First Responder Robotic Operations System Test (FRROST): Small Unmanned Aircraft Systems for Search and Rescue

Assessment Report

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FOREWORD

The U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) initiated a program to better understand how small unmanned aircraft systems (UAS) can support first responder missions. One component of this program was the First Responder Robotic Operations System Test (FRROST), a test and evaluation effort to assess specific UAS for specific public safety missions of interest to first responders.

Under the FRROST program, the National Urban Security Technology Laboratory (NUSTL) assessed commercially available UAS under realistic field conditions according to priority use cases identified by S&T's First Responder Resource Group (FRRG). The FRRG is an all-volunteer working group made up of first responders from all major disciplines and different regions of the country. The group helps DHS S&T maintain focus on the top-priority needs of responders in the field. Following the model established by the DHS S&T NUSTL System Assessment and Validation for Emergency Responders (SAVER) Program, FRROST conducted a focus group and assessment of UAS in one priority use case identified by FRRG. NUSTL coordinated these efforts with the National Institute of Standards and Technology (NIST) and DHS S&T Office of Mission & Capability Support (MCS).

The purpose of FRROST was to identify the needs and requirements of first responders when using UAS in particular use cases; to assess commercially available UAS and sensors; to validate NIST standard development efforts; and to create knowledge products to aid responders in making purchasing decisions.

Moving forward, another DHS S&T project called Joint Unmanned Systems Testing in Collaborative Environment, or JUSTICE, will assess UAS and sensors for the Homeland Security Enterprise. JUSTICE is managed by the S&T MCS Air Based Technologies Program and a team of experts from the Mississippi State University Raspet Flight Research Laboratory.

For more information on S&T NUSTL, visit www.dhs.gov/science-and-technology/national-urban-security-technology-laboratory.

For more information on S&T MCS, visit www.dhs.gov/science-and-technology/office-mission-and-capability-support.

For more information on NUSTL's SAVER Program, visit www.dhs.gov/science-and-technology/SAVER.

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EXECUTIVE SUMMARY

In November 2019, the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) National Urban Security Technology Laboratory (NUSTL) assessed small unmanned aircraft systems (UAS) under the First Responder Robotic Operation System Test (FRROST) program. Commonly called "drones," small UAS consist of an unmanned aerial vehicle (UAV) with a gross take-off weight of less than 55 pounds, associated sensors, and a ground control station. The evaluation took place at the Combined Arms Collective Training Facility located at Camp Shelby, MS. The facility provided both simulated urban and rural environments.

Four UAS products were evaluated by first responders during this assessment. The evaluation criteria and scenarios used in this assessment were derived from the results of a focus group of first responders with experience using UAS for search and rescue missions. [1] At the recommendation of the focus group, a large range of sizes and prices of UAS were selected for evaluation. Several responders who participated in the focus group were also present at the assessment.

Responders flew the UAS in two simulated scenarios focused on search and rescue. In one scenario the first responders searched for survivors in a "post disaster" simulation. In the other scenario the first responders looked for a "lost hiker" in the rural environment. Both scenarios were then repeated in twilight conditions. Following each scenario, the responders were surveyed about their impression of various evaluation criteria relevant to that scenario. Responders also tested the UAS on a course created for assessing UAS capabilities and pilot skill by the National Institute of Standards and Technology (NIST). Responders also assessed how suitable each UAS's specifications were for their needs.

While FRROST follows the DHS S&T NUSTL System Assessment and Validation for Emergency Responders (SAVER) Program's paradigm employing user-defined criteria for the evaluation of commercial-off-the-shelf technology, one notable difference between this and a typical SAVER assessment report is the presentation of results. This report does not use SAVER's categories or quantitative scoring formula because the large disparity in size, weight, cost, and primary use between the products renders them not directly comparable. Therefore, the results included in this report are presented individually for each UAS.

Four models were assessed: Autel Robotics EVO, Intel Falcon 8+, FLIR SkyRanger R60/R70, and Solute Eagle XF. Overall, the Autel Robotics EVO is the smallest, lightest, and least expensive of the UAS assessed; it is also the only model of those assessed with a collision avoidance feature. Evaluators stated that the EVO is a good retail model with some public safety applications.

