.5 Data Collection

2.5.1 Objective Data

The objective data collected for Study 1 (Chart Usability) and Study 2 (Airport Markings) were the same, unless otherwise noted. These data included:

- *Average taxi speed*. Taxi speeds were recorded from the simulator at a 30 Hz sampling rate. The average speed across the entire scenario was calculated starting from 1 kt ground speed for departures and 10 kt ground speed for arrivals to the end of the scenario. Only overall taxi speeds (e.g., as opposed to taxi speeds at specified locations) were calculated.
- *Total taxi time.* Total taxi time was calculated across the entire scenario. Similar to average taxi speed, only overall taxi time was calculated.

- *Flightcrews' compliance with ATC instructions*. Compliance, as observed from video recordings, addressed whether flightcrews taxied to the cleared location and whether they accurately reported their position when asked by ATC. Flightcrew compliance was further broken down into several categories (see Appendix G).
- *Crew actions in response to ILS hold and approach hold lines.* A number of scenarios included ILS and approach hold lines and crew actions were recorded and categorized according to level of understanding of procedural requirements for these markings.
- *Crew actions in response to LVO/SMGCS program "difficult" markings.* One scenario included confusing LVO/SMGCS GPM and taxiway markings to determine crew actions in these types of areas.
- *Percent head-up time.* Head-up time was recorded via the head and eye tracker. These data were analyzed primarily for Study 2 (Airport Markings) to understand how pilots were looking out-the-window at the airport markings.

Flightcrews' actions might be affected by their familiarity with the airport layout and charts, so the researchers also considered whether the objective measures showed differences in flightcrew actions based on the following factors: flightcrews' operational experience at KMEM, the day (1 or 2) that they completed the LVO/SMGCS studies (which may affect their knowledge of the airport layout), and chart familiarity (whether flightcrews used the provider's charts regularly or not). A statistical examination (chi-square; significant at $p<.05$) of the objective measures verified that flightcrew actions were not influenced by these factors.

2.5.2 Subjective Data

The subjective data gathered in each study consisted of the following:

- Study 1 (Chart Usability)
  - Feedback on LVO/SMGCS chart usability
  - Perceived symbol shape representativeness & usefulness
  - Perceived workload and situation awareness
  - Interview responses
- Study 2 (Airport Markings)
  - Feedback on the airport markings seen out-the-window
  - Perceived workload and situation awareness
  - Interview responses

3. Results

The results are summarized below for each study. The section begins by examining each scenario and detailing flightcrew compliance with ATC instructions for each event in the scenario (e.g., whether flightcrews held at the instructed location and reported their position when asked). In addition to flightcrew compliance, the FAA was interested in whether flightcrews used the detailed hot spots depicted on the FAA prototype LVO/SMGCS charts when they were taxiing through hot spots, and pilot feedback is provided where applicable. The FAA was also interested in whether flightcrews stopped at ILS hold lines and approach holds, and any discussion they had about these hold lines that indicated confusion about their function and applicability. The average taxi speed and total taxi time across the entire scenario are also reported. After examining each scenario, the section discusses the findings from the questionnaires and interviews.

3.1 Study 1: Chart Usability

3.1.1 Scenarios

3.1.1.1 Scenario 1

Scenario 1 was a departure scenario, as depicted in Figure 10. The scenario began at GPM 9 on taxiway Victor and ended just after GPM 7S. The taxi clearance provided to the flightcrew was "*taxi to runway 36 Center via Sierra, Romeo; hold at spot [GPM] 7 Sierra; report passing spot 1 Sierra; cleared to cross runway 9* Note that the ATC instructions and taxi route given during this scenario was representative of what pilots might receive at KMEM, that is to say in most respects this clearance complied with ATC clearance protocols. However, the clearance should have been broken down into two parts, with the flightcrew receiving and repeating the first half, before receiving the second half. Giving the clearance in two parts would have made it fully ATC clearance protocol compliant.

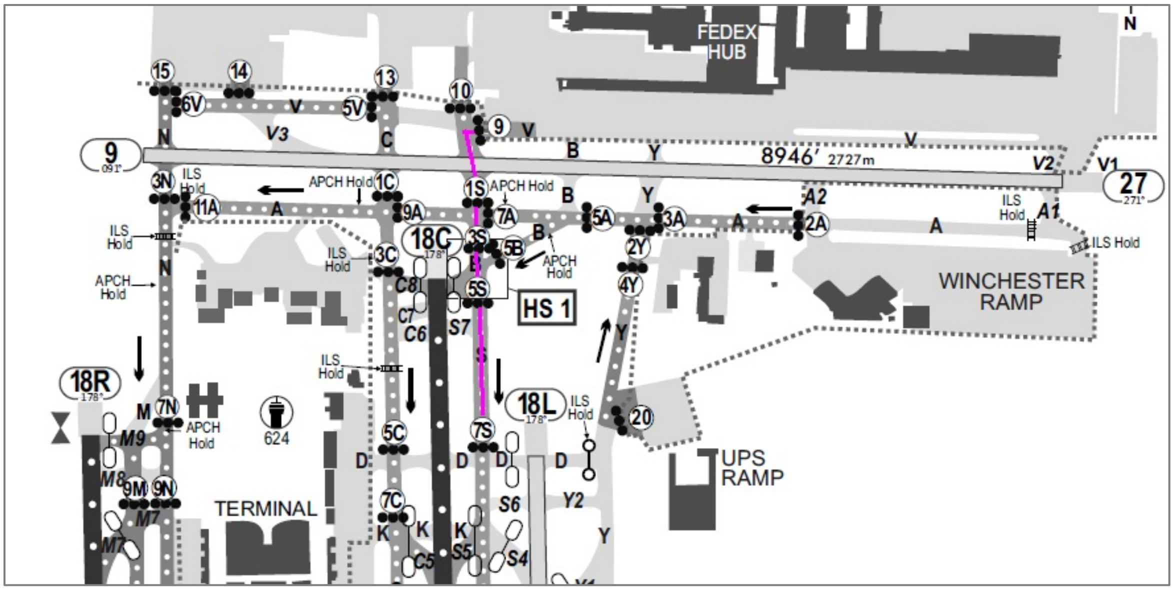


Figure 10. Planned Route for Scenario 1

The average taxi speed throughout this scenario was 9.03 kt (*SD* = 1.18) and the average total taxi time was 4 minutes 29 seconds.

The order of events in this scenario is outlined below, along with flightcrews' responses to each event.

1. Flightcrews crossed non-LVO/SMGCS runway 9. All twelve flightcrews crossed runway 9 as cleared. None of the flightcrews commented on the alternating green/yellow centerline lights as they crossed, which the FAA team wanted to know for possible future training purposes.
2. Flightcrews were expected to report passing GPM 1S, as instructed by ATC in the taxi clearance. All twelve flightcrews reported passing GPM 1S.
3. Flightcrews taxied through a hot spot between GPMs 3S and 5S. In addition to flightcrew compliance, the FAA was interested in whether flightcrews used the detailed hot spot provided (on a separate page) with the FAA prototype LVO/SMGCS chart (see Appendix B). Five flightcrews (ten pilots) used the FAA prototype chart for this scenario. The study did not reveal objective data to show flightcrews' use of the detailed hot spot during this scenario, but the study did gather their opinions in the post-scenario interview:
    - Four of the ten pilots (two PF and two PM from different flightcrews) provided their opinion that depicting the details of the hot spot was not helpful. Three of these four pilots (two PFs and one PM) specifically indicated that they did not feel the hot spot depiction added to their understanding of the hot spot. The other pilot (PM) felt that it was "cumbersome to flip back and forth" from the detailed hot spot to the chart and thought that the detailed hot spot was redundant on the "full sized" (8.5 x 11 inch/21.59 x 27.94 cm) charts. However, this pilot did feel that the detailed hot spot depiction could be beneficial "if the charts were actual size," since some chart providers produce charts on smaller paper sizes. Note that this pilot may have misunderstood the question or have been thinking of the standard approach charts

rather than LVO/SMGCS charts, since some commercial chart providers' LVO/SMGCS taxi charts are larger than their standard approach plates, due to the amount of information needed on the LVO/SMGCS chart.

- Two of the ten pilots (one PF and one PM from different flightcrews) felt that the detailed hot spot depiction was helpful. The PF said "once I figured out what they were, I think they were a good source of reference," and that the detailed hot spot "gives [me] a clearer idea" and "it makes it easier for me."
- Four of the ten pilots did not comment on the depiction of the detailed hot spot.

4. Between GPMs 5S and 7S, ATC asked flightcrews to "*report present position*." All twelve flightcrews reported their position within eight seconds on average (*SD* = 2 seconds, *range* = 5-13 seconds). All flightcrews reported with some variation of "approaching 7 Sierra."
5. Immediately following flightcrews' position report (event 4), ATC instructed flightcrews to "*report spot 7 Sierra*." This instruction was not fully ATC clearance protocol compliant, since actual ATC practice would have included restating "hold at spot 7 Sierra." Flightcrews were also expected to hold at GPM 7 Sierra, as instructed in the original taxi clearance. Data from only eleven flightcrews were available for this event because the scenario ended for the twelfth flightcrew before they had a chance to report their position. Of the eleven flightcrews, ten flightcrews held at GPM 7S and reported their position; this report occurred even though the recorded ATC reminder to "report spot 7 Sierra" was not triggered for five of the eleven flightcrews. One of the eleven flightcrews reported passing 7S instead of holding; the flightcrew's discussions indicated that they thought that ATC's instruction to "report 7S" meant that they no longer needed to hold at 7S (that is, the researchers believe that the flightcrew's failure to hold at 7S was a result of the non-compliant ATC clearance). One other flightcrew also discussed their confusion with this instruction, but decided to hold anyway.
6. Immediately following flightcrews' position report at 7S, ATC instructed flightcrews to "*continue taxiing to spot 11 Sierra*." The scenario ended shortly after flightcrews continued taxiing from 7S.

3.1.1.2 Scenario 2

Scenario 2 was a departure scenario, as depicted in Figure 11. The ATC instructions provided during the second portion of this scenario were deliberately created to use similar-sounding GPM and taxiway names to examine the effect of this similarity on flightcrews' position awareness. Additionally, the taxi route used for this scenario took flightcrews through an ILS hold line and an approach hold to examine flightcrews' knowledge of procedures for ILS hold lines and approach holds in LVO/SMGCS conditions. The scenario began at GPM 15 (FedEx Ramp) and ended at GPM 9M. The taxi clearance (not ATC clearance protocol compliant) provided to the flightcrew was "*taxi to runway 36 Left via November, Mike 9, Mike; hold short spot 7 November; report passing taxiway Alpha; you're cleared to cross runway 9.*" This clearance should have been given in two parts to be fully compliant.

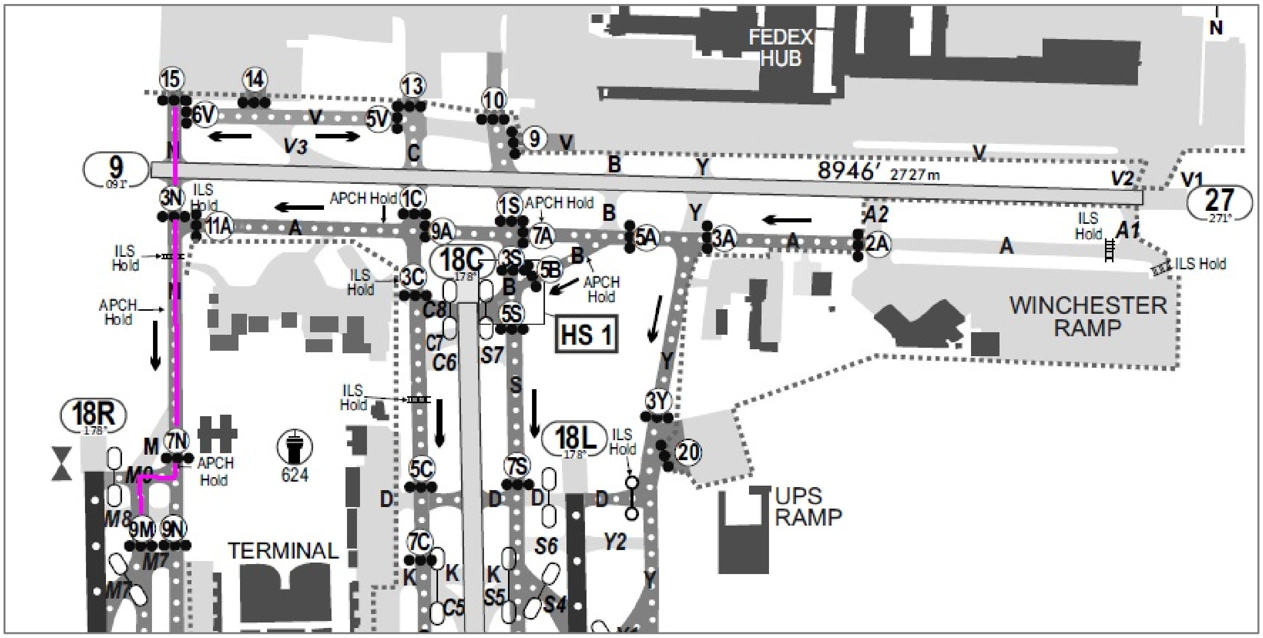


Figure 11. Planned Route for Scenario 2

The average taxi speed throughout this scenario was 8.37 kt (*SD* = 1.18) and the average total taxi time was 6 minutes 10 seconds.

The order of events in this scenario is outlined below, along with flightcrews' responses to each event.

1. Flightcrews were expected to report passing taxiway A, as instructed by ATC in the taxi clearance. All twelve flightcrews reported passing taxiway A.
2. Flightcrews passed an ILS hold line and an approach hold on taxiway N. The FAA was interested in gathering information about flightcrews' understanding of whether and/or when to stop at ILS hold lines and approach holds in LVO/SMGCS conditions. FAA policy is that flightcrews were not expected to stop at the ILS hold line or approach hold unless instructed to by ATC. Flightcrews that stopped or asked for a clearance to cross were considered to exhibit conservative but appropriate actions, although this action still reflects a misunderstanding of the ILS and approach hold lines.
    - In this scenario none of the twelve flightcrews stopped at or asked ATC about the ILS hold or the approach hold lines. However, two flightcrews noted the approach hold as part of their flight deck discussions; one flightcrew member of the first flightcrew said, "that's the approach hold," but the flightcrew did not stop, and one flightcrew member of the second flightcrew said "there's an 18R approach so that checks; let's slow down here so we don't miss anything" (this is the exact quotation from the flightcrew).
    - Three flightcrews (six pilots) used the FAA prototype LVO/SMGCS chart for this scenario, which depicted the ILS and approach hold lines. When asked during the post-scenario interview about the depiction of ILS hold lines (they were not asked about

approach hold lines), flightcrews' comments reflected different levels of understanding regarding procedures for ILS hold lines in LVO/SMGCS conditions:

- Four of the six pilots provided their opinion that the depiction of ILS hold lines was helpful. One pilot said he liked having the ILS hold lines depicted on the chart because "I live a lot internationally and it is very common even in low vis situations to get a clearance to hold short of an ILS hold line" (e.g., Hong Kong). This comment illustrates the different procedures that may exist internationally and suggests a need for improved international standardization of LVO/SMGCS procedures, specifically the use of ILS and approach hold lines as demonstrated by this scenario.
- One pilot provided his opinion that the depiction of ILS hold lines was not helpful because he "was not paying attention to the ILS hold lines" and had not used them in years.
- One pilot was undecided about whether the depiction of ILS hold lines was helpful. This pilot said that the ILS hold lines depicted on the chart were "kind of handy for orientation," but added "clutter."

3. ATC asked the flightcrews to "*please state your present position*" after they had passed both the ILS and approach hold lines. All twelve flightcrews reported their position within 12 seconds on average (*SD* = 7 seconds, *range* = 5-29 seconds). All flightcrews responded with some variation of "approaching 7 November."
4. Flightcrews were expected to hold at GPM 7N, as instructed by ATC in the taxi clearance. Data from only eleven flightcrews were available for this event because one flightcrew's data were not recorded due to a simulator technical error. All eleven flightcrews held at GPM 7N and also voluntarily reported their position to ATC.
5. Immediately after flightcrews reported GPM 7N, ATC instructed them to "*taxi to spot 9 Mike via Mike 9, Mike; report passing taxiway Mike 8.*" This instruction was not fully ATC clearance protocol compliant, since actual ATC practice would have included restating "hold at spot 9 Mike." Again this clearance was deliberately designed to use similar taxiway and GPM names (Mike 9 and 9 Mike, respectively) to see if the confusing GPM and taxiway identification terms would affect flightcrew position awareness. Memphis ATC would never give this clearance because they analyze these types of complicators during development of an LVO/SMGCS airport program, and they mitigate out confusing situations by breaking up clearances into smaller elements. Data from only eleven flightcrews were available because one flightcrew's data were not recorded due to a simulator technical error (this was the same flightcrew whose data were not available at event 4). Flightcrews responded to this event as follows:
   - Five of the eleven flightcrews commented on the clearance. Three of the five flightcrews asked ATC to repeat the clearance. Having ATC repeat confusing instructions is a correct crew action at KMEM. After ATC repeated the clearance, all three flightcrews correctly read back the clearance and continued taxiing. Four of the five flightcrews (including two of the three who asked ATC to repeat the clearance) said in their flight deck discussions that the similar-sounding taxiways and GPMs were "confusing" or "complicated."