Of the models assessed, the Intel Falcon 8+ is the second lightest and the only one designed as a non-networked system with no connections to the internet. Evaluators stated that the Falcon 8+ may not be rapidly deployable or rugged enough for some of their public safety missions. Some offered that it may be best suited for inspections, fire prevention, brush clearance, geographic information systems (GIS)/engineering, and pre-deployment planning missions.

The FLIR SkyRanger R60 and R70 are the second largest of the UAS models assessed and the only models among the four with integrated strobe lights, self-heating batteries, and the ability to manually select radio frequencies. Evaluators gave positive feedback about many of the features of the aircraft but stated that many agencies would likely buy less expensive models.

The Solute Eagle XF is the largest and heaviest model in this assessment and the only model that requires two-person operation. Evaluators pointed out that this is a larger and more complex UAS than they would typically want for their search and rescue missions, but that its high payload capacity could accommodate different cameras to expand its uses. They noted that it may be best suited for long-range/heavy-lift missions (e.g., wildfire fighting) or for industrial applications.

The table below summarizes evaluator feedback on the advantages and disadvantages of each UAS based on the highest- and lowest-rated evaluation criteria.

Advantages/Disadvantages Summary Table

Manufacturer/Product	Advantages	Disadvantages
 **Autel Robotics EVO**	• packaging is portable, compact and lightweight • fast and simple to deploy • quick and easy battery replacement • easy to use; intuitive and responsive • good live view capability	• is not IP rated • does not have hot-swappable or self-heating batteries • does not have a swappable camera payload or good payload capacity • no third-party control software
 **Intel Falcon 8+**	• hot-swappable and easy to change batteries • 35 to 45-minute battery recharge time • good visual warnings and audible alerts • easily swappable camera pack	• does not have self-heating batteries • no option to wirelessly relay video to a remote location or secondary display • short flight time and short range from controller • does not have collision avoidance feature
 **FLIR SkyRanger R60/R70**	• hot-swappable batteries (R70) and self-heating batteries • good live view capability (R70) • 30-50-minute flight times • wind tolerances of 40 mph sustained and 56 mph gusts • good return to home capability	• does not have hot-swappable batteries (R60) • lack of first-person view (R60) • difficulty with reliability of video feed during the assessment (R60) • does not have collision avoidance feature
 **Solute Eagle XF**	• clear image and video • good omnidirectional pan/tilt capability of camera • adaptable to swapping cameras and payloads • good dual optical and infrared camera • accurate and smooth waypoint flight	• larger than evaluators need • lengthy deployment time • does not have hot-swappable or self-heating batteries • complicated to use • short 30-day warranty

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1.0 INTRODUCTION

Small unmanned aircraft systems (UAS), those with a gross take-off weight under 55 pounds, offer tremendous potential for first responders supporting public safety missions. UAS have widespread applications in public safety, can carry out missions at a fraction of the cost of manned aerial response, and may keep responders out of personal danger. They may be used for situational awareness, reconnaissance, or search and rescue operations, for example.

In November 2019, the Department of Homeland Security (DHS) National Urban Security Technology Laboratory (NUSTL), in collaboration with the National Institute of Standards and Technology (NIST) under the First Responder Robotic Operations System Test (FRROST) program, conducted an operationally-oriented assessment of UAS for search and rescue missions at Camp Shelby Joint Forces Training Center (hereafter "Camp Shelby") near Hattiesburg, Mississippi.

The purpose of this assessment was to obtain information on UAS that will be useful in making operational and procurement decisions. The activities associated with this assessment were based on recommendations from a June 2018 focus group of first responders with experience using UAS for search and rescue. [1]

1.1 EVALUATOR INFORMATION

Nine evaluators from law enforcement, fire services, and emergency management agencies nationwide participated in the FRROST assessment. Evaluators were selected for the assessment based on their respective responder discipline, geographic location, and professional and operational experience. Each evaluator was required to be an experienced UAS pilot and a Certified Remote Pilot under the Federal Aviation Administration's Small UAS Rule, Part 107. [2]

Evaluators signed rules of behavior, informed consent, and Camp Shelby hold-harmless forms. They were asked to bring the gloves they use during first responder missions to evaluate the gloves' compatibility with various UAS ground control stations (hereafter, "controllers"). Evaluator information is listed in Table 1-1.