- When flightcrews reached taxiway M8, all eleven flightcrews reported taxiway M8. Two of these eleven flightcrews also stopped at M8 and reported their position to ATC. This was considered to be a conservative and correct action since the flightcrews did not pass GPM 9M.
- Immediately after flightcrews reported passing taxiway M8, ATC told them to "*report spot 9 Mike.*" Flightcrews were also expected to hold at 9 Mike, as instructed by ATC in the previous clearance. Data from only ten flightcrews were available for this event because the scenario ended before the eleventh flightcrew had the chance to report. Nine of the ten flightcrews held at GPM 9M and reported their position. Only one of the ten flightcrews made an error by reporting passing GPM 9M instead of holding; when the flightcrew reported passing 9M, ATC told the flightcrew to hold.

6. The scenario ended with flightcrews holding at GPM 9M.

3.1.1.3 Scenario 3

Scenario 3 was a departure scenario, as depicted in Figure 12. This scenario was designed to examine flightcrews' use of the detailed hot spot pages provided with the FAA prototype LVO/SMGCS chart (see Appendix B). The scenario began at the Winchester Ramp and ended at taxiway S7 on taxiway Sierra. The taxi clearance provided to the flightcrew was "*taxi to runway 36 Center via Alpha, Bravo, Sierra, Romeo; call passing taxiway Yankee.*" This clearance is compliant with ATC clearance protocols.

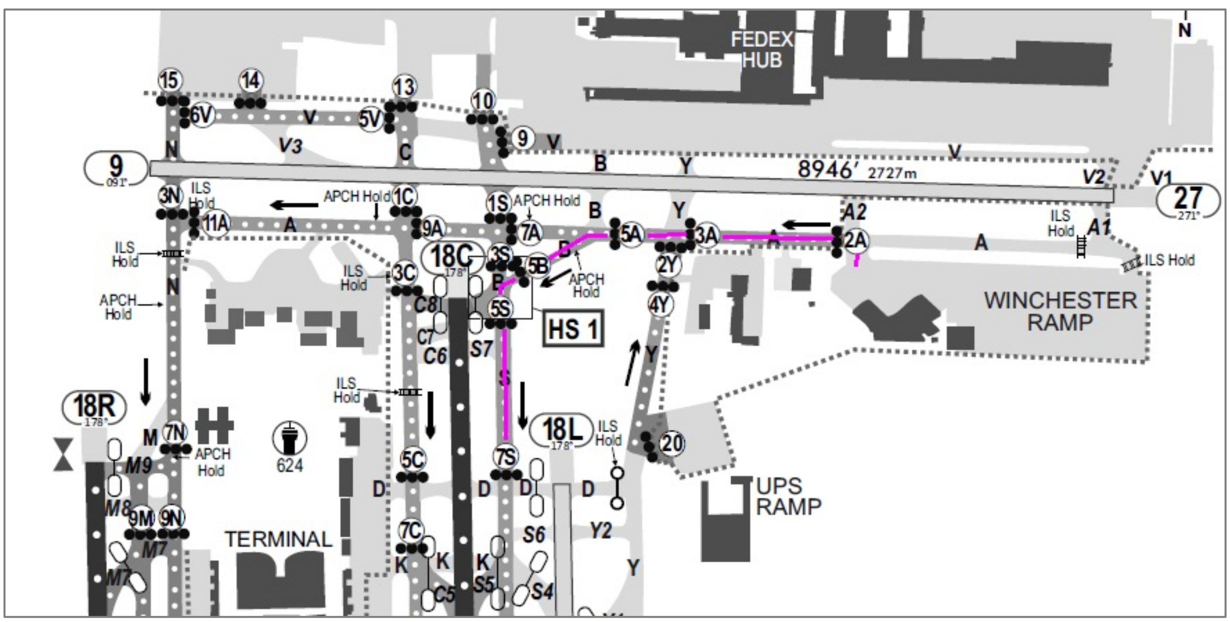


Figure 12. Planned Route for Scenario 3

The average taxi speed throughout this scenario was 6.68 kt (*SD* = 1.16) and the average total taxi time was 6 minutes 37 seconds.

The order of events in this scenario is outlined below, along with flightcrews' responses to each event.

1. Flightcrews were expected to report passing taxiway Y, as instructed by ATC in the taxi clearance. All twelve flightcrews reported passing taxiway Y.
2. ATC instructed flightcrews to "*hold short of Sierra on Bravo*." Before reaching taxiway S, flightcrews passed an approach hold on taxiway B. Flightcrews were not expected to stop at the approach hold in accordance with LVO/SMGCS procedures. However, five of the twelve flightcrews (only one of whom used the FAA prototype chart with the approach hold line depiction for this scenario) exhibited conservative but correct actions by stopping at the approach hold.
    - Three of the five flightcrews confirmed their location as part of their flight deck discussions, and then continued taxiing without contacting ATC.
    - One flightcrew questioned whether they were cleared to cross as part of their flight deck discussions, but they did not contact ATC. This flightcrew held at the approach hold until ATC contacted them and said "we see you holding your position." The flightcrew then replied that they were "holding short of Sierra on Bravo" and ATC told them to "cross the approach hold line and continue taxiing, hold short of Sierra on Bravo." This flightcrew used the FAA prototype chart with the approach hold line depiction for this scenario.
    - One flightcrew contacted ATC and said they were "holding short of taxiway Sierra on Bravo." ATC responded to "cross the approach hold line and continue taxi, hold short of Sierra on Bravo."

    The researchers were interested in examining flightcrews' behavior with respect to approach holds in this scenario relative to Scenario 2. The approach hold in this scenario was located some distance prior to a taxiway intersection where flightcrews were required to stop. This contrasts with the approach hold in Scenario 2 which was not near a point where flightcrews were required to stop. The data show that five of the twelve flightcrews stopped at this approach hold, whereas none of the flightcrews stopped at the approach hold in Scenario 2. The difference in responses suggests that flightcrews' understanding of approach hold procedures in LVO/SMGCS conditions varied depending on the location of the approach hold relative to the hold point. Note again that only one flightcrew who used the FAA prototype chart stopped at the approach hold.

3. As the flightcrews turned left on taxiway B, they taxied through a hot spot between GPMs 5B and 5S. Four flightcrews (eight pilots) used the FAA prototype LVO/SMGCS chart with a detailed hot spot page for this scenario (these were four different flightcrews from the ones who used the FAA prototype chart in Scenario 1), and the FAA was interested in pilot feedback related to the detailed hot spot page. The objective data did not show flightcrews' use of the detailed hot spot page, but flightcrews provided their feedback on the depiction of the detailed hot spot during the post-scenario interview. Note that this scenario was paired with Scenario 6, which also required pilots to taxi through a hot spot.

- One pilot (PM) said that depicting the details of the hot spot was helpful, but he did not elaborate. His crewmember (PF) did not comment.
- Two flightcrews did not provide any comments on the depiction of the detailed hot spot.
- One flightcrew said that they did not notice the detailed hot spot page.

The lack of feedback on the detailed hot spot page may be a result of some flightcrews not remembering that the detailed hot spot page was included in their chart packets, even though flightcrews were briefed on the hot spot page in the briefing prior to simulator training and again in simulator training. The detailed hot spot page was provided only for the FAA prototype LVO/SMGCS charts, which are not currently in use, so prior to the briefing pilots had no expectation that such a depiction was provided. Consequently, more research may be needed to examine flightcrews' use of the detailed hot spot page.

4. Flightcrews were expected to hold short of taxiway S, as instructed by ATC. Data from only eleven flightcrews were examined for this event; one flightcrew's data were not included because the ATC instruction was overridden by an early trigger of the next pre-recorded clearance. All eleven flightcrews held short of taxiway S. Nine of these eleven flightcrews also voluntarily reported their position to ATC, a correct action above and beyond ATC clearance protocol requirements.
5. Immediately after the flightcrews reported holding at taxiway S, ATC told them to "continue taxiing; hold your position on Sierra abeam taxiway Sierra 7." Data from only eleven flightcrews were available because one flightcrew's data were not recorded due to a simulator technical error. All eleven flightcrews accurately held short or abeam at taxiway S7 and also voluntarily reported their position to ATC. Ten of the eleven flightcrews held conservatively at GPM 5S ahead of taxiway S7, and ATC told them to continue taxiing until abeam of S7. Note that one chart incorrectly showed GPM 5S at the intersection of taxiway S7; only two flightcrews used this chart for the scenario, and both flightcrews stopped conservatively at GPM 5S.
6. The scenario ended with flightcrews holding at S7.

3.1.1.4 Scenario 4

Scenario 4 was an arrival scenario, as depicted in Figure 13. The scenario started 1,000 ft (304.8 m) HAT and ended at GPM 4N. The landing clearance provided to the flightcrew was "*cleared to land runway 36 Left; call ground and hold at the first GPM after clearing the runway for further clearance*." This clearance was not compliant with ATC clearance protocols, and was designed so that the FAA could examine how flightcrews operated in landing conditions where multiple runway exits were possible if not specified by ATC. In actual practice ATC would have told flightcrews which taxiway to exit 36L on, or to exit at the runway end.

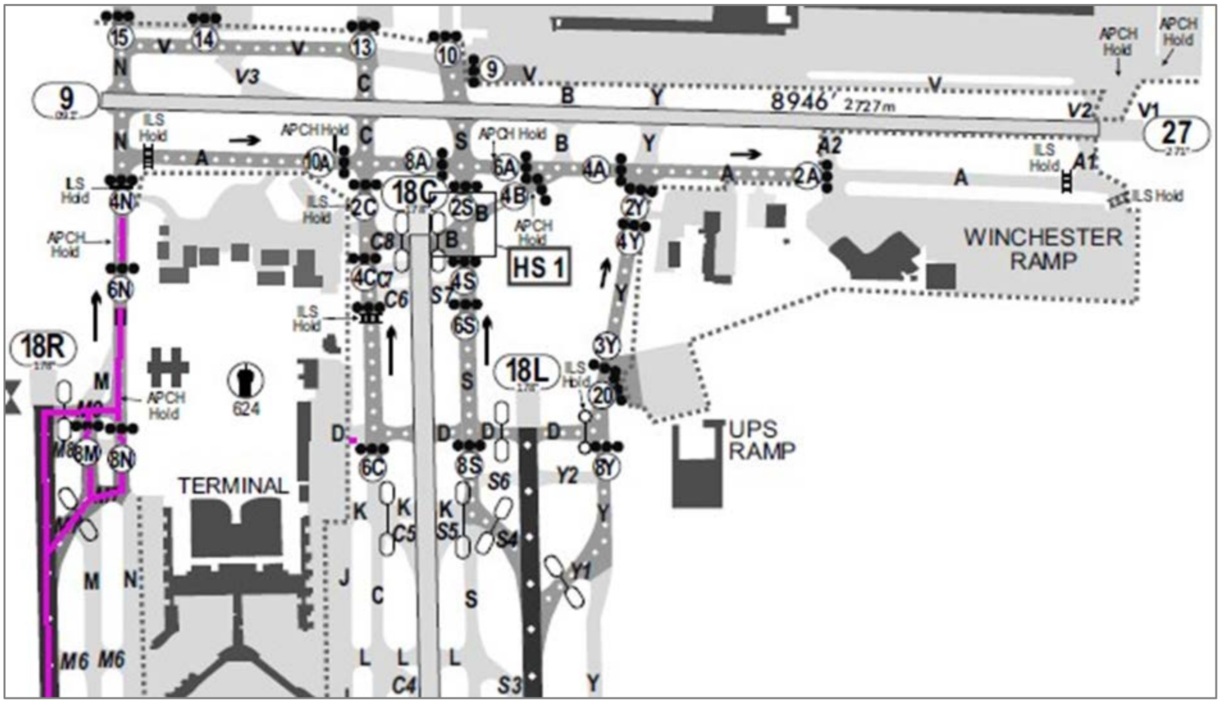


Figure 13. Planned Route for Scenario 4

The average taxi speed throughout this scenario 8.38 kt (*SD* = 2.12) and the average total taxi time was 4 minutes 41 seconds.

The order of events in this scenario is outlined below, along with flightcrews' responses to each event.

1. Flightcrews landed on runway 36L and could have exited the runway via taxiway M7 or M9. All twelve flightcrews exited the runway via taxiway M7.
2. Flightcrews were expected to report the first GPM they saw after exiting the runway, as instructed by ATC in the landing clearance. Flightcrews would have seen 8M, 8N, or 6N, depending on which taxiway(s) they took. This clearance was designed to examine whether flightcrews might be confused by the similar names for GPMs and taxiway identifiers. None of the twelve flightcrews explicitly commented on the similar names for the GPMs and taxiway identifiers in this scenario, and this issue was not explicitly called out in the interviews. All twelve flightcrews reported the first GPM within an average of 1 minute 29 seconds after exiting the runway (*SD* = 41 seconds, *range* = 55 seconds to 3 minutes 19 seconds). Five of the twelve flightcrews taxied via M7 onto taxiway M, the first parallel taxiway after exiting the runway, and reported GPM 8M. Seven of the twelve flightcrews exited via M7 onto taxiway N. Of these seven flightcrews, six reported GPM 8N and one flightcrew reported "6N" because they were looking at GPM 9N upside down (GPM 9N is used for takeoff). ATC corrected the flightcrew and told them to continue to GPM 8N; the flightcrew continued taxiing and reported 8N as instructed. Note that in reviewing the audiotapes of the flightcrews' discussions, one flightcrew member from another flightcrew who exited via M7 onto taxiway M also confused GPM 9M with GPM "M6," but caught his error before reporting their position.

3. Flightcrews that reported GPM 8M were instructed to "*taxi to spot 10 via Mike, Mike 9, November, Alpha, Sierra; hold and report spot 10A.*" Flightcrews that reported GPM 8N were instructed to "*taxi to spot 10 via November, Alpha, Sierra; hold and report spot 10A*."
4. Flightcrews passed an approach hold on taxiway N, just past taxiway M9. The FAA again here was interested in whether flightcrews understood the procedures for approach holds in LVO/SMGCS conditions. In accordance with LVO/SMGCS procedures, none of the twelve flightcrews stopped at the approach hold. As in Scenario 2, flightcrews may not have stopped at the approach hold in this scenario compared to Scenario 3 because the approach hold in this scenario was not located near a hold point to which the flightcrew was cleared.
5. Just after flightcrews passed GPM 6N on taxiway N, ATC instructed them to "*hold at spot 4N.*" Data from only eleven flightcrews were available for this event because one flightcrew experienced technical difficulties with their headphones and did not receive the ATC instruction. Ten of the eleven flightcrews held at GPM 4N, and nine of these ten flightcrews also voluntarily reported their position to ATC. Only one of the eleven flightcrews made an error by failing to hold at GPM 4N.
6. The scenario ended with flightcrews holding at GPM 4N.

3.1.1.5 Scenario 5

Scenario 5 was an arrival scenario, as depicted in Figure 14. The scenario started 1,000 ft (304.8 m) HAT and ended at GPM 2A. The landing clearance provided to the flightcrew was "*cleared to land runway 36 Center, exit on Bravo at the end; hold at and report spot 4 Bravo*." This clearance was fully ATC clearance protocol compliant.

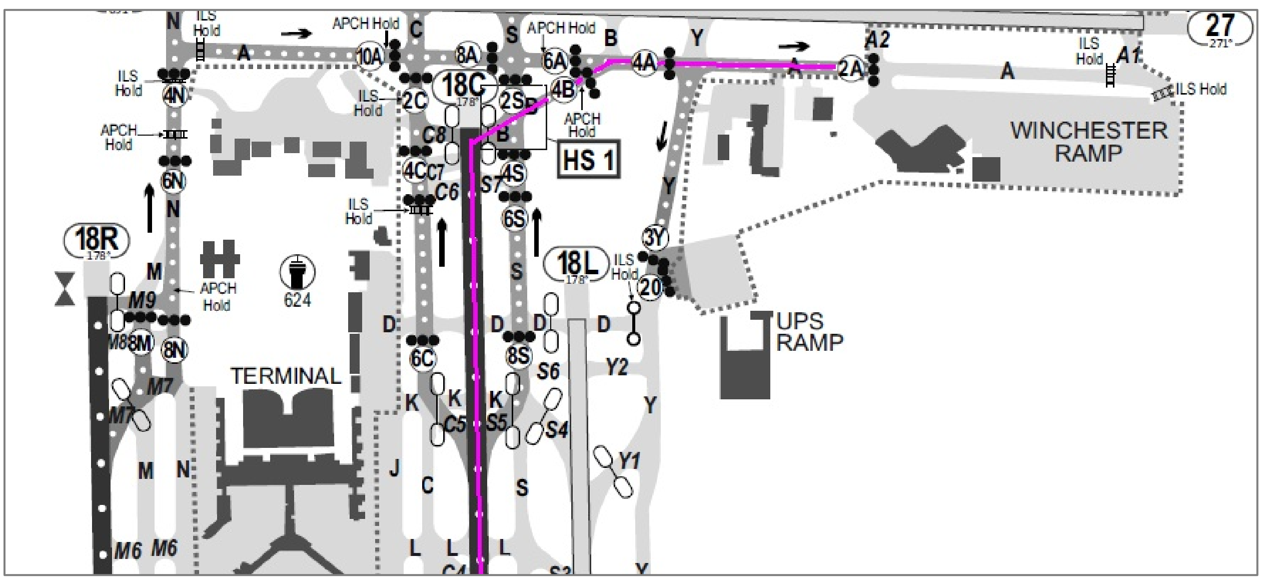


Figure 14. Planned Route for Scenario 5

The average taxi speed throughout this scenario was 8.98 kt (*SD* = 1.89) and the average total taxi time was 3 minutes 44 seconds.

The order of events in this scenario is outlined below, along with flightcrews' responses to each event.

1. Flightcrews landed on runway 36C and were expected to exit on taxiway B, as instructed by ATC in the landing clearance. All twelve flightcrews exited the runway on taxiway B. Two of the twelve flightcrews also voluntarily reported to ATC that they were clear of the runway.
2. Flightcrews taxied through a hot spot after entering taxiway B. Three flightcrews used the FAA prototype LVO/SMGCS chart with detailed hot spots for this scenario (these were three different flightcrews from the ones who used the FAA prototype chart in Scenarios 3 and 6). The FAA was interested in whether flightcrews used the detailed hot spot page during this scenario. No objective data were available to show flightcrews' use of the detailed hot spot page, but flightcrews provided their feedback on the depiction of the detailed hot spot during the post-scenario interview:
    - One flightcrew provided their opinion that depicting details about the hot spot was helpful.
    - One flightcrew said they did not notice the detailed hot spot page. As noted earlier, flightcrews may have forgotten that the hot spot page was provided with their chart packet, even though they received information on the hot spot page during the study briefing and simulator training. When the researcher pointed out the detailed hot spot page during the interviews, both pilots in the flightcrew said they liked it and would have used it during the scenario if they had known about it.
    - The third flightcrew did not comment on the depiction of the detailed hot spot.
3. Flightcrews passed an approach hold on taxiway B. The FAA was again interested in whether flightcrews understood the procedures for approach holds in LVO/SMGCS conditions. None of the flightcrews stopped at the approach hold, in accordance with LVO/SMGCS procedures. Note that the approach hold in this scenario was located prior to a hold point as in Scenario 3, but flightcrews were taxiing away from the runway in this scenario whereas they were taxiing towards the runway in Scenario 3. In Scenario 3, five flightcrews stopped conservatively at the approach hold, suggesting that flightcrews' understanding of approach hold procedures may vary depending on the location of the approach hold relative to the hold point, the direction of the runway, or a combination of both.
4. Flightcrews were expected to hold at GPM 4B and report their position, as instructed by ATC in the landing clearance. Eleven of the twelve flightcrews held at GPM 4B and reported their position. The twelfth flightcrew held at 4B but did not report their position until ATC queried them about their position. When this flightcrew responded to ATC, they indicated they were holding at GPM 4B.
5. Immediately after the flightcrews reported holding at GPM 4B, ATC told them to "*taxi to spot 2 Alpha via Bravo, Alpha, and report passing taxiway Yankee*." This instruction was fully ATC clearance protocol compliant. All twelve flightcrews continued taxiing via taxiway B and took a right on taxiway A.
6. Flightcrews were expected to report passing taxiway Y, as requested by ATC. All twelve flightcrews reported passing taxiway Y.
7. Immediately after the flightcrews reported taxiway Y, ATC told them to "*report spot 2 Alpha.*" This instruction should have been "report spot 2 Alpha and hold" to be fully ATC

clearance protocol compliant. Flightcrews were also expected to hold at GPM 2A, as requested by ATC in Event 5. Eleven of the twelve flightcrews held at GPM 2A and reported their position. Only one of the twelve flightcrews made an error by failing to hold at GPM 2A (the flightcrew reported passing instead), and ATC did not correct them. During this flightcrew's flight deck discussions, the PM said he thought they were supposed to hold at GPM 2A but the PF thought the ATC instruction was to "report passing."

8. The scenario ended with flightcrews holding at GPM 2A.

3.1.1.6 Scenario 6

Scenario 6 was an arrival scenario, as depicted in Figure 15. The scenario started 1,000 ft (304.8 m) HAT and ended at runway 9/27. The landing clearance provided to the flightcrew was "*cleared to land runway 36 Right, exit to the west; hold at and report first GPM on Sierra.*" To be properly ATC clearance protocol compliant this clearance should have included specific instructions on which taxiway the crew was to use exiting the runway, or to taxi off at the runway end.

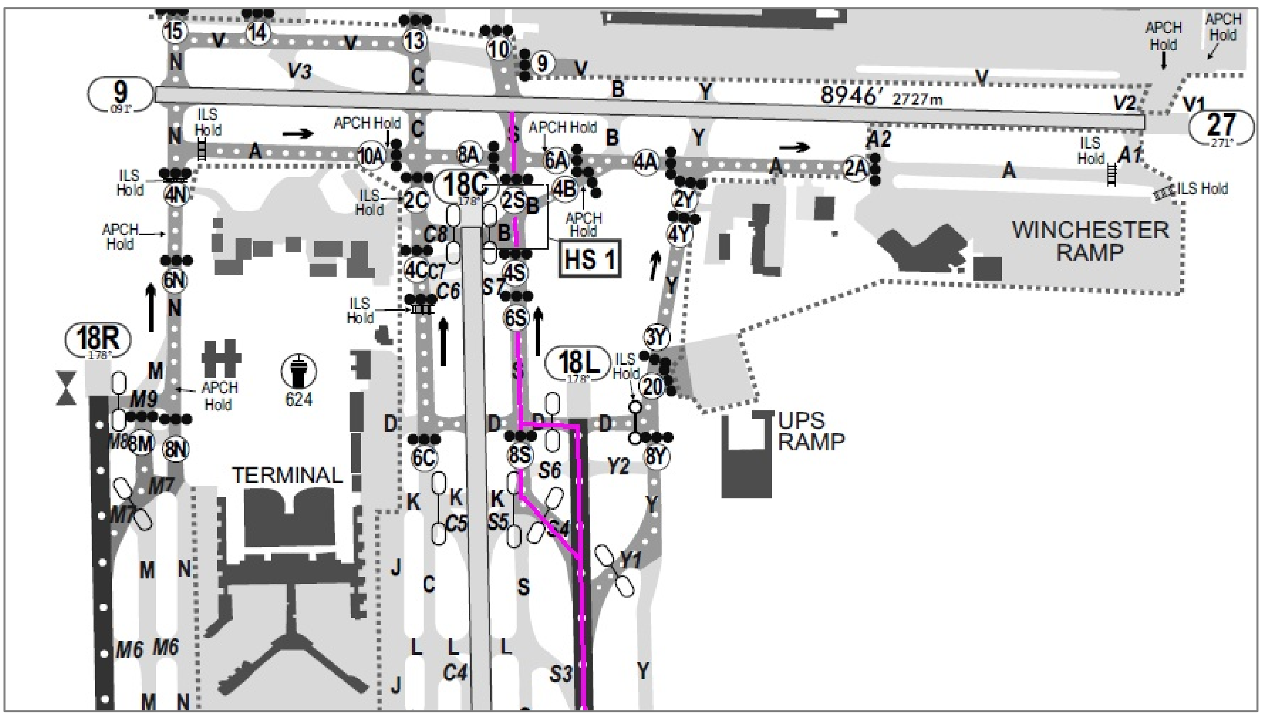


Figure 15. Planned Route for Scenario 6

The average taxi speed throughout this scenario was 9.97 kt (*SD* = 1.00) and the average total taxi time was 4 minutes 12 seconds.

The order of events in this scenario is outlined below, along with flightcrews' responses to each event.

1. Flightcrews landed on runway 36R and exited the runway to the west, as instructed by ATC in the landing clearance. Data from only eleven flightcrews were available for this event because one flightcrew's data were not included due to an error in presenting the out-the-window

scene; taxiway centerline lights appeared out-the-window on non-LVO/SMGCS taxiway S3 thus creating an inconsistency between the chart and the out-the-window view. This error only occurred for this flightcrew. (Data for this flightcrew were available for the other events in this scenario.)

Ten of the eleven flightcrews exited the runway via taxiway S4. Five of these ten flightcrews also voluntarily reported their position to ATC when they were clear of the runway. The eleventh flightcrew exited (incorrectly) via non-LVO/SMGCS taxiway S3. This flightcrew initially thought they were on taxiway S4, but eventually realized their true position when they arrived at the intersection of taxiways S4 on S, at which time they notified ATC.

2. Flightcrews were expected to hold at and report their first GPM, as instructed by ATC in the landing clearance. The first GPM all twelve flightcrews reached was GPM 8S. However, six flightcrews did not have a chance to report their position because the subsequent recorded ATC instruction (to "*continue taxiing to GPM 10 via taxiway S"*) was triggered early. The other six flightcrews reached GPM 8S in an average of 1 minute 2 seconds (*SD* = 14 seconds, *range* = 1 minute 3 seconds to 1 minute 40 seconds), held at the GPM, and reported their position to ATC. ATC responded with "*cleared to spot 10 via Sierra*."
3. Flightcrews entered a hot spot between GPMs 4S and 2S. Four of the twelve flightcrews used the FAA prototype LVO/SMGCS chart with the detailed hot spots for this scenario. (These were the same four flightcrews who used the FAA prototype chart in Scenario 3.) Flightcrews' comments about the detailed hot spot in this scenario are provided in Scenario 3.
4. After passing GPM 4S, ATC instructed the flightcrews to "*report passing taxiway Bravo*." All twelve flightcrews reported passing taxiway B. Once again ATC clearance protocols were not followed here since the correct clearance would have included "hold short of Runway 9/27."
5. Immediately after the flightcrews reported passing taxiway B, ATC instructed them to "*continue taxiing and report passing taxiway Alpha*," and should have included "hold short of Runway 9/27." Data from only eleven flightcrews were available for this event; data from one flightcrew were not included because the ATC instruction was overridden by an early trigger of the next ATC instruction. All eleven flightcrews reported passing taxiway A.
7. Immediately after the flightcrews reported passing taxiway A, ATC instructed them to *hold short of runway 9/27*. Data from only eight flightcrews were available for this event because four flightcrews were not given the instruction to hold short of runway 9/27; these four flightcrews had crossed the runway—this not being considered an incorrect action—and flightcrew discussion suggested that three of these four flightcrews thought it was appropriate to cross the runway without ATC clearance because they saw green lights (no red; as flightcrews crossed the runway, those lights changed to alternating yellow and green in the simulator as they would in actual LVO/SMGCS operations). All eight of the remaining flightcrews held short at runway 9/27 as instructed; five of these eight flightcrews also voluntarily reported their position to ATC.
8. The scenario ended with flightcrews holding at runway 9/27.

3.1.2 Questionnaires and Interviews

Both pilots in each flightcrew independently provided feedback on the questionnaires after completing a departure and arrival taxi scenario with LVO/SMGCS charts from one of the chart providers. After the questionnaires, the flightcrew completed a post-scenario interview. The goal of the questionnaires and interviews were to gain an understanding about the general usability of LVO/SMGCS charts, not to compare the usability across chart providers. Pilots' feedback on each questionnaire and the interviews is described in the following sections.

3.1.2.1 Chart Usability Questionnaire

The chart usability questionnaire was used to gain an understanding of the general usability of LVO/SMGCS charts, not to compare the usability across chart providers. Pilots responded to the questionnaire using a five-point Likert scale (depending on the question, 1 = *strongly disagree* and 5 = *strongly agree*; or 1 = *hindered*, 3 = *did not change*, and 5 = *improved*). The average chart usability ratings across all pilots are presented in Table 6 for each question.

Since chart familiarity might influence pilots' responses on the questionnaires, the researchers considered whether pilots' responses were influenced by whether or not they were familiar with the charts. *Chart familiarity* reflected whether the charts used in the scenario were developed by the chart provider the pilot indicated s/he used currently in operations: *familiar* charts were by the same chart provider, *unfamiliar* charts were by a different chart provider. If a pilot indicated s/he used two provider's charts currently, s/he was considered to be familiar with charts from both providers. The FAA prototype chart was considered unfamiliar to all pilots since the FAA does not currently provide LVO/SMGCS charts. The researchers conducted statistical tests (Analysis of Variance, ANOVA) to examine responses from pilots who used familiar charts and pilots who used unfamiliar charts. Differences in responses based on chart familiarity were considered "significant" if the probability that the results could have occurred by chance was less than 5% ($p < 0.05$) and "marginally significant" if the probability was less than 10% ($p < 0.10$).

Table 6. Average Ratings on Chart Usability Questionnaire

Question	Average Rating (SD)
1. The LVO/SMGCS charts I needed were easy to identify and select (1=strongly disagree, 5=strongly agree)	3.88 (0.90)
2. The information on the LVO/SMGCS charts I needed was easy to find (1=strongly disagree, 5=strongly agree)	3.81 (0.85)
3. I could read all the information on the LVO/SMGCS chart in the lighting conditions I encountered (1=strongly disagree, 5=strongly agree)	3.84 (0.88)
4. I recognized and was able to tell the LVO/SMGCS chart's scale (1=strongly disagree, 5=strongly agree)	3.60 (0.89)
5. All the LVO/SMGCS charts I needed were available (1=strongly disagree, 5=strongly agree)	4.47 (0.93)
6. The LVO/SMGCS chart showed the information I needed to establish, maintain, and/or regain positional awareness on the airport surface (1=strongly disagree, 5=strongly agree)	4.24 (0.91)

Question		Average Rating (SD)
7.	Use of the LVO/SMGCS chart ___ my understanding of taxi route clearances when communicating with air traffic control (1=hindered, 3=did not change, 5=improved)	3.92 (0.90)
8.	The LVO/SMGCS chart I used provided sufficient awareness of my position with respect to runways (1=strongly disagree, 5=strongly agree)	4.16 (0.89)
9.	The LVO/SMGCS chart provided sufficient awareness of my position when approaching runway-taxiway intersections (1=strongly disagree, 5=strongly agree)	3.99 (0.87)
10.	The LVO/SMGCS chart helped me determine which taxiway I was on (1=strongly disagree, 5=strongly agree)	4.10 (0.93)
11.	The LVO/SMGCS chart helped me identify necessary geographical positions relative to my LVO/SMGCS route (1=strongly disagree, 5=strongly agree)	3.99 (0.87)
12.	Runways were easily distinguishable from taxiways and other movement areas on the LVO/SMGCS chart (1=strongly disagree, 5=strongly agree)	4.20 (0.88)
13.	The presentation of ILS hold lines on the LVO/SMGCS chart _____ my understanding of my position on the airport surface (1=hindered, 3=did not change, 5=improved) (for FAA charts only)	3.60 (0.95)
14.	The availability of detailed information on the hotspots _my understanding of my position when taxiing through those locations (1=hindered, 3=did not change, 5=improved) (for FAA charts only)	3.32 (0.84)
15.	The training I received on how to use the LVO/SMGCS chart was adequate (1=strongly disagree, 5=strongly agree)	3.78 (1.0)

As Table 6 shows, pilots gave moderate to high overall ratings for chart usability (across all usability questions 1-15, the average rating ranged from 3.32 to 4.47), indicating that pilots felt positive about the charts in general. The ratings were generally consistent regardless of chart familiarity. In fact, there was only one difference due to chart familiarity. The ratings showed a marginally significant influence of chart familiarity on pilots' ratings of whether the training they received was adequate, $F(1,22) = 3.87$; $p = 0.062$. Pilots who were using LVO/SMGCS charts from the chart provider they used currently (familiar) gave higher ratings as to the adequacy of the training (*mean* = 4.04, *SD* = 0.82) than pilots who were using charts from chart providers they did not use currently (unfamiliar; *mean* = 3.83, *SD* = 0.89). Although statistically significant, these differences are not operationally significant with both means (familiar and unfamiliar) indicating that pilots agreed (a rating of 4 equates to "agree" on this measure) that they had received adequate training on the charts used.