Table 1-1 Evaluator Information

Evaluator	State
Firefighter	California
Firefighter/Paramedic	California
Police Officer	Colorado
Emergency Manager	Kansas
Firefighter	New York
Police Officer	Texas
Firefighter	Virginia
Firefighter/Remote Pilot	Virginia
Police Officer/Remote Pilot	Virginia

1.2 ASSESSMENT PRODUCTS

Four UAS from the products recommended by the focus group were selected for the assessment. Focus group participants expressed an interest in evaluating the capabilities of UAS from different manufacturers, spanning a wide range of sizes and price points. Focus group participants were interested in seeing how lower priced UAS compare to more expensive UAS. Final selection was based on how well each UAS met the product selection criteria identified by the focus group, could be acquired for testing, and gained approval for flight operations at Camp Shelby. Because of the large disparity in their size, weight, cost, and primary uses, the products are not directly comparable to one another. Therefore, results are presented individually for each UAS. NIST supplied the UAS through agreements with vendors who participated to support the UAS familiarization and assessment. UAS were equipped with sensors and cameras recommended by the focus group. In one case, the vendor (FLIR) brought an older version (R60) and current generation (R70) of the SkyRanger UAS. Evaluators provided feedback on individual features of each SkyRanger model.

Table 1-2 presents the assessed products, organized from smallest to largest UAS, along with key specifications from manufacturers' literature, internet resources, or vendor communications. The ingress protection (IP) ratings that apply to the products are listed in the table with their respective meanings explained at the bottom. The sections of this report that follow provide a more detailed discussion of each of the four UAS that were evaluated.

Table 1-2 Assessed Products Key Specifications

Key Specifications	Autel Robotics EVO	Intel Falcon 8+	FLIR SkyRangerR60/R70	Solute Eagle XF
Image				
Price Range	$1,000 - $1,500	$25,000 - $50,000	$70,000 - $120,000	$25,000 - $50,000
Size	10.4” x 10.1” x 5.4”	30.2” x 32.2” x 6.3”	R60: 23.6” R70: 31.5” (motor to motor)	71” (propeller tip to propeller tip)
Weight	1.9 lbs.	4.4 lbs.	R60: 5.3 lbs. R70: 9.9 lbs.	28.5 lbs.
Flight Time	30 min	16-26 min	R60: 30-50 min R70: 40-50 min	45 min
Range from Controller	4.3 miles	0.6 miles	R60: 1.86 miles* R70: 5 miles	1.24 miles
Maximum Horizontal Speed	45 mph	40 mph	R60: 31 mph R70: 31 mph	11 mph
Payload Capacity	0.3 lbs.	1.76 lbs.	R60: 1.5 lbs. R70: 4.4 lbs.	7 lbs.
Temperature Range	32°F to 104°F	23°F to 104°F	-22°F to 122°F	20°F to 104°F
Ingress Protection (IP) Rating	Not Rated	Not Rated	R60: IP53 R70: IP54	IP21
Self-Heating Batteries	×	×	✓	×
Thermal Imaging	EVO II	✓	✓	✓
Collision Avoidance	✓	×	×	×
Manual Frequency Change Capability	×	×	✓	×
Ability to Save Preprogrammed Flights	✓	✓	✓	✓

✓— product is equipped with corresponding feature
× — product is not equipped with corresponding feature

* With standard antenna. Range can be increased to 6.21 miles with optional directional antenna.

IP = Ingress Protection Rating, where:
IP21 = protected from particles larger than 12.5 mm and vertical dripping water
IP53 = protected from dust and spraying water at any angle up to 60 degrees from vertical
IP54 = protected from dust and water splashing from any direction.

1.2.1 AUTEL ROBOTICS EVO

The Autel Robotics EVO (Figure 1-1) is a small quadcopter that measures approximately 10 by 10 inches. It weighs 1.9 lbs. and can carry a 0.3 lb payload. It has a range of 4.3 miles and flight time up to 30 minutes.

Figure 1-1 Autel Robotics EVO Assembled and Packaged

The controller (Figure 1-2) has an integrated 3.3-inch display. An available option allows pilots to connect a phone for a larger graphical user interface screen, but a phone is not required for flight control. Mission planning software is built into the main platform and its outputs work with existing mapping software.