3.1.2.2 Symbol Identification

The symbol identification questionnaire was used to gain an understanding of the representativeness and usefulness of a subset of LVO/SMGCS chart symbol shapes. Pilots viewed symbol shapes without context, and were asked to provide the meaning of each symbol shape via free response. Responses for each symbol shape were coded as correct or incorrect based on feedback from FAA LVO/SMGCS SMEs. To determine symbol shape "representativeness," the researchers conducted statistical tests (chi-square, χ^2) that compared the number of correct (or incorrect) responses against the probability that the responses occurred by chance (e.g., if the pilots had guessed). A symbol shape was considered to be *representative* (or *not representative*) if the number of correct (or incorrect) responses was “significantly” higher than it would be by chance (“significant” means the probability that the results occurred by chance was less than 5%, $p < .05$). Since pilots’ identification of symbol shapes might be influenced by their familiarity with the charts, the researchers also examined pilot responses separately by chart familiarity (familiar vs. unfamiliar, i.e., whether or not the pilot indicated s/he used that provider’s charts currently).

After identifying each symbol shape, pilots were asked to provide their opinion on how useful they felt that symbol shape was during taxi operations in LVO/SMGCS conditions. Pilots provided their opinion by providing a rating on a 3-point scale (1 = *very useful*, 2 = *somewhat useful*, and 3 = *not useful*). When examining pilot feedback on usefulness, the researchers only considered responses from pilots who correctly identified a symbol shape; when pilots incorrectly identified a symbol shape (e.g., misidentified a stop bar symbol shape as a clearance bar), it was not clear whether they were rating the usefulness of the information type for what they thought (incorrectly) the symbol shape represented (stop bar) or the information type that the symbol shape actually represented (clearance bar). For each correctly identified symbol shape, the researchers calculated the percentage of pilots who rated the symbol shape as *very useful* and the average (*avg*) and median rating across pilots. The main findings of the symbol identification task are reported below. Statistical values are reported where significant. It is important to note that the usefulness ratings reported below reflect pilot’s subjective opinion only and does not reflect the safety impact or the need for depicting (or not depicting) an information element.

- *Geographic Position Marking (GPM).* Pilots identified symbol shapes depicted as a number (GPM identifier) inside a circle as being representative of GPMs. The three symbol shapes that fit this description were identified as representative of GPMs, $\chi^2(1)$ ranged from 8.17 to 19.17, $p < .01$. Pilots’ chart familiarity did not influence their understanding of the representativeness of GPM symbol shapes. Pilots who correctly identified the symbol shapes representing GPMs rated the depiction of GPMs as very useful 98% of the time (*avg* = 1.02, *median* = 1).
- *ILS Hold Line.* Pilots identified a “ladder” shape as representative of an ILS hold line, $\chi^2(1) = 36.36$, $p < 0.0001$. Pilots’ chart familiarity did not influence their understanding of the representativeness of ILS hold line symbol shapes. Pilots who correctly identified the symbol shapes representing ILS hold lines rated the depiction of ILS hold lines as very useful 58% of the time and somewhat useful 39% of the time (*avg* = 1.45, *median* = 1).
- *Stop Bar.* Pilots identified a line connecting two smaller-sized open circles as representative of a stop bar, $\chi^2(1) = 8.89$, $p < 0.05$. Pilots’ chart familiarity did not influence their understanding of the representativeness of stop bar symbol shapes. Pilots who correctly identified the symbol shapes representing stop bars rated the depiction of stop bars as very useful approximately 88% of the time (*avg* = 1.12, *median* = 1).
- *Runways and Taxiways.* Pilots identified a solid “dark” gray rectangular bar as representative of a runway, $\chi^2(1) = 4.26$, $p < 0.05$, and a solid “light” gray rectangular bar as representative of a taxiway, $\chi^2(1) = 8.05$, $p < 0.05$. It is important to note that the definitions of “dark” and “light” are relative to the shade of other symbol shapes shown on the same chart. No representative

symbol shapes were identified for the information types "runways with centerline lights" or "taxiways with centerline lights." In fact, the addition of circles to the light gray bar to symbolize centerline lights was considered not representative of "taxiways with centerline lights," $\chi^2(1) = 7.35$, $p < 0.05$. No representative symbol shapes were identified for the information type "low visibility taxi routes" (taxiways used when LVO/SMGCS operations are in effect). Pilots' chart familiarity did not influence their understanding of the representativeness of runway or taxiway symbol shapes. Pilots who correctly identified the symbol shapes representing runways rated the depiction of runways as very useful 83% of the time and somewhat useful 17% of the time (*avg* = 1.17, *median* = 1). The depiction of taxiways was rated very useful 69% of the time and somewhat useful 31% of the time (*avg* = 1.3, *median* = 1).

- *Clearance Bar.* No representative symbol shapes were identified for a clearance bar. Additionally, the data showed that the FAA prototype chart symbol shape—three filled circles—was considered not representative, $\chi^2(1) = 3.86$, $p < 0.05$. Pilots' chart familiarity did not influence their understanding of the representativeness of clearance bar symbol shapes. No usefulness ratings are reported for clearance bar symbol shapes because no symbol shapes were found to be representative.
- *Non-Movement Area.* No representative symbol shapes were identified for a non-movement area. Pilots' chart familiarity did not influence their understanding of the representativeness of non-movement area symbol shapes. No usefulness ratings are reported for non-movement area symbol shapes because no symbol shapes were found to be representative.
- *Approach Hold Line.* Approach hold line symbol shapes were not presented on the symbol identification questionnaire, but the FAA was interested in whether pilots misidentified any other symbol shapes as approach holds. This was not the case; no pilots identified any of the symbol shapes as approach holds. However, it should be noted that in a number of cases, crews held at approach hold lines when not required.

In summary, pilots identified representative symbol shapes for GPMs, stop bars, runways, taxiways, and ILS hold lines. No representative symbol shapes were identified for runways with centerline lights, taxiways with centerline lights, low visibility taxi routes, clearance bars, or non-movement areas. In the questionnaire, all symbol shapes were shown without context (i.e., not on a chart background). Context may help pilots to identify representative symbol shapes for some information types (e.g., pilots may use context to help them identify non-movement area symbol shapes, which were depicted in the questionnaire as a line or a box without any inside content).

3.1.2.3 Workload

The NASA-TLX gathered information on both crewmembers' perceived workload with respect to six dimensions: mental demand, physical demand, temporal demand, effort, frustration, and performance. Pilots rated their workload for each dimension on a scale ranging from 0 (*low*) to 100 (*high*) [except for performance ratings, where the scale was 0 (*poor*) to 100 (*good*)].

Pilots reported an overall low level of workload across scenarios (average rating of 37.30, *SD* = 15.29) and generally self-rated their overall performance highly (average rating of 81.25, *SD* = 16.31) across all scenarios.

3.1.2.4 Interviews

The goal of the interviews was to gather pilot opinions about the general usability of LVO/SMGCS charts. No questions were asked that required a comparison across chart providers; however there were two questions that addressed the FAA prototype LVO/SMGCS chart specifically. The interview results are organized into two sections:

- *General Comments on LVO/SMGCS Charts* (from all three chart providers: the two currently in use and the FAA prototype chart)
- *Comments Specific to the FAA Prototype* LVO/SMGCS Chart

The interview results focus on responses that were provided by three or more flightcrews. One disadvantage of interviewing pilots together as a flightcrew—as the researchers did in this study—is that the researchers did not obtain individual opinions from every pilot. Although both pilots in each flightcrew were given the opportunity to respond to each interview question, often one of the pilots would answer the question and the other pilot would simply agree or not provide any further comments. At times, pilots in the same flightcrew followed up on each other's answers; in these cases, the researchers considered the pilots to be in agreement on their response.

3.1.2.4.1 General Comments on LVO/SMGCS Charts

During the interviews, flightcrews were asked general questions about the chart layout, chart symbols, and their ability to find and read information. When flightcrews were asked what the most effective feature was on the LVO/SMGCS charts, all twelve flightcrews responded with GPMs because the GPMs provided position awareness. GPMs were considered effective regardless of the color with which they were presented (that is, they were considered effective on the black-and-white charts and on the charts with color). Eight flightcrews also provided their opinions that the use of color was effective when using charts printed in color, and five of these flightcrews felt that the "red [or pink] GPM" or the "color of the GPM" was the most effective feature on the charts printed in color. (Note that the use of color does not come without its costs, for example, with contrast issues described later in this section.) Three of the twelve flightcrews also felt that the distinction between active and non-active taxi routes was equally as effective as GPMs for providing position awareness.

All twelve flightcrews commented on legibility. Note that some of these flightcrews provided multiple comments addressing different aspects of legibility, so their opinions may be presented in more than one place. Seven flightcrews identified information elements that were difficult to read in low-light conditions because of low contrast between the text and the chart background; five of the seven flightcrews cited the depiction of GPMs as an example and two of the seven flightcrews noted taxiway identifiers.

Seven flightcrews commented on legibility due to the chart size. Four of these seven flightcrews felt that legibility was impacted by the small size of the text on the charts; two of these four flightcrews specifically noted that GPM text was too small and two other flightcrews mentioned small text size only generally. Three of the seven flightcrews noted that the charts used in the study were larger than what might be used in operations, but these flightcrews may have been thinking of the standard approach charts. Consequently, these three flightcrews anticipated that the text on the charts used in this study might not be legible if printed on smaller paper. Four flightcrews (including three of the seven who commented on legibility due to size) felt that the small size of the charts themselves and the symbology on the charts could potentially reduce safety.

Flightcrews were asked if there was any information they would like to add to or delete from the charts. Ten flightcrews felt that the charts were cluttered. When eight flightcrews (four were not asked) were asked in general if clutter impacted their ability to find information, all eight said that it did not, but then provided statements that contradicted this opinion. For example, four flightcrews said that information was difficult to find in cluttered areas of the chart, and four flightcrews said they would have liked the charts to be de-cluttered. Three flightcrews said that information was difficult to read due to clutter, and four flightcrews felt that clutter could potentially reduce safety, but they did not specify why.

Seven flightcrews provided other comments on findability; four flightcrews suggested that stop bar symbols be made more prominent and another three flightcrews suggested that active runways and taxiways be made more distinguishable from non-active runways and taxiways. However, when asked generally if the charts were sufficient for finding information, ten flightcrews (including six of the seven who commented on findability) said that they were sufficient.

When asked if the chart legend section helped or hindered them in familiarizing themselves with the charts, flightcrews generally felt that a chart legend was helpful. Five flightcrews recommended adding a legend when one was not provided. Note that all of the chart providers used in this study provide legends with their charts, but in the study, the legend for one chart provider was not included in the chart booklet. Four flightcrews specifically stated that the legend helped because they were not familiar with or forgot the symbology. Three flightcrews liked having the legend on the same page as the chart.

Finally, four flightcrews felt that the similar naming convention for GPMs and taxiways (e.g., GPM 7S and taxiway S7) could be “confusing” and may reduce safety.

3.1.2.4.2 Comments Specific to the FAA Prototype LVO/SMGCS Chart

Flightcrews were specifically asked for their perceptions and opinions on the design and layout of the FAA prototype chart. Features of particular interest to the FAA were the depiction of ILS holds lines, detailed hot spots, and lead-in notes that were only depicted on the FAA prototype charts. Eight of twelve flightcrews felt that depicting the ILS hold lines was helpful, one flightcrew said that it was not helpful, and three flightcrews could not come to an agreement between themselves as to whether the ILS hold line depiction was helpful. Flightcrews were not asked to hold at ILS hold lines. With respect to the depiction of the detailed hot spot, two flightcrews said that it was helpful, two flightcrews said it was not helpful, and two flightcrews could not come to an agreement with each other. One flightcrew said they did not notice the detailed hot spot, and the other five flightcrews did not provide an opinion on the detailed hot spot (either the researcher did not specifically ask the question, or the flightcrew commented on hot spots in general and did not specifically address the detailed depiction of the hot spots).

When flightcrews were asked if the lead-in notes helped or hindered them in gaining a better understanding of specific LVO/SMGCS equipage and procedures information for charts, eight flightcrews said that the lead-in notes helped, three flightcrews said that they neither helped nor hindered, and one flightcrew said that they did not use the lead-in notes.

3.1.3 Summary of Chart Usability (Study 1) Findings

The results of the Chart Usability study showed that flightcrews generally complied with ATC instructions and reported their locations correctly while taxiing in LVO/SMGCS conditions. When unsure, flightcrews held conservatively and/or contacted ATC for guidance. All pilots felt that the 8.5 x 11 inch (21.59 x 27.94 cm) charts were easy to use and sufficient for maintaining their position awareness in LVO/SMGCS conditions. Pilots perceived their workload to be low. In the symbol identification questionnaire, pilots identified representative symbol shapes for GPMs, ILS hold lines, stop bars, runways, and taxiways. No representative symbol shapes were identified for centerline lights on runways/taxiways, clearance bars, and non-movement areas. It is possible that these information elements may be more recognizable with context. This is an area for further research.

Pilot interviews provided opinions about specific chart features and addressed topics such as clutter, legibility, chart and symbol size, and confusion resulting from similar naming conventions for GPMs and taxiways. Pilots' opinions on the depiction of ILS hold lines and on the FAA prototype chart were mixed according to the subjective data gathered from the questionnaires and interviews. For example, for the ILS hold lines, eight out of the twelve flightcrews agreed that depicting ILS hold lines on the FAA prototype chart was helpful, but in the questionnaire, pilots provided the opinion that the presentation of the ILS hold lines on the chart did not change or only somewhat improved their understanding of position on the airport surface. Regarding the detailed hot spots depicted on the FAA prototype chart, both the interview and questionnaire responses showed that pilots had mixed opinions regarding the helpfulness of depicting detailed hot spots.

3.2 Study 2: Airport Markings and Pilot Response in Off-Nominal Conditions

3.2.1 Scenarios

3.2.1.1 Scenario 7

Scenario 7 was a departure scenario, as depicted in Figure 16. This scenario was designed to gather data on how pilots taxi when no GPMs are depicted. Note that the scenario route contained no GPMs for 5,000 ft (1,524 m) of taxiway.

The scenario began on the Terminal Ramp and ended at runway 36C. The taxi clearance provided to the flightcrew was "*taxi to Runway 36 Center via Lima, Charlie, Pappa, Juliet, Romeo*." This clearance was given in compliance with ATC clearance protocols.

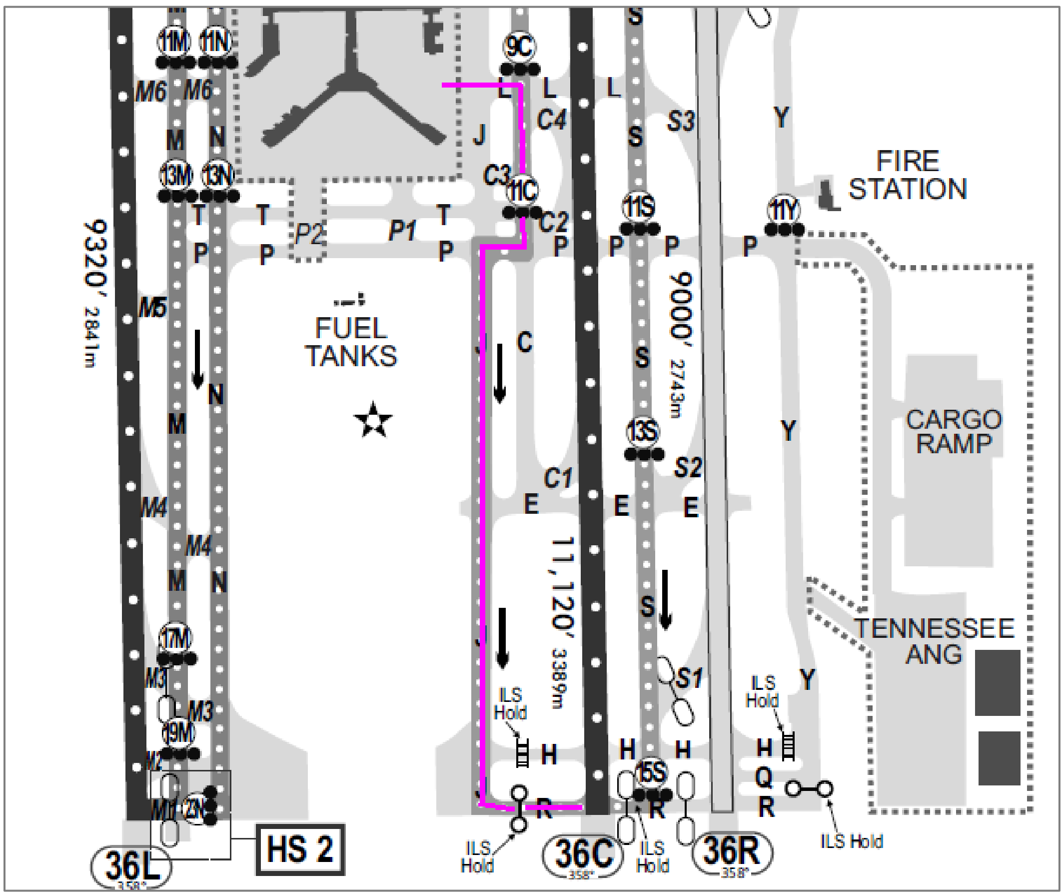


Figure 16. Planned Route for Scenario 7

The average taxi speed throughout this scenario was 10.91 kt (*SD* = 2.18) and the average total taxi time was 6 minutes 11 seconds. On average, PFs spent 72% (*SD* = 17) of their time heads-up (out-the-window) during this scenario, and PMs spent 62% (*SD* = 16) of their time heads-up.

The order of events in this scenario is outlined below, along with flightcrews' responses to each event.

1. Flightcrews began to taxi along taxiway L to taxiways C, P, then J. Taxiway J had no GPMs. All twelve flightcrews taxied along the cleared route.
2. Flightcrews passed taxiway E on J. Flightcrews were not instructed to acknowledge passing taxiway E, but eight of the twelve flightcrews noted it as part of their flight deck discussions (i.e., they did not call out their position to ATC). The actions of these eight flightcrews show extra coordination efforts to help ensure proper flightcrew actions in reduced visibility conditions. The other four flightcrews did not note the taxiway in their discussions or notify ATC of their position.
3. Flightcrews passed taxiway H on J. Flightcrews were not instructed to acknowledge passing taxiway H, but ten of the twelve flightcrews noted it as part of their discussions. Again this demonstrates extra flightcrew effort at maintaining position awareness. The other two flightcrews did not note the taxiway in their discussions or notify ATC of their position.
4. Flightcrews approached taxiway R, where they were expected to turn left, according to ATC's instruction in the taxi clearance. Flightcrews were not instructed to acknowledge approaching taxiway R, but all twelve flightcrews noted approaching taxiway R as part of their flight deck discussions, demonstrating extra flightcrew effort at maintaining position awareness. All twelve flightcrews turned left on taxiway R as instructed.
5. Flightcrews were expected to hold short of runway 36C, as instructed by ATC in the taxi clearance. All twelve flightcrews held short of runway 36C and all twelve also voluntarily reported their position to ATC. Eight of these twelve flightcrews held at the runway hold line and the other four held at the ILS hold line. It should be noted that there was a discrepancy between the FAA prototype chart and the airport surface markings in the simulation. On the chart, the ILS hold line on taxiway R was correctly collocated with a stop bar, but on the simulated airport surface, the stop bar was incorrectly collocated with the runway guard lights at the intersection with the runway. Three of the twelve flightcrews noted this discrepancy in their discussions.
6. The scenario ended with flightcrews holding at runway 36C or the ILS hold line.

3.2.1.2 Scenario 8

Scenario 8 was a departure scenario, as depicted in Figure 17. This scenario was designed to look at the effects of GPM spacing. Three GPMs were added along the route—15N, 17N, and 19N—and to the chart. However, the first two flightcrews did not have the charts depicting the extra GPMs so their data were not included, resulting in data for only ten flightcrews.

The scenario began at GPM 13N and ended at runway 36L. The taxi clearance provided to the flightcrew was "*continue taxi to runway 36 Left*." This clearance was given in compliance with ATC clearance protocols.

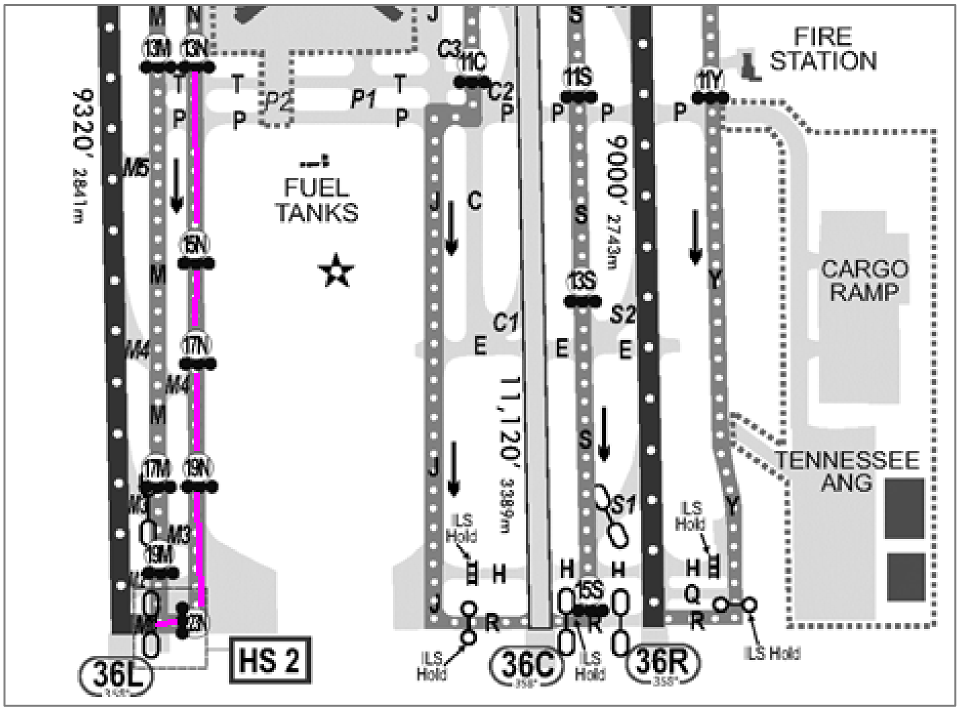


Figure 17. Planned Route for Scenario 8

The average taxi speed throughout this scenario was 11.53 kt (*SD* = 1.58), and the average total taxi time was 5 minutes 8 seconds. On average, PFs spent 75% (*SD* = 10) of their time heads-up during this scenario, and PMs spent 58% (*SD* = 16) of their time heads-up.

The order of events in this scenario is outlined below, along with flightcrews' responses to each event.

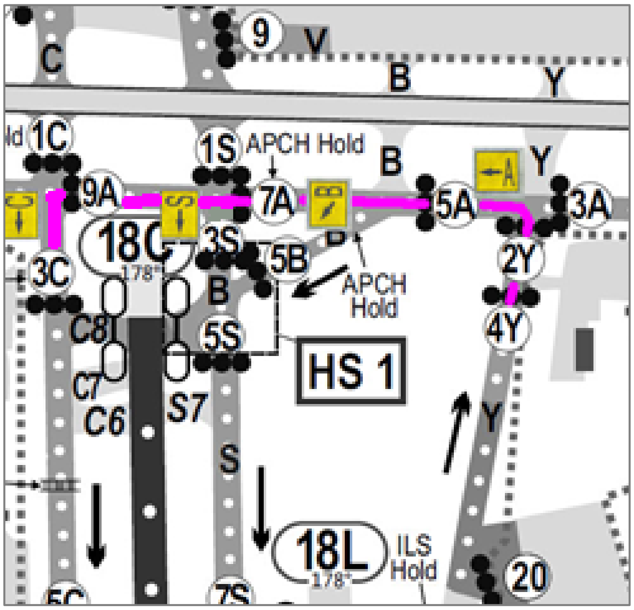
1. Flightcrews began to taxi from GPM 13N.
2. Flightcrews passed GPM 15N. Flightcrews were not instructed to acknowledge passing GPM 15N, but seven of the ten flightcrews noted it as part of their flight deck discussions (i.e., they did not call out their position to ATC). The other three flightcrews did not note the GPM in their discussions or notify ATC of their position.
3. Flightcrews passed GPM 17N. Flightcrews were not instructed to acknowledge passing GPM 17N, but seven of the ten flightcrews noted it as part of their discussions. The other three flightcrews did not note the GPM in their discussions or notify ATC of their position.
4. Flightcrews passed taxiway M4. Flightcrews were not instructed to acknowledge passing taxiway M4, but three of the ten flightcrews noted it as part of their discussions. The other seven flightcrews did not note the taxiway in their discussions or notify ATC of their position.
5. Flightcrews passed GPM 19N. Flightcrews were not instructed to acknowledge passing GPM 19N, but six of the ten flightcrews noted it as part of their discussions. The other four flightcrews did not note the GPM in their discussions or notify ATC of their position.
6. Flightcrews passed taxiway M3. Flightcrews were not instructed to acknowledge passing taxiway M3, but eight of the ten flightcrews noted it as part of their discussions. The other two flightcrews did not note the taxiway in their discussions or notify ATC of their position.

7. Flightcrews passed taxiway M2. Flightcrews were not instructed to acknowledge passing taxiway M2, but six of the ten flightcrews noted it as part of their discussions. The other four flightcrews did not note the taxiway in their discussions or notify ATC of their position.
8. Flightcrews approached taxiway M1, where they were expected to turn right as instructed by ATC in the taxi clearance. Flightcrews were not instructed to acknowledge approaching taxiway M1, but four of the ten flightcrews noted it in their discussions. The other six flightcrews did not note the taxiway in their discussions or notify ATC of their position. All ten flightcrews turned right on taxiway M1 as instructed.
9. Flightcrews reached the threshold for runway 36L. All ten flightcrews held short of runway 36L and also voluntarily reported their position. Two of these ten flightcrews held conservatively at GPM 23N before the runway, and ATC instructed them to proceed and hold short at runway 36L.

3.2.1.3 Scenario 9

Scenario 9 was a departure scenario, as depicted in Figure 18. This scenario was designed to look at the effects of “enhanced” GPMs and “enhanced” taxiway identifiers added as additional ground markings. Compared to standard GPMs, the “enhanced” GPMs (see Figure 8) were designed to be larger in size and were oval instead of circular. In this scenario, enhanced GPMs replaced standard GPMs on the simulated airport surface, but no changes were made to the symbol shapes on the chart. The “enhanced” taxiway ground marking identifiers (see Figure 9) were pavement markings shown as yellow rectangles drawn around the taxiway identifier, with an arrow pointing in the direction of the taxiway. These additional “enhanced” taxiway ground marking identifiers were shown on the simulated airport surface—in addition to the standard taxiway signs—at the intersections of all taxiways in the scenario (taxiways A, B, S, and C). The locations of the enhanced taxiway identifiers are shown in Figure 18, but note that they were not depicted on the chart flightcrews used for this scenario.

Scenario 9 started at GPM 4Y on the UPS Ramp and ended at GPM 3C. The taxi clearance provided to the flightcrew was “*taxi to runway 36 Center via Yankee, Alpha, Charlie, Pappa, Juliet, Romeo; hold at and report spot 3 Charlie.*” The clearance should have been provided in two parts to be ATC clearance protocol compliant.



Notes:

1) The four "enhanced" taxiway signs were painted on Yankee; proceeding up Yankee, the Alpha taxiway marking with left pointing arrow was on Yankee taxiway left of the centerline just prior to where the centerline directed the left turn onto Alpha. All the other airport markings were done according to the same protocol.

2) The charts used by the pilots did not show "enhanced" features (i.e., charts showed standard GPM symbol shapes and standard taxiway identifiers).

Figure 18. Planned Route for Scenario 9

The average taxi speed throughout this scenario was 10.78 kt (*SD* = 2.18), and the average total taxi time was 3 minutes 59 seconds. PFs spent an average of 72% (*SD* = 18) of their time heads-up during Scenario 9, and PMs spent 53% (*SD* = 17) of their time heads-up.

The order of events in this scenario is outlined below, along with flightcrews' responses to each event.

1. Flightcrews began to taxi from GPM 4Y and were expected to turn left on A, as instructed by ATC in the taxi clearance. All twelve crews accurately taxied along the cleared route. Flightcrews were not instructed to acknowledge approaching taxiway A, but ten of the twelve flightcrews noted is as part of their flight deck discussions (i.e., they did not call out their position to ATC). The other two flightcrews did not note the taxiway in their discussions or notify ATC of their position.
2. Flightcrews passed "enhanced" GPM 5A. Flightcrews were not instructed to acknowledge GPM 5A, but four of the twelve flightcrews noted it as part of their discussions. The other six flightcrews did not note the GPM in their discussions or notify ATC of their position.
3. Flightcrews passed "enhanced" taxiway B pavement marking. Flightcrews were not instructed to acknowledge passing taxiway B, but nine of the twelve flightcrews noted it as part of their

discussions. The other three flightcrews did not note the taxiway in their discussions or notify ATC of their position.

4. Flightcrews passed “enhanced” GPM 7A. Flightcrews were not instructed to acknowledge GPM 7A, but nine of the twelve flightcrews noted it as part of their discussions. The other three flightcrews did not note the GPM in their discussions or notify ATC of their position.
5. Flightcrews passed “enhanced” taxiway S pavement marking. Flightcrews were not instructed to acknowledge passing taxiway S, but nine of the twelve flightcrews noted it as part of their discussions. The other three flightcrews did not note the taxiway in their discussions or notify ATC of their position.
6. Flightcrews passed “enhanced” GPM 9A. Flightcrews were not instructed to acknowledge GPM 9A, but five of the twelve flightcrews noted it as part of their discussions. The other seven flightcrews did not note the GPM in their discussions or notify ATC of their position.
7. Flightcrews approached “enhanced” taxiway C pavement marking, where they were expected to turn left, as instructed by ATC in the taxi clearance. Flightcrews were not instructed to acknowledge approaching taxiway C, but all twelve flightcrews noted taxiway C in their flight deck discussions as they approached it. All twelve flightcrews turned left on the taxiway as cleared.
8. Flightcrews were expected to hold at “enhanced” GPM 3C and report their position, as instructed by ATC in the taxi clearance. Ten of the twelve flightcrews held at GPM 3C and reported their position to ATC. The other two flightcrews did not hold at or report GPM 3C, and ATC contacted them and told them to hold.

3.2.1.4 Scenario 10

Scenario 10 was a departure scenario, as depicted in Figure 19. This scenario was designed to understand how pilots use LVO/SMGCS charts to maintain position awareness during an off-nominal event. In this scenario, the ownship aircraft (with the study flightcrew) was one minute behind a traffic aircraft on the same route. The flightcrew could not see the traffic aircraft at any point during the scenario, but they could hear the flightcrew of the traffic aircraft communicating with ATC. As both aircraft were taxiing, ATC announced that there had been an ASDE-X failure and instructed all aircraft to stop. ATC asked the flightcrew of the traffic aircraft to report their position; that flightcrew stated that they were uncertain of their exact location, but thought they were on taxiway C between taxiways D and L, and that they had just passed a GPM. Looking at the chart, this report would suggest that the traffic aircraft was positioned past GPM 7C. The ownship aircraft, which was holding at GPM 3C, was then cleared by ATC to GPM 7C. After the ownship aircraft began taxiing, the flightcrew of the traffic aircraft reported that they were, in fact, at GPM 5C. The researchers were interested in understanding if and how flightcrews stayed oriented in LVO/SMGCS conditions when position-relevant cues were absent (ASDE-X) or inaccurate (traffic aircraft position), including whether flightcrews detected the conflict with the traffic aircraft.

The scenario began with the ownship aircraft holding at GPM 2A on taxiway A and the traffic aircraft also on taxiway A but ahead of ownship aircraft, west of GPM 2A. ATC cleared the traffic aircraft to “*taxi to* *runway 36 Center via Alpha, Charlie, Pappa, Juliet, Romeo.*" One minute later, ATC gave the same clearance to the ownship aircraft, adding that they should "*hold at spot 3 Charlie.*"

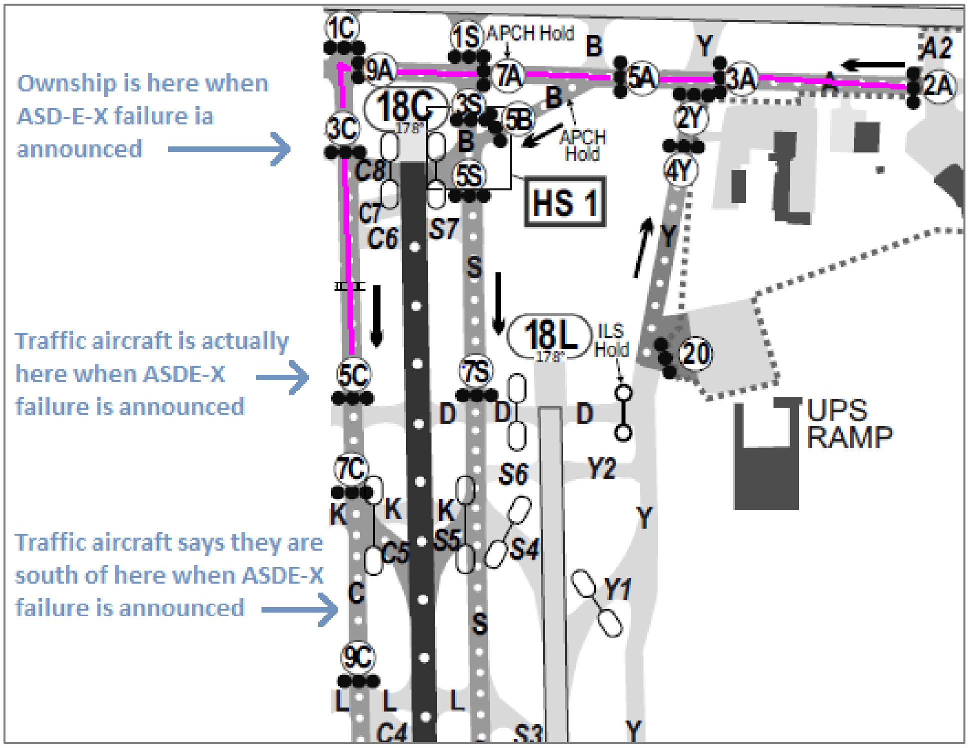


Figure 19. Planned Route for Scenario 10

The average taxi speed between the start of this scenario and GPM 3C where the ASDE-X failure occurred was 11.84 kt (*SD* = 1.66). Flightcrews took an average total of 3 minutes 57 seconds to taxi to GPM 3C. After flightcrews were cleared to continue taxiing following the ASDE-X failure, seven flightcrews continued taxiing (five flightcrews held to check on the traffic aircraft location). The seven flightcrews who continued to taxi did so at an average speed of 5.87 kt (*SD* = 2.11). On average, PFs spent 77% (*SD* = 16) of their time heads-up during this scenario, and PMs spent 63% (*SD* = 19) of their time heads-up.