The EVO does not have an ingress protection rating as the level of environmental protection against particles and water has not been evaluated. During the assessment, the vendor stated that the UAS can operate in light rain.


Figure 1-2 Autel Robotics EVO Controller

For the assessment, the EVO was equipped with a 4K optical camera with 8x digital zoom and a 3-axis gimbal. The camera did not have thermal imaging capability. The evaluators were also able to examine a pre-production prototype of the next model, the EVO II, at the assessment. The EVO II does have a camera payload option that includes thermal imaging. Assessment data (in the above table and in a later section) is based on the original EVO, as the EVO II was not yet commercially available, something that makes it ineligible to be evaluated under FRROST's mandate. Evaluators did however provide feedback on the EVO II's thermal payload.

1.2.2 INTEL FALCON 8+

The Falcon 8+ (Figure 1-3) is an octocopter UAS sold by Intel. Its measurement profile is 30.2 by 32.2 by 6.3 inches. It weighs approximately 4.4 lbs. and can carry a maximum weight of 1.76 lbs. This product has a range of 1 km (0.6 miles) and a video feed reliable up to 500 m (0.3 miles).

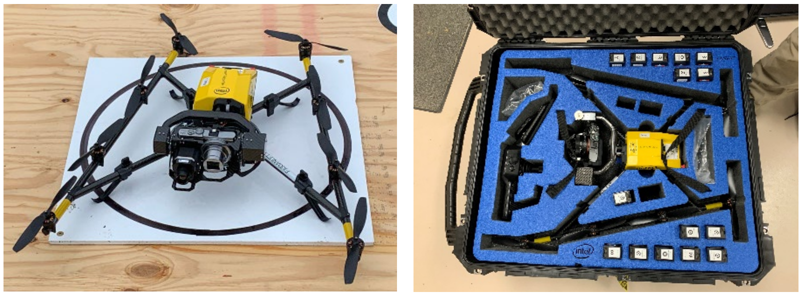
Figure 1-3 Intel Falcon 8+ Assembled and Packaged

Unlike the other UASs in the assessment, the Falcon 8+ is designed as a non-networked system, which means it has no ability to contact the internet without a physical connection.

Figure 1-4 Intel Falcon 8+ Controller

The ground controller (Figure 1-4) features a dual joystick and is held with a harness during operation. With its unique controller grip, the UAS can be controlled with one hand. The Falcon 8+ UAS can undertake autonomous missions with proprietary Intel Mission Control software. This means pilots can model three-dimensional structures for the purpose of mission planning. If a mission has been flown before, it is possible to save the flight and run the same flight path again autonomously.

The Intel Falcon 8+ has hot-swappable batteries with a 30 second turnaround. The ground controller can be operated for 2.5 hours before requiring a recharge. Batteries require 35 minutes to recharge. The product can operate in 26.8 mph winds in its Height Mode, and 35.8 mph winds in its Manual Mode. The Falcon 8+ does not have an ingress protection rating because its level of environmental protection against particles and water has not yet been evaluated.

For the assessment, the Falcon 8+ was equipped with a FLIR 640 TAU thermal camera and Lumix optical camera payload with 10x optical and 20x digital zoom.

1.2.3 FLIR SKYRANGER R60/R70

Two models of the FLIR SkyRanger, the R60 and R70, were evaluated. The SkyRanger was originally marketed as the Aeryon SkyRanger, prior to FLIR's acquisition of Aeryon. The R70, shown packaged and ready to fly in Figure 1-5, is considered the current generation, while the R60, pictured in Figure 1-6, is a legacy system. The R60 weighs 5.3 lbs. while the R70 weighs 9.9 lbs.

Figure 1-5 FLIR SkyRanger R70 Packaged and Assembled

The controller pictured in Figure 1-7 can be used with both the R60 and the R70. It features two panels with various buttons and joysticks, one on either side of a tablet. The UAS can be flown manually by using the joysticks and buttons or by using a stylus on the screen of the tablet. The aircraft can also be flown using just the tablet, with the joystick portions that frame it removed.