The order of events in this scenario is outlined below, along with flightcrews' responses to each event.

1. The traffic aircraft began to taxi along taxiway A toward taxiway C.
2. One minute after the traffic aircraft began taxiing, the ownship aircraft began taxiing from GPM 2A via taxiway A toward taxiway C (on the same route as the traffic aircraft). All twelve flightcrews taxied along the cleared route.
3. Flightcrews in the ownship aircraft were expected to hold at GPM 3C, as instructed by ATC in the taxi clearance. All twelve flightcrews held at GPM 3C and also voluntarily reported their position to ATC.
4. One minute after the ownship aircraft reported their position at GPM 3C, and while they were still holding there, ATC announced: "*Attention all aircraft on this frequency: Memphis Airport has*

lost ASDE-X, Ground Surveillance Radar. All aircraft stop and hold your positions." All twelve flightcrews continued to hold their position at GPM 3C.

5. One minute after ATC announced the ASDE-X failure, ATC asked the traffic aircraft to "say your position." Forty-five seconds later, the ownship aircraft heard the traffic aircraft reply, "holding our position on Charlie between Delta and Lima; we just passed a GPM, but we don't recall the number."
6. Immediately after the traffic aircraft reported their position, ATC asked the ownship aircraft to "*say your position."* All twelve flightcrews reported their position at GPM 3C.
7. Immediately after the ownship aircraft reported their position at GPM 3C, ATC cleared them to "*spot 7 Charlie, report reaching.*" In actual current LVO/SMGCS program practice ATC would not allow the ownship aircraft to begin taxiing again until they determined the exact position of the traffic aircraft (see event 5) and made sure the ownship aircraft was advised of that position. The scenario was designed to examine how a flightcrew would handle this kind of ambiguity of position reporting from another participating aircraft.
    - Seven of the twelve flightcrews taxied toward GPM 7C; as they taxied, all seven flightcrews discussed the traffic aircraft position and decided to watch for the traffic aircraft as they taxied. The other five flightcrews held their position at GPM 3C and queried ATC about the position of the traffic aircraft.
    - After the seven flightcrews in the ownship aircraft continued taxiing from GPM 3C, they heard the traffic aircraft announce that they were "in fact holding at spot 5 Charlie." All seven flightcrews in the ownship aircraft realized the potential for a traffic conflict and stopped prior to coming into visual range of the traffic aircraft (within 300 ft/91.44 m). The average braking time was approximately 17 seconds after the traffic aircraft corrected their position.
8. The scenario ended with the ownship aircraft holding their current position (for seven flightcrews, wherever they stopped after the traffic aircraft announced their position; for the other five flightcrews, at GPM 3C).

3.2.2 Questionnaires and Interview

Both pilots in each flightcrew independently provided feedback on the questionnaires. Pilots completed the NASA-TLX (workload) and SART (situation awareness) after completing each scenario and the airport markings questionnaire after completing all four scenarios using the FAA prototype LVO/SMGCS chart. After the airport markings questionnaire, the flightcrew completed a post-scenario interview. Pilots' feedback on the questionnaire and the interview is described in the following sections.

3.2.2.1 Workload and Situational Awareness

Pilots generally reported low workload (the average rating across all four scenarios was 25.05, *SD* = 3.51, out of 100) and good situation awareness (average rating of 7.36, *SD* = .65, on a scale of -5 to 13). There were no significant differences in workload or situation awareness across scenarios.

3.2.2.2 Airport Markings Questionnaire

The airport markings questionnaire was used to gain an understanding of flightcrews' perceptions and opinions of the airport markings used in Study 2 (Airport Markings). Pilots responded to the questionnaire using a five-point Likert scale. The average airport marking ratings across all pilots are presented in Table 7 for each question.

Pilots generally rated their experience with the LVO/SMGCS charts positively (an average rating of 4 or greater; see questions 1-11). Pilots' neither agreed nor disagreed that the GPM spacing was different between scenarios (question 13) and they did not appear to notice a difference in the presentation of GPMs (question 14).

Table 7. Average Ratings on Airport Markings Questionnaire

Question	Average Rating (SD)
1. The LVO/SMGCS charts I needed were easy to identify and select (1=strongly disagree, 5=strongly agree)	4.29 (0.62)
2. The information on the LVO/SMGCS charts I needed was easy to find (1=strongly disagree, 5=strongly agree)	4.33 (0.70)
3. I could read all the information on the LVO/SMGCS chart in the lighting conditions I encountered (1=strongly disagree, 5=strongly agree)	3.96 (1.00)
4. All the LVO/SMGCS charts I needed were available (1=strongly disagree, 5=strongly agree)	4.46 (0.66)
5. The LVO/SMGCS chart showed the information I needed to establish, maintain, and/or regain positional awareness on the airport surface (1=strongly disagree, 5=strongly agree)	4.42 (0.65)
6. Use of the LVO/SMGCS chart ___ my understanding of taxi route clearance when communicating with air traffic control (1=hindered, 3=did not change, 5=improved)	4.33 (0.56)
7. The LVO/SMGCS chart I used provided sufficient awareness of my position with respect to runways (1=strongly disagree, 5=strongly agree)	4.46 (0.59)
8. The LVO/SMGCS chart provided sufficient awareness of my position when approaching runway-taxiway intersections (1=strongly disagree, 5=strongly agree)	4.29 (0.62)
9. The LVO/SMGCS chart helped me determine which taxiway I was on (1=strongly disagree, 5=strongly agree)	4.38 (0.71)
10. The LVO/SMGCS chart helped me identify necessary geographical positions relative to my LVO/SMGCS route (1=strongly disagree, 5=strongly agree)	4.25 (0.61)
11. Runways were easily distinguishable from taxiways and other movement areas on the LVO/SMGCS chart (1=strongly disagree, 5=strongly agree)	4.38 (0.65)

Question		Average Rating (SD)
12.	The GPMs supported my positional awareness while taxiing (1=strongly disagree, 5=strongly agree)	4.63 (0.58)
13.	The distance from one GPM to another was the same in all the scenarios (1=strongly disagree, 5=strongly agree)	2.13 (1.03)
14.	Was the presentation of the GPM on the airport surface appear more visible in one of the scenarios than the others? (Yes/No)	5 pilots replied "Yes" and 19 replied "No"
15.	The pavement markings for taxiways provided sufficient awareness of my position with respect to other taxiways relative to the LVO/SMGCS chart alone (1=strongly disagree, 5=strongly agree)	3.83 (0.87)

3.2.2.3 Interview

Flightcrews were interviewed after completing all four scenarios. The interview questions focused on pilots' impressions of the surface markings seen in the scenarios. Similar to the results reported for Study 1 (Chart Usability), this section reports the number of flightcrews who provided similar answers. As noted before, because pilots were interviewed together as a flightcrew, the researchers could not obtain detailed comments from each pilot; often one of the pilots would answer the question and the other pilot would not comment or would express agreement implicitly. Any disagreements among flightcrews are noted in the discussion of the interview findings. The interview results are organized into two general areas:

- *GPM Spacing, Enhanced GPMs, and Enhanced Taxiway Identifiers*
- *ILS Hold Lines and Approach Holds*

3.2.2.3.1 GPM Spacing, Enhanced GPMs, and Enhanced Taxiway Identifiers

Flightcrews were asked if they noticed a difference in the presentation of GPMs (in terms of both spacing and size). Only two of the twelve flightcrews said that they noticed a difference in GPM presentation in general (size or spacing not specified) and nine of the twelve flightcrews said that they did not. For the twelfth flightcrew, the PM said he noticed a difference but the PF said he did not. When asked whether they noticed the "enhanced" taxiway markings, six of the twelve flightcrews said that they noticed the taxiway markings and found them to be helpful. Five of the twelve flightcrews said that they did not notice the taxiway markings. Three of these five flightcrews commented that they may not have noticed the markings because they were not looking for them or because their attention was focused on something else (e.g., taxiway lights or signs). For the twelfth flightcrew, the PM said he noticed the markings and that they were helpful, but the PF said he did not notice them.

3.2.2.3.2 ILS Hold Lines and Approach Holds

Flightcrews were asked whether there were any taxiway or runway markings that were confusing as to pilot responsibility. Four of the twelve flightcrews said they were unsure about whether to stop at ILS hold lines. Three of these four flightcrews specifically mentioned confusion over ILS hold lines that are just short of the runway. The other eight of the twelve crews said they were not confused about any of the markings.

Flightcrews were also asked to describe their understanding of how approach holds apply during taxi operations. Specifically, the FAA was interested in whether pilots understood the difference between approach holds and ILS hold lines, and to understand if pilots knew when to hold at approach holds and ILS hold lines in LVO/SMGCS conditions. Nine of the twelve flightcrews thought this interview question was referring to ILS hold lines, not approach holds. Seven of the twelve flightcrews thought that they would stop at ILS hold lines or approach holds only if instructed to by ATC; that is, they would not hold if they had been cleared past the hold line. Two of the twelve flightcrews said that they would stop at the ILS hold line or approach hold and contact ATC before crossing. For one of the twelve flightcrews, the PF thought the flightcrew should continue if cleared past the hold line, but the PM thought the flightcrew should stop at the hold line and contact ATC. Another one of the twelve flightcrews said that they would only cross the ILS hold line or approach hold if the alternating green and yellow lights (lead-on lights) were on, which might mean that this flightcrew was focused specifically on hold lines close to a runway. One of the twelve flightcrews did not say whether or not they would stop, but noted that ILS hold lines function to protect the ILS critical area.

3.2.3 Summary of Airport Markings (Study 2) Findings

Pilots generally followed ATC instructions and maintained their position awareness in LVO/SMGCS conditions using the FAA prototype chart. Pilots' responses to the questionnaire and interview questions revealed that the majority of pilots did not notice differences in GPM spacing or size. With regard to the "enhanced" taxiway markings, flightcrews' interview responses indicated that approximately half of the flightcrews noticed them and provided their opinion that they found the "enhanced" taxiway markings to be helpful. Pilot feedback also showed that flightcrew actions at ILS hold lines and approach hold lines are not clear. Most pilots indicated that they would only stop at ILS hold lines and approach holds if instructed to by ATC, which is in accordance with LVO/SMGCS procedures. However, some pilots provided feedback that they were unsure of the procedures for ILS hold lines and approach holds, particularly when they are located just short of the runway.

4. Summary and Recommendations

4.1 Summary

The results showed that an 8.5 x 11 inch (21.59 x 27.94 cm) black-and-white paper LVO/SMGCS chart was sufficient for flightcrews to maintain position awareness under worst-case scenario conditions for LVO/SMGCS. Flightcrews generally responded to ATC instructions properly and reported their locations correctly, demonstrating that LVO/SMGCS operations are generally safe. Flightcrews generally asked ATC for guidance when they were unsure of ATC instructions or LVO/SMGCS procedures.

All twelve flightcrews commented that GPMs were one of the most effective chart features for supporting their position awareness in LVO/SMGCS conditions. Feedback during the interviews also suggested improvements in the design of LVO/SMGCS charts. First, flightcrews indicated they could not always find and read information that was located within “cluttered” areas, where there was a lot of information. Second, flightcrews noted that low contrast between text and the background made some text difficult to read. Third, flightcrews found GPM symbols too small to read the GPM number inside the symbol. Fourth, flightcrews liked the readability of the 8.5 x 11 inch (21.59 x 27.94 cm) charts used in the study but commented that the chart size was larger than some providers’ charts and questioned whether the same information could be presented as effectively on a smaller chart.

The results from the symbol identification task showed that pilots reliably identified representative symbol shapes for GPMs and ILS hold lines. GPMs were identified as circles around a numeric GPM identifier and ILS hold lines were identified as a ladder shape. Pilots did not reliably identify representative symbols shape for clearance bars or non-movement areas. The results also suggested that pilots did not identify the dots as centerline lights used to distinguish active LVO/SMGCS runways and taxiways from non-active LVO/SMGCS runways and taxiways. It is important to note that the symbol shapes were shown in isolation without any chart context. With chart context available, pilots might have enough information to distinguish active and non-active runways and taxiways. Chart usability ratings indicated that flightcrews generally felt that the legends provided with the charts showed the information needed to establish, maintain, and/or regain position awareness. Interview responses indicated that flightcrews felt that a legend was important to have with the charts because flightcrews may not be familiar with or may have forgotten LVO/SMGCS symbology since LVO/SMGCS operations are conducted only rarely. Three flightcrews specified that they would like to have the legend depicted on the chart itself.

With regard to the “enhanced” airport markings, flightcrew objective measures showed no observable differences in taxi speed or compliance with ATC instructions due to variations in the depiction of GPMs or taxiway identifiers. Subjective measures showed that flightcrews generally did not notice differences in GPM spacing and size. About half of the flightcrews said that they noticed the “enhanced” taxiway identifiers and found them helpful, whereas the other half said that they did not notice them. Regarding LVO/SMGCS procedures, objective observations and interview findings indicated that most flightcrews understood that they needed to stop at ILS hold lines and approach holds only if instructed to by ATC.

However, some flightcrews noted that they were not sure about ILS hold line or approach hold procedures, particularly for ILS hold lines and approach holds located close to a runway. Additionally, several flightcrews appeared to be unaware of the difference between ILS hold lines and approach holds. Flightcrews also expressed concerns about the safety of LVO/SMGCS operations due to similarly-named taxiways and GPMs (e.g., taxiway Sierra 7 and GPM 7 Sierra).

To better understand flightcrew behavior the researchers examined each scenario, focusing on the flightcrew errors in an attempt to identify potential contributing factors and to understand whether those errors were the result of LVO/SMGCS charting. The next section presents the findings and Appendix G gives specific details on the total number of useable events (392 total) encountered and number of errors (8 total) made by the crews.

4.2 Flightcrew Error Analysis

The analysis of flightcrew errors focused on eight situations (out of a total of 392 events):

- There were six flightcrew failures to stop taxi and hold at positions instructed by ATC.
- There was one failure to report a position as instructed by ATC.
- There was one wrong turn of an aircraft off a runway onto a non-LVO/SMGCS short high-speed taxiway to an LVO/SMGCS parallel taxiway.

While the researchers made a best attempt to simulate a realistic flight deck and operating environment, the simulator did not have a designated area for the flightcrew to place their charts which possibly prohibited flightcrews from easily taking notes and recording ATC clearances. This is a standard practice in commercial operations today to ensure disciplined and correct flightcrew actions under extremely variable flight and weather conditions. In addition, the researchers introduced other variables in the study to examine flightcrew compliance under differing kinds of distractions. Examples included giving the flightcrews complex ATC clearances beyond the allowed number of ATC instructions per clearance, intentionally providing the flightcrew with confusing terminology in difficult airport locations—e.g. 9M, M9, 9N, N9 etc., and repeated queries to flightcrews about their current position without restating required hold instructions.

The eight flightcrew errors are reviewed below by scenario:

1. In Scenario 1, one of the eleven flightcrews reported passing 7S instead of holding. Flightcrew discussions indicated that they thought that ATC's instruction to "report 7S" meant that they no longer needed to hold at 7S. The researchers believe that a potential factor contributing to this failure to hold at 7S is that the ATC clearance was incorrectly given as "report spot 7 Sierra." ATC clearance protocols would have required this clearance to be "report spot 7S, and hold at 7S."
2. In Scenario 2 one flightcrew (out of 10) failed to hold at GPM 9M. Scenario 2 contained the most complicated clearances in this study; five of the flightcrews commented about the initial clearance, and three of the five flightcrews had ATC repeat it. Additionally, when the flightcrews

were on taxiway M8 they were instructed to report spot 9M without including the required "and hold at 9M."