Figure 1-6 FLIR SkyRanger R60 Assembled and Packaged

Missions can be planned and executed from the tablet, which runs the Microsoft Windows operating system. The R60 and R70 use the same flight software. The R70 can also be operated and powered via an optional tether (not evaluated). It can also be equipped with a drop system, allowing for delivery of payloads up to 4.4 lbs. (not evaluated). The R60 and R70 have self-heating batteries. Both aircraft are rated to IP53 and IP54 respectively.

Figure 1-7 FLIR SkyRanger Controller

For the assessment, two payloads were evaluated, a different one on each model: the HDZoom (consisting of a 30x optical and 60x digital zoom) installed on the R60, and the EO/IR MK-II (featuring both visible light and infrared cameras) installed on the R70.

1.2.4 SOLUTE (UAV-AMERICA) EAGLE XF

The Eagle XF (Figure 1-8) is a quadcopter UAS made by UAV-America, a subsidiary of Solute Inc. Avion Unmanned Solutions, the company's training partner, supplied and flew the Eagle XF at the assessment. The Eagle XF is 71 inches across from propeller tip to propeller tip. It weighs approximately 28.5 lbs. and can carry 7 lbs. It has a range of 1.26 miles and flight time of 45 minutes.

Figure 1-8 Solute Eagle XF Assembled and Packaged

The Eagle XF requires two operators. One operator positions the payload and the other flies the UAS with the controller (Figure 1-9). The UAS is capable of planning autonomous flight tracks.

The Eagle XF uses 22000 milliampere hour (mAh) 6-cell batteries. It has an environmental protection rating of IP21.

The payload connections for this system are modular, which allows any payload with the right configuration to be used. During the assessment, the Eagle XF had an 18x zoom EO/IR 4K camera with zoom and infrared.

Figure 1-9 Solute Eagle XF Controller

2.0 EVALUATION CRITERIA

Evaluators were asked to rate the UAS according to criteria established in the focus group. For each criterion, evaluators rated how the UAS specification or performance would meet their mission needs on a scale from 1 to 5. In this case, 1 meant "strongly disagree," 2 meant "disagree," 3 meant "neither agree nor disagree," 4 meant "agree," and 5 meant "strongly agree." For example, if the criterion "ease of use" was given a rating of 5, that meant that the evaluator strongly agreed the UAS's ease of use met the evaluator's mission needs. For criteria that could not be tested during the operational assessment (e.g., wind tolerance), evaluators rated the criterion according to the manufacturer's stated value.

For those criteria that could be assessed operationally, NUSTL personnel collected feedback in individual interviews after the evaluator piloted the aircraft. For criteria evaluated according to manufacturer's specifications, evaluators completed written surveys during their lunch periods and, in one instance, during the vendor familiarization portion of the assessment.

Table 2-1 details the evaluation criteria. The functional categories shown in the table were added after the event to help organize data. Within the functional categories, the criteria are listed in order of importance to the responders.

Table 2-1 Evaluation Criteria

Functional Category	Evaluation Criteria	Description
Physical Features	Cache packaging	The size, weight, and portability of the UAS and its associated sensors and batteries as packed for transport
	Time to deploy	The amount of time it takes a remote pilot to unpack, setup, and launch the UAS
	IP rating	The ingress protection rating, or IP rating, of the UAS, which measures housing protection from intrusion of dust and moisture
	Temperature range	The operational temperature range of the UAS
	Size	The size of the UAS platform when deployed

Functional Category	Evaluation Criteria	Description
Battery Features	Hot-swappable batteries	The ability to change UAS batteries without powering the system down, which aims to reduce system down-time
	Batteries for continuous operation	The number of batteries necessary to power the UAS continuously during an operational period
	Ease of battery replacement	The ease with which batteries can be replaced in the field
	Recharge time	The amount of time it takes to recharge UAS batteries (for aircraft and controller).
	Self-heating batteries	UAS batteries that maintain appropriate temperature for operation when not in use.
User Interface	Ease of use	How easy it is for a remote pilot to learn, operate, and control the UAS and its camera package
	Anti-glare screen	The ability of a remote pilot to view the UAS controller screen in direct sunlight
	Live view capability	The ability of a remote pilot to switch between a map view and live video
	Visual warnings	The visual warning indicators (e.g., low battery, lost links) displayed on the UAS user interface
	Intuitive GUI	How intuitive the remote pilot finds the layout of the UAS controller's graphical user interface (GUI)
	Controller ergonomics	The placement and ease of use of the physical buttons and/or joysticks on the UAS controller
	Multiple controllers	The ability to use two controllers for the UAS, for example, when a second controller is used to operate the camera
	Use with gloves	The ease with which a remote pilot can use the controller, specifically when wearing gloves
	First Person View (FPV) capability	The ability of the remote pilot to fly the UAS from a point of view that uses a front-facing camera on the aircraft (separate from the payload)
Camera/Video	Video quality	The quality of live and streaming video from the aircraft
	Omnidirectional pan/tilt capability	The ability of the camera platform to pan and tilt in all directions, including the pilot's user experience with the controls
	Onboard camera recording	The ability of the system to store camera/video data onboard the aircraft, which can be reviewed after the flight if needed.
	Zoomable lens	The zooming capability of the UAS camera
	Thermal imaging	The capability of the UAS sensor package to provide thermal images and those thermal images' quality
	Non-proprietary recording media	The type of recording media used by the UAS, with preference for standard, non-proprietary media (e.g., Secure Digital (SD) cards)
	Swappable camera pack	The ability to and ease of swapping out the UAS camera payload to other available camera payloads
	Video relay options	The ability to output live video from the controller to an on-site large screen or to the ability to stream video over a network to a remote command center
	Dual optical/IR camera	The availability of optical and infrared (IR) sensors in a single payload

Functional Category	Evaluation Criteria	Description
Capabilities	Flight time	The approximate amount of time the UAS can remain airborne under normal conditions (equivalent to battery life)]
	Range from controller	The distance the aircraft can travel from the controller
	Communications reliability	The reliability of control and data links between the aircraft and controller
	Maximum speed	The maximum speed at which the UAS can travel while maintaining stability and control
	Payload capacity	The amount of weight the UAS aircraft can carry
	Wind tolerance	The maximum sustained and gusting wind the UAS can endure while remaining stable
	Operating frequencies	The radio frequencies used for command and control and for video streaming, as well as the ability to choose different frequency bands
Features	Return home	The ability of the aircraft to automatically navigate back to a specified location
	Autoland	A feature allowing the aircraft to safely land itself, particularly in the event of loss of aircraft control or other system issue
	Intelligent flight mode	UAS flight mode that assists a remote pilot in simultaneously piloting the aircraft and capturing still or video images
	Precision hold/hover	A feature of the UAS that, when activated, automatically controls the throttle to maintain the current altitude
	Collision avoidance	A feature of the UAS that uses sensors to detect and avoid obstacles in its path; also, the ability to disable the collision avoidance feature when necessary
	Program from tablet	The ability to use a tablet to program a search-pattern flight plan with Global Positioning System (GPS) coordinates and the ease of such programming
	Download maps for offline use	A feature of the UAS that allows maps to be downloaded and cached for use in areas with low or no internet connectivity
	3rd party software	The ability of the UAS to integrate with third party software, for example, control software or mapping software used by other agencies
	Waypoint movement	The ability of the UAS to navigate through GPS waypoints with precise three-dimensional positioning (i.e., longitude, latitude, altitude)
	Reconfigurable alerts	The ability of a remote pilot to program their own warning indicators
	Onboard record telemetry	The ability of the UAS to record telemetry data onboard the aircraft and the ability to extract telemetry logs at the end of flights
Warranty/ Maintenance	Hardware reliability	The number of hours of operation before service is needed or (if operation hours data was not available) the perceived ruggedness of the system
	Service center ease	The ease with which UAS can be serviced by the manufacturer and whether the system needs to be shipped overseas for maintenance
	In-house serviceability	The ability or ease with which a responder agency can perform their own repair and maintenance on the UAS without having to send it to the manufacturer's service center (includes the availability of replacement parts and ability to use non-proprietary tools)
	Warranty	The terms of the warranty provided by the manufacturer of the UAS

3.0 ASSESSMENT METHODOLOGY

The FRROST assessment of UAS for search and rescue missions, held November 12-15, 2019 at Camp Shelby, Mississippi, consisted of an operational assessment of four different UAS. Evaluators assessed one model of UAS per day. Each day consisted of familiarization or practice sessions followed by simulated operational scenarios in daytime and twilight/night conditions. NUSTL personnel collected feedback from the evaluators at the completion of each scenario.