3. In Scenario 4 after flightcrews passed spot 6N taxiing northbound they were instructed to hold at GPM 4N, which is about 974 feet (296.88 m) north of spot 6N on the taxiway. At 10 knots taxi speed the flightcrews had less than 1 minute to remember they were to hold at 4N. One flightcrew (out of 11) failed to hold there, and but there is no explanation of any contributing factor that might have affected the flightcrew's ability to follow the instruction.
4. In Scenario 5, the initial clearance was fully compliant with ATC clearance protocols. Flightcrews were instructed to land runway 36C, exit on Bravo at the end of the runway, then to hold and report at Spot 4B. One flightcrew held at Spot 4B but did not report, while the other 11 flightcrews correctly complied with the clearance. There is not any obvious contributing factor that could have influenced the crew action in this case.
5. Also in scenario 5, flightcrews were instructed by ATC to "report spot 2 Alpha and hold" after passing taxiway Yankee. Eleven flightcrews correctly complied with this instruction, but one flightcrew did not. The flightcrew discussions suggest that there was some confusion about the ATC instruction. That is, the PM indicated that he thought they were supposed to hold at GPM 2A but the PF thought the ATC instruction was to report passing. This discussion reflects the flightcrew's aeronautical decision making and may be indicative of a failure in crew resource management (CRM). That is, the PM perception should have encouraged the PF to take a conservative position, which would have led the PM to query ATC about the possible hold instruction.
6. Also in Scenario 6, one flightcrew departed runway 36R at the intersection with Sierra 3, a high speed taxiway for exiting 36R but one that did not have lead-off lights, and was not supposed to be used for LVO/SMGCS operations. This flightcrew initially thought they were on taxiway S4, but eventually realized their true position when they arrived at the intersection of taxiways S4 on S. In the night light environment of a flight deck in LVO/SMGCS conditions, and at 300 ft/75 m RVR, S3 and S4 are both high speeds, and the LVO/SMGCS charts in use show varying shades of gray between LVO/SMGCS taxiways and non-LVO/SMGCS taxiways. These varying gray shades on taxiways are not always distinguishable in night lighting conditions, and thus this error may reflect potential issues related to current LVO/SMGCS charting practices.
7. The last two errors identified during the study were failures to hold at ATC instructed hold points in Scenario 9. The ATC clearance for this scenario read "taxi to Runway 36C via Yankee, Alpha, Charlie, Pappa, Juliet, Romeo; hold at and report spot 3 Charlie." Ten of the twelve flightcrews followed the clearance correctly, but two flightcrews did not hold at or report GPM 3C. There are no apparent factors directly involved with these two flightcrews not correctly following their ATC clearance in this case.

Based on the preliminary examination of flightcrew errors, the researchers were surprised that flightcrews did not go back to ATC to clarify the confusing instructions (other than in Scenario 2). The researchers believe this finding suggests that flightcrews may have been operating somewhat differently in this simulation than in actual operational conditions, in which the daily disciplined practices of safe carriers encourages flightcrews to contact ATC when they are uncertain about the clearances and/or need clarification. (Notable exceptions to this practice may be found at JFK and ORD, where the radio frequencies are so busy that ATC cannot manage repeating instructions.) Based on the type of errors—where flightcrews did not contact ATC for clarification—it appears that flightcrews behaved as if these were simulated taxi scenarios, regardless of instructions that stressed that flightcrews operate as if they were on the line.

4.3 Recommendations

This research was conducted at KMEM and was designed to take into full consideration the true nature of LVO/SMGCS operations at that airport. Consequently, the specific scenarios have limited generalizability, particularly to more complex airports, and additional research is needed to understand how airport structures have mitigated complexity with respect to LVO/SMGCS plans. Regardless, our hope is that the results of this study provide an understanding of general LVO/SMGCS chart usability, particularly in the following areas. Each area noted below includes a summary of the issue and recommendations from relevant regulatory or guidance material.

- *Finding Information.* The results of these studies suggested that flightcrews may have had difficulty finding information on the LVO/SMGCS charts due to clutter. Flightcrews were of the opinion that some symbol shapes should be made more prominent, mainly, symbol shapes representing stop bars and active vs. non-active runways and taxiways. Information addressing these issues is provided in regulatory and guidance material:
    - "When different information elements are adjacent to each other on a display, the elements should be separated visually so the pilots can easily distinguish between them. Visual separation can be achieved with, for example, spacing, delimiters, or shading in accordance with the overall flight deck information management philosophy. Required information presented in reversionary or compacted display modes following a display failure should still be uncluttered and still allow acceptable information access time." [AC 25-11A, 31.e.(3); Electronic Flight Deck Displays]
    - "Information elements should be distinct and permit the pilots to immediately recognize the source of the information elements when there are multiple sources of the same kind of information." [AC 25-11A, 31.a.(1); Electronic Flight Deck Displays]
    - "The presentation of information shall be accurate, free from distortion and clutter, unambiguous, and be readable under all normal operating conditions." [ICAO Annex 4 to the Convention on International Civil Aviation, 2.1.3; Aeronautical Charts].
- *Legibility.* The results of these studies suggested that flightcrews may have had difficulty reading information due to clutter and small size (of text or the charts themselves). Flightcrews were also of the opinion that text was difficult to read in low-light conditions when there was a low contrast between the text and the chart background (e.g., black text on a gray taxiway and text on shaded GPMs). Information addressing these issues is provided in regulatory and guidance material regarding other applications:

    - "Information elements (text, symbol, etc.) should be large enough for the pilot to see and interpret in all foreseeable conditions relative to the operating environment and from the flightcrew station" [AC 25-11A, 31.a.(1); Electronic Flight Deck Displays]
    - "The contrast between all symbols, characters, lines, and their associated backgrounds should be sufficient to preclude confusion or ambiguity of any necessary information" [AC 25.11A, 16.a.(4)(b); Electronic Flight Deck Displays].
    - "Symbols should not have shapes, colors, or other attributes that are ambiguous or could be confused with the meaning of similar symbols" [Advisory Circular, AC 12.1311-1C, 17.1; Installation of Electronic Display in Part 23 Airplanes].
    - "Colours or tints and type size used shall be such that the chart can be easily read and interpreted by the pilot in varying conditions of natural and artificial light" [ICAO Annex 4 to the Convention on International Civil Aviation, 2.4.1; Aeronautical Charts].
    - "Sufficient contrast shall be provided between all displayed information and the display background to ensure that the required information can be perceived by the user under all expected lighting conditions" [MIL-STD-1472G, 5.2.1.5; Department of Defense Design Criteria Standard—Human Engineering].
- *LVO/SMGCS Operations and Procedures*. The results of this study suggested that flightcrews may be unclear about the procedures for ILS hold lines and approach holds during LVO/SMGCS conditions, particularly ILS hold lines and approach holds near the runway. The results also suggested that similar naming conventions for GPMs and taxiway identifiers could potentially lead to confusion when taxiing in LVO/SMGCS conditions. Mitigations may be needed when GPM and taxiway identifiers with similar naming conventions are used in the same clearance.
    - Information addressing procedures for LVO/SMGCS is provided in FAA guidance material:
    - "The SMGCS plan should identify any aspects of the following list of items that are specific or unique to the airport, relative to low visibility operations. Aircraft operators should address these items in appropriate training programs for all flightcrew and ground support personnel who may be involved in aircraft or vehicle operations on the movement or non-movement areas of the airport. Such training should also be documented. Training items include but are not limited to:
        - ILS critical areas, runway safety areas, and obstacle free zones
        - Taxiway centerline lights, including ILS critical area alternating green and yellow lights from runway centerline
        - Taxiway and runway hold position markings" [AC 120-57A, 12; Surface Movement Guidance and Control Systems (note: some items listed in this reference were not included because they were not relevant to ILS hold line or approach hold procedures)].
- *Future Research.* Future research is recommended in the following areas:
    - *LVO/SMGCS Chart Symbology.* Future research should identify representative symbol shapes for a broader range of symbol shapes and information types. Symbology

research should also consider the influence of chart context on the identification of symbol shapes. The Volpe Center is conducting this research currently.

- *Complex Airport Structures.* Future research should examine complex airport structures to understand how they have mitigated taxiway complexity with respect to LVO/SMGCS. The results described in this report are applicable to KMEM with some application to airports in general. However, airport procedures and geography vary enough from airport to airport that additional situations—especially larger and more complex airports—bear further scrutiny.

5. References

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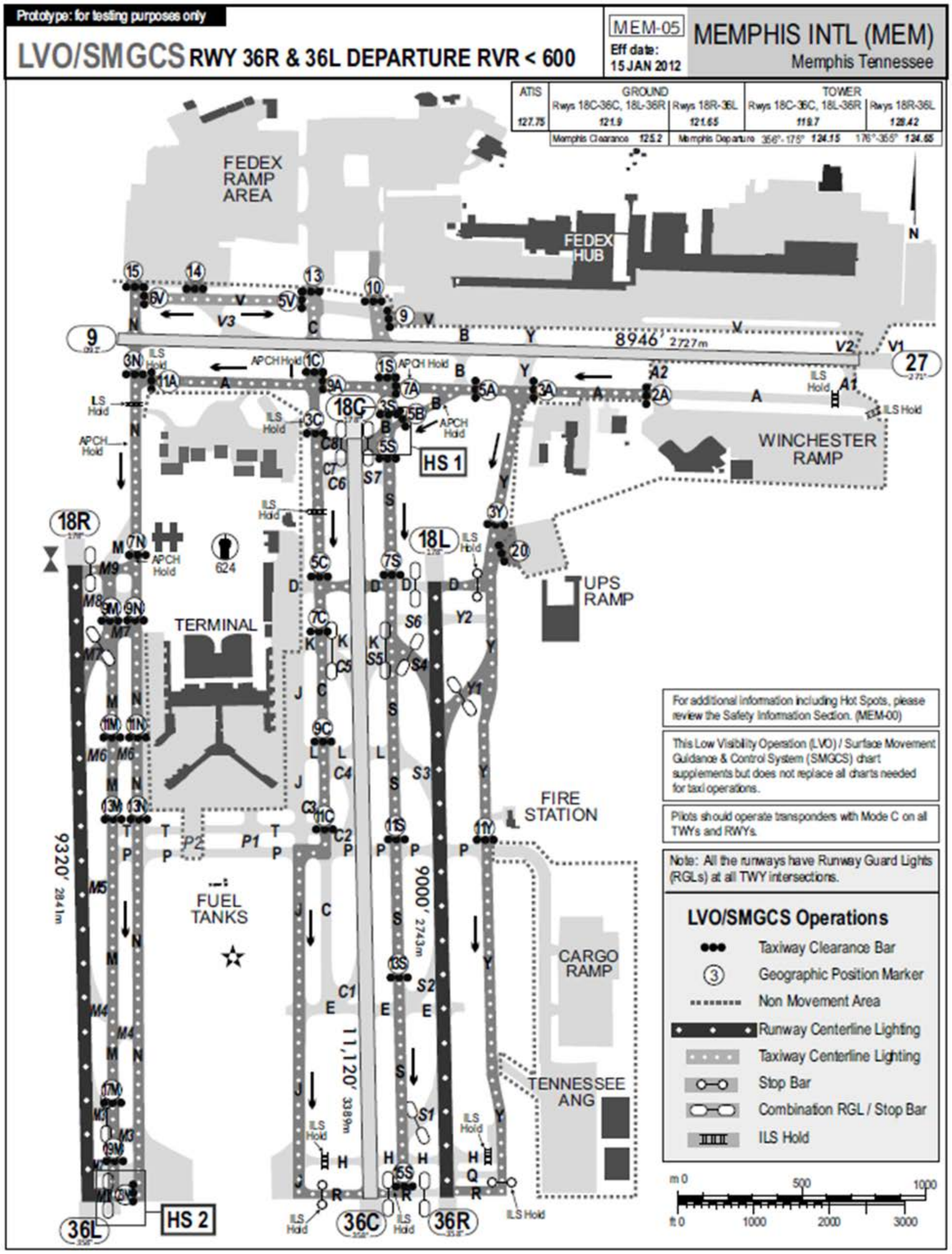
Appendix A: Example FAA Prototype LVO/SMGCS Taxi Chart



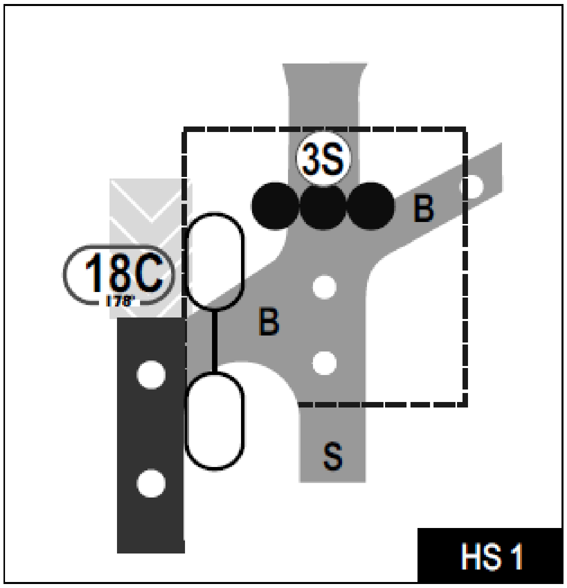
Appendix B: Example FAA Prototype Detailed Hot Spot and Lead-in Notes

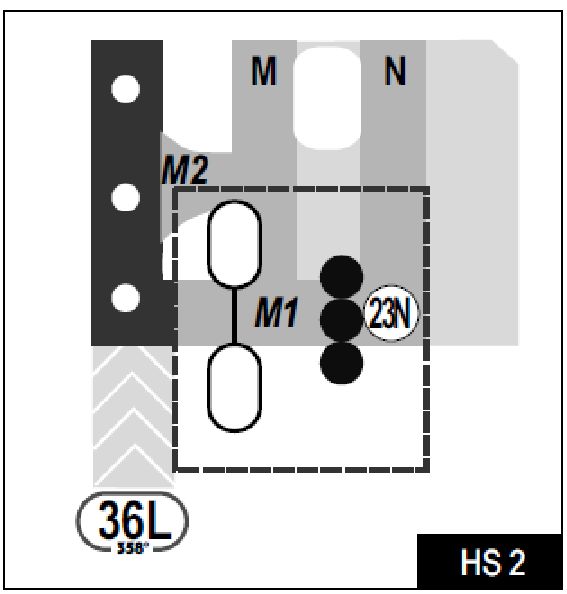
Prototype: for testing purposes only

KMEM LVO/SMGCS Safety Information Section

MEM-00
Eff date:
15 JAN 2012

MEMPHIS INTL (MEM)
Memphis Tennessee





This Low Visibility Operation (LVO) / Surface Movement Guidance & Control System (SMGCS) chart supplements but does not replace all charts needed for taxi operations. See other charts for additional information including Hot Spots.

Pilots should operate transponders with Mode C on all TWYs and rwys.

Memphis LVO/SMGCS

Notes:

Caution: Crews must be careful to choose the correct Departure or Arrival LOV/SMGCS chart for the taxi Flow Procedure in effect at time of operation.

RGLs are at all runway taxiway intersections and are not depicted on the charts.

Runways and taxiways not being used for SMGCS will have lights extinguished.

LVO/SMGCS routes taxiing north to south the applicable GPMs are odd numbered.

LVO/SMGCS routes taxiing south to north the applicable GPMs are even numbered.

GPM numbering starts at 1 in the northeast corner of the airport, and increases to the largest number at the southwest corner.

The GPM letter to the right of the Number corresponds to the taxiway on which the GPM is located.

Runways on the LVO/SMGCS taxi chart at Memphis shown in gray and outlined in black color have all runway lights extinguished for that particular taxi flow.

All non LVO/SMGCS taxiways at Memphis have all lights turned off during LVO/SMGCS operations.

Appendix C: Biographical Questionnaire

A. GENERAL BACKGROUND

1. What current flight ratings do you hold?

2. What is your current flying position (Captain, First Officer, Flight Engineer, Other)?

3. Flight experience:
   a. Total hours flying (approximately):
   b. Years flying (approximately):

4. Do you wear glasses while flying? (circle one) Yes / No
   If yes, what is your correction? (circle one) Bifocal / Trifocal / Distance / Reading

B. SURFACE OPERATIONAL EXPERIENCE

1. How many flight hours of SMGCS/Low Viz Ops (<1200' RVR) experience do you have?
   a. SMGCS simulator experience (in hours):
   b. SMGCS flight experience (in hours):

2. Please estimate the number of actual surface operations hours under:
   a. 1200'-600' RVR
   b. 500'-300'RVR
   c. Please estimate the number of total surface operations hours
   d. Please estimate the number of surface operations hours of which you've been pilot-in-command during taxi?

C. CHART EXPERIENCE

1. What type of manufacturer charts (Jeppesen Lido, FAA) do you currently use for surface (e.g., airport diagrams) operations?

2. Please estimate your familiarity, on scale from 0 (None) to 10 (Highly Familiar) with the following charts for general surface operations:
   a. Jeppesen
   b. Lido
   c. FAA

3. Please estimate your familiarity, on scale from 0 (None) to 10 (Highly Familiar) with the following charts for SMGCS low Visibility Operations (LVO):
   a. Jeppesen
   b. Lido

D. MEMPHIS EXPERIENCE

1. Please estimate your familiarity, on scale from 0 (None) to 10 (Highly Familiar) with the Memphis International (KMEM) airport:

2. Please estimate the number of surface operation hours at KMEM

3. Please estimate the number of surface operation hours of which you've been pilot-in-command during taxi at KMEM

E. TECHNOLOGY EXPERIENCE

1. Please estimate the number of hours and type of head-up display experience you have:

2. Please estimate the number of hours and type of enhanced vision (EV) or enhanced flight vision system (EFVS) experience you have:

   a. EV/EFVS simulator experience (in hours):
   b. EV/EFVS flight experience (in hours):

Appendix D: Chart Usability Questionnaire

Instructions – Chart Usability:

- Give Numerical Score Using Scale Provided.
- Please Add Additional Information As Appropriate.
- Were you the Pilot Taxiing? Yes No (Circle One)

1. The LVO/SMGCS charts I needed were easy to identify and select.

Strongly Disagree				Strongly Agree
1	2	3	4	5

Comments: ______________________________

2. The information on the LVO/SMGCS charts I needed was easy to find.

Strongly Disagree				Strongly Agree
1	2	3	4	5

Comments: ______________________________

3. I could read all the information on the LVO/SMGCS chart in the lighting conditions I encountered.

Strongly Disagree				Strongly Agree
1	2	3	4	5

Comments: ______________________________

4. I recognized and was able to tell the LVO/SMGCS chart's scale.

Strongly Disagree | Strongly Agree

1 2 3 4 5

Comments: ____

____

____

5. All the LVO/SMGCS charts I needed were available.

Strongly Disagree | Strongly Agree

1 2 3 4 5

Comments: ____

____

____

6. The LVO/SMGCS chart showed the information I needed to establish, maintain, and/or regain position awareness on the airport surface.

Strongly Disagree | Strongly Agree

1 2 3 4 5

Comments: ____

____

____

7. Use of the LVO/SMGCS chart _________ my understanding of taxi route clearances when communicating with air traffic control.

Hindered | Did Not Change | Improved

1 2 3 4 5

Comments: ____

____

____

8. The LVO/SMGCS chart I used provided sufficient awareness of my position with respect to ***runways.***

Strongly Disagree   Strongly Agree

1   2   3   4   5

Comments: ______________________________

9. The LVO/SMGCS chart provided sufficient awareness of my position when approaching ***runway-taxiway intersections****.*

Strongly Disagree   Strongly Agree

1   2   3   4   5

Comments: ______________________________

10. The LVO/SMGCS chart helped me determine which taxiway I was on.

Strongly Disagree   Strongly Agree

1   2   3   4   5

Comments: ______________________________

11. The LVO/SMGCS chart helped me identify necessary geographic positions relative to my LVO/SMGCS route.

Strongly Disagree   Strongly Agree

1   2   3   4   5

Comments: ______________________________

12. Runways were easily distinguishable from taxiways and other movement areas on the LVO/SMGCS chart.

Strongly Disagree   Strongly Agree

1   2   3   4   5

Comments: ____

____

____

13. The presentation of ILS hold lines on the LVO/SMGCS chart ________ my understanding of my position on the airport surface. ***[for FAA chart only]***

Hindered   Did Not Change   Improved

1   2   3   4   5

Comments: ____

____

____

14. The availability of detailed information on the hot spots ________ my understanding of my position when taxiing through those locations. ***[for FAA chart only]***

Hindered   Did Not Change   Improved

1   2   3   4   5

Comments: ____

____

____

15. The training I received on how to use the LVO/SMGCS chart was adequate.

Strongly Disagree   Strongly Agree

1   2   3   4   5

Comments: ____

____

____

What additional training would you like (if any)?

____

____

Appendix E: Symbol Identification Questionnaire

There were three symbol identification questionnaires, one for each chart provider used in Study 1 (Chart Usability). Each questionnaire asked specifically about the LVO/SMGCS chart symbols shown on the charts that the flight crew had just used during the scenarios. For example, after completing scenarios using the FAA prototype LVO/SMGCS chart, flight crews completed a questionnaire that asked about symbols shown on the FAA prototype LVO/SMGCS chart. The three questionnaires are provided below.

Symbol Identification Questionnaire 1:

SMGCS Symbol Usefulness

Directions: For each symbol shown in the table below, please write what you think the symbol means and how useful it was to you during your taxi operations.

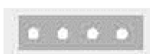
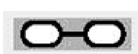
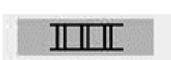
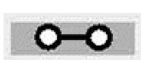
Symbol	What does the symbol mean?	Very useful	Somewhat useful	Not useful
	Identifies runway location	✓		
				
				
				
				
				
				

E X A M P L E

Symbol Identification Questionnaire 2:

SMGCS Symbol Usefulness

Directions: For each symbol shown in the table below, please write what you think the symbol means and how useful it was to you during your taxi operations.

Symbol	What does the symbol mean?	Very useful	Somewhat useful	Not useful
	Identifies runway location	✓		
				
				
				
				
				
				
				
				

E X A M P L E

Symbol Identification Questionnaire 3:

SMGCS Symbol Usefulness

Directions: For each symbol shown in the table below, please write what you think the symbol means and how useful it was to you during your taxi operations.

Symbol	What does the symbol mean?	Very useful	Somewhat useful	Not useful
	Identifies runway location	✓		
				
				
				
				
				
				
				
				

E X A M P L E

Appendix F: Airport Markings Questionnaire

Instructions – Chart Usability:

- Give Numerical Score Using Scale Provided.
- Please Add Additional Information As Appropriate.
- Were you the Pilot Taxiing? Yes No (Circle One)

1. The LVO/SMGCS charts I needed were easy to identify and select.

Strongly Disagree				Strongly Agree
1	2	3	4	5

Comments: ____

____

____

2. The information on the LVO/SMGCS charts I needed was easy to find.

Strongly Disagree				Strongly Agree
1	2	3	4	5

Comments: ____

____

____

3. I could read all the information on the LVO/SMGCS chart in the lighting conditions I encountered.

Strongly Disagree				Strongly Agree
1	2	3	4	5

Comments: ____

____

____

4. All the LVO/SMGCS charts I needed were available.

Strongly Disagree				Strongly Agree
1	2	3	4	5

Comments: ____

____

____

5. The LVO/SMGCS chart showed the information I needed to establish, maintain, and/or regain position awareness on the airport surface.

Strongly Disagree				Strongly Agree
1	2	3	4	5

Comments: ____

____

____

6. Use of the LVO/SMGCS chart ________ my understanding of taxi route clearances when communicating with air traffic control.

Hindered		Did Not Change		Improved
1	2	3	4	5

Comments: ____

____

____

7. The LVO/SMGCS chart I used provided sufficient awareness of my position with respect to ***runways.***

Strongly Disagree				Strongly Agree
1	2	3	4	5

Comments: ____

____

____

*8. The LVO/SMGCS chart provided sufficient awareness of my position when approaching **runway-taxiway intersections**.*

Strongly Disagree Strongly Agree

1 2 3 4 5

Comments: ______________________________

____

____

9. The LVO/SMGCS chart helped me determine which taxiway I was on.

Strongly Disagree Strongly Agree

1 2 3 4 5

Comments: ______________________________

____

____

10. The LVO/SMGCS chart helped me identify necessary geographic positions relative to my LVO/SMGCS route.

Strongly Disagree Strongly Agree

1 2 3 4 5

Comments: ______________________________

____

____

11. Runways were easily distinguishable from taxiways and other movement areas on the LVO/SMGCS chart.

Strongly Disagree Strongly Agree

1 2 3 4 5

Comments: ______________________________

____

____

12. The GPMs supported my position awareness while taxiing.

Strongly Disagree Strongly Agree

1 2 3 4 5

Comments: ______________________________

____

____

13. The distance from one GPM to another was the same in all the scenarios.

Strongly Disagree Strongly Agree

1 2 3 4 5

Comments: ______________________________

____

____

14. Was the presentation of the GPM on the airport surface appear more visible in one of the scenarios than the others?

__________ Yes

__________ No

15. The pavement markings for taxiways provided sufficient awareness of my position with respect to ***other taxiways*** *relative to the LVO/SMGCS chart alone.*

Strongly Disagree Strongly Agree

1 2 3 4 5

Comments: ______________________________

____

____

Appendix G: Categorization of Flight Crew Compliance with ATC Instructions

Table 1 shows the total number of errors made for each location type (e.g., GPMs, taxiways) across all scenarios. The "total number of events" column contains the total number of events across all crews and scenarios, including those that were used in the error counts and those that were not. The "events not used" column provides the number of events that were omitted from the error counts, with a reason provided in the "reason event not used" column. The events that *were used* were categorized into the following error types:

- No errors
- Failed to report
- Failed to hold
- Wrong turn

As the last row in Table 1 shows, 22 out of 408 total events were not used in the examination of flightcrew compliance. This resulted in a total of 392 total events included in the examination. Of these, there were 378 events with no flightcrew errors and 8 events with flightcrew errors. A detailed summary of the errors by scenario is provided in Table 2.

Table 1. Error Totals by Location Type

Location	Total Number of Events	Events Not Used	Reason Event Not Used	Error Counts for Events Used				*Total Errors*
				No Errors	Failed to Report	Failed to Hold	Wrong Turn	
LVO/SMGCS Runway	24	0		24	0	0	0	*0*
Non-LVO/SMGCS Runway	36	4	- ATC failed to give the instruction to hold	32	0	0	0	*0*
Taxiway	132	5	- ATC instruction was overridden by an early trigger of the next pre-recorded instruction (2 events) - Simulator froze and data were lost (2 events) - Discrepancy between chart and out-the-window (OTW) view: lights seen OTW on non-LVO/SMGCS taxiway (1 event)	126	0	0	1	*1*
GPM	156	11	- ATC instruction was overridden by an early trigger of the next pre-recorded instruction (6 events) - Simulator froze and data were lost (2 events) - Researcher ended simulation before the event occurred (2 events) - ATC failed to give the instruction due to their headphones malfunctioning (1 event)	138	1	6	0	*7*
Approach Hold	48	0		48	0	0	0	*0*
ILS Hold	12	0		12	0	0	0	*0*
Total	*408*	*20*		*380*	*1*	*6*	*1*	*8*

Table 2 contains detailed information about the errors from Table 1 by scenario. Also provided are counts and descriptions of additional actions taken by crews (e.g., stopping or reporting position) that were not instructed by ATC. Relevant communications with ATC are also included. Communications with ATC include those related to errors as well as correct actions.

Table 2. Detailed Error Summary by Scenario and Location Type

Scen-ario	Location	Total Number of Events	Events Not Used	Error Counts				Error Description	Additional Crew Actions Not Instructed by ATC	Communications with ATC
				No Errors	Failed to Report	Failed to Hold	Wrong Turn			
1	Non-LVO/ SMGCS Runway	12	0	12	0	0	0			
	GPM	36	1	34	0	1	0	1 crew reported passing 7S instead of holding. The ATC instruction was to "hold at spot 7 Sierra." About 3 min later when ATC told the crew to "report spot 7 Sierra," the pilot flying (PF) said to the pilot monitoring (PM) "ok so we don't have to hold 7 Sierra."		

Scen-ario	Location	Total Number of Events	Events Not Used	Error Counts				Error Description	Additional Crew Actions Not Instructed by ATC	Communications with ATC
				No Errors	Failed to Report	Failed to Hold	Wrong Turn			
2	Non-LVO/ SMGCS Runway	12	0	12	0	0	0			
	Taxiway	24	1	23	0	0	0		2 crews held at M8. ATC's instruction was to "report passing" M8.	
	GPM	36	3	32	0	1	0	1 crew reported passing 9M instead of holding. The reason was not specified by the crew. The ATC instruction was to "taxi to spot 9 Mike." About 1 min later ATC told the crew to "report spot 9 Mike. This was the same crew who reported passing instead of holding in scenario 1.	11 crews reported their position to ATC when holding at 7N. ATC's instruction was to "hold short spot 7 November."	ATC told 1 crew to hold their position when the crew did not hold at 9M.
	Approach Hold	12	0	12	0	0	0			

Scen-ario	Location	Total Number of Events	Events Not Used	Error Counts				Error Description	Additional Crew Actions Not Instructed by ATC	Communications with ATC
				No Errors	Failed to Report	Failed to Hold	Wrong Turn			
	ILS Hold	12	0	12	0	0	0			
3	Taxiway	36	2	34	0	0	0		8 crews stopped at GPM 5S ahead of S7. ATC's instruction was to "hold your position abeam taxiway Sierra 7."	
	Approach Hold	12	0	12	0	0	0		5 crews stopped at the approach hold; 3 of the 5 moved on without contacting ATC; 2 of the 5 talked to ATC.	ATC asked 1 crew for their position they noticed the crew holding at the approach hold. The crew responded that they were holding short of taxiway S. 1 crew contacted ATC while holding at the approach hold; the crew said they were holding short of taxiway S.
4	Taxiway	12	0	12	0	0	0			

Scen-ario	Location	Total Number of Events	Events Not Used	Error Counts				Error Description	Additional Crew Actions Not Instructed by ATC	Communications with ATC
				No Errors	Failed to Report	Failed to Hold	Wrong Turn			
	GPM	24	1	22	0	1	0	1 crew failed to hold at 4N (reason unknown).	9 reported their position to ATC when holding at 4N. ATC's instruction was to "hold at spot 4 November."	1 crew reported their first GPM as 6M (9M upside down) and ATC corrected them.
	Approach Hold	12	0	12	0	0	0			
5	Taxiway	24	0	24	0	0	0		2 crews reported to ATC that they were clear of the runway (on taxiway B).	
5	GPM	24	0	22	1	1	0	- 1 crew reported passing 2A instead of holding. The ATC instruction was to "taxi to spot 2 Alpha," followed about 1 min later by the instruction to "report spot 2 Alpha." About 1 min later at 2A, the PM thought they were supposed to hold but the PF thought they were instructed to report passing (based on crew's discussion). - 1 crew failed to report their position when holding at 4B (reason unknown).		ATC asked 1 crew for their position when the crew failed to report at 4B. The crew responded with the correct location.

Scen-ario	Location	Total Number of Events	Events Not Used	Error Counts				Error Description	Additional Crew Actions Not Instructed by ATC	Communications with ATC
				No Errors	Failed to Report	Failed to Hold	Wrong Turn			
	Approach Hold	12	0	12	0	0	0			
6	Non-LVO/ SMGCS Runway	12	4	8	0	0	0		5 crews reported holding short of runway 9. ATC's instruction was to "hold short of runway 9."	6 crews asked ATC if they were cleared to cross 9 before they reached the runway; ATC told 2 of the 6 to hold but did not respond to the other 4 (the 4 includes 1 of the events not used)
	Taxiway	36	2	33	0	0	1	1 crew exited 36R on non-LVO/SMGCS taxiway S3. ATC's instruction was to "exit to the west." The crew initially thought they were on S4 but realized the error when they reached the intersection with S4 on Sierra.	5 crews reported to ATC that they were clear of runway (on taxiway S4).	The crew who exited on S3 notified ATC when they realized their actual location at the intersection of S4 on Sierra.
	GPM	12	6	6	0	0	0			
7	LVO/ SMGCS Runway	12	0	12	0	0	0		- 12 crews reported holding short of 36C. The ATC	

Scen-ario	Location	Total Number of Events	Events Not Used	Error Counts				Error Description	Additional Crew Actions Not Instructed by ATC	Communications with ATC
				No Errors	Failed to Report	Failed to Hold	Wrong Turn			
									instruction was to "taxi to runway 36 Center." - 4 crews held at the ILS hold before runway 36C.	
8	LVO/ SMGCS Runway	12	0	12	0	0	0		- 12 crews reported holding short of 36L. The ATC instruction was to "taxi to runway 36 Left." - 3 crews held at GPM 23N before runway 36L (including 2 or the 4 crews who held at the ILS hold in scenario 7).	
9	GPM	12	0	10	0	2	0	2 crews failed to hold or report at 3C (reason unknown).		ATC told 2 crews to hold their position when the crews failed to hold or report at 3C.
10	GPM	12	0	12	0	0	0		12 crews reported holding at 3C. ATC's instruction was to "hold at spot 3 Charlie."	

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