3.1 ASSESSMENT DESIGN

This assessment focused on evaluating the operational usability of UAS for search and rescue missions by obtaining responder feedback during simulated scenarios. The assessment did not attempt to address all possible search and rescue scenarios, nor all possible UAS that could be used for this application. The evaluation criteria and the UAS used in this assessment, however, were based on recommendations from a focus group of first responders with experience using UAS for search and rescue. Scenarios for this assessment were conducted in fields, woods, and a mock village available at Camp Shelby. The environment and flight conditions varied somewhat during the week but were not representative of all possible conditions. The assessment schedule allowed for a full day of evaluation of four different UAS. The schedule is noted in Table 3-1 below.

Table 3-1 Assessment Schedule

Date	UAS Evaluated
Tuesday, November 12	FLIR SkyRanger R60/R70
Wednesday, November 13	Autel Robotics EVO
Thursday, November 14	Intel Falcon 8+
Friday, November 15	Solute Eagle XF

With the exception of the first day's introductory briefings, each day's assessment activities were planned to be the same. Table 3-2 shows the proposed daily activity schedule. Nevertheless, due to weather and equipment issues, each day's schedule was slightly different. The test team communicated any changes to evaluators and vendors and ensured that enough time was provided to collect data. Data collectors gathered feedback in individual interviews after an evaluator piloted the UAS. During the working lunch, evaluators also completed specification surveys that allowed them to rate the products on the basis of vendor-supplied specifications. In one deviation from the test plan, evaluators did not to pilot the Eagle XF because of its size and complexity. For this UAS, evaluators based their feedback on observations of the flights performed by the vendor pilot and camera operator. Another deviation from the test plan occurred later in the week, when evaluators began completing the specification surveys at the start of each day during the vendor familiarization sessions (rather than during lunch) in order to capture that information.

Table 3-2 Daily Schedule

Activity	Location
Arrival and Check-in	Classroom
Overview of Daily Activities and Safety Briefing	Classroom
Vendor Overview of UAS	Classroom
Vendor Demonstration	Outdoor NIST Lanes
UAS Hands-on Familiarization	Outdoor NIST Lanes
Working Lunch (Specification Surveys)	Classroom
Search and Rescue Scenarios	Outdoor Field/Village
Overview of Twilight/Night Scenario	Classroom
Twilight/Night Scenario	Outdoor Field/Village
Group Discussion	Classroom

Evaluators were broken into two groups – one of four evaluators and one of five evaluators – during the familiarization and operational scenarios. They stayed in the same groups for the first and second days of the assessment, then new groups were formed during the third and fourth days to allow the evaluators to interact with a different group of peers. The initial groupings paired evaluators with prior experience using NIST standard test methods with evaluators unfamiliar with these test methods.

3.1.1 NIST STANDARD TEST METHODS

NIST Standard Test Methods and apparatus were used for the vendor flight demonstrations, UAS hands-on familiarizations, and within the operational scenarios. The Standard Test Methods, developed by NIST in coordination with DHS S&T and the American Society for Testing and Materials (ASTM) International Standards Committee on Unmanned Aircraft Systems, are a suite of aerial training tasks carried out on low-cost, easily-replicable apparatuses to measure the capabilities of the UAS and the skill of their pilots. These methods provide quantitative measurements of key flight tasks for comparison of performance across pilots and UAS. In this assessment, the Standard Test Methods provided a structured methodology to address the skills needed for the pilots' familiarization and operational tasks.

Vendors and evaluators used NIST test lanes for maneuverability and payload (MAN/PAY) tasks during vendor demonstration and evaluator familiarization. The MAN/PAY lanes (Figure 3-1) include tasks for position, traverse, orbit, spiral, and sustain speed/deliver accurately. These tasks are detailed in the NIST Standard Test Methods for Small Unmanned Aircraft Systems Maneuvering (MAN 1-5) and Payload Functionality (PAY 1-5) Quick Start Guide. [3]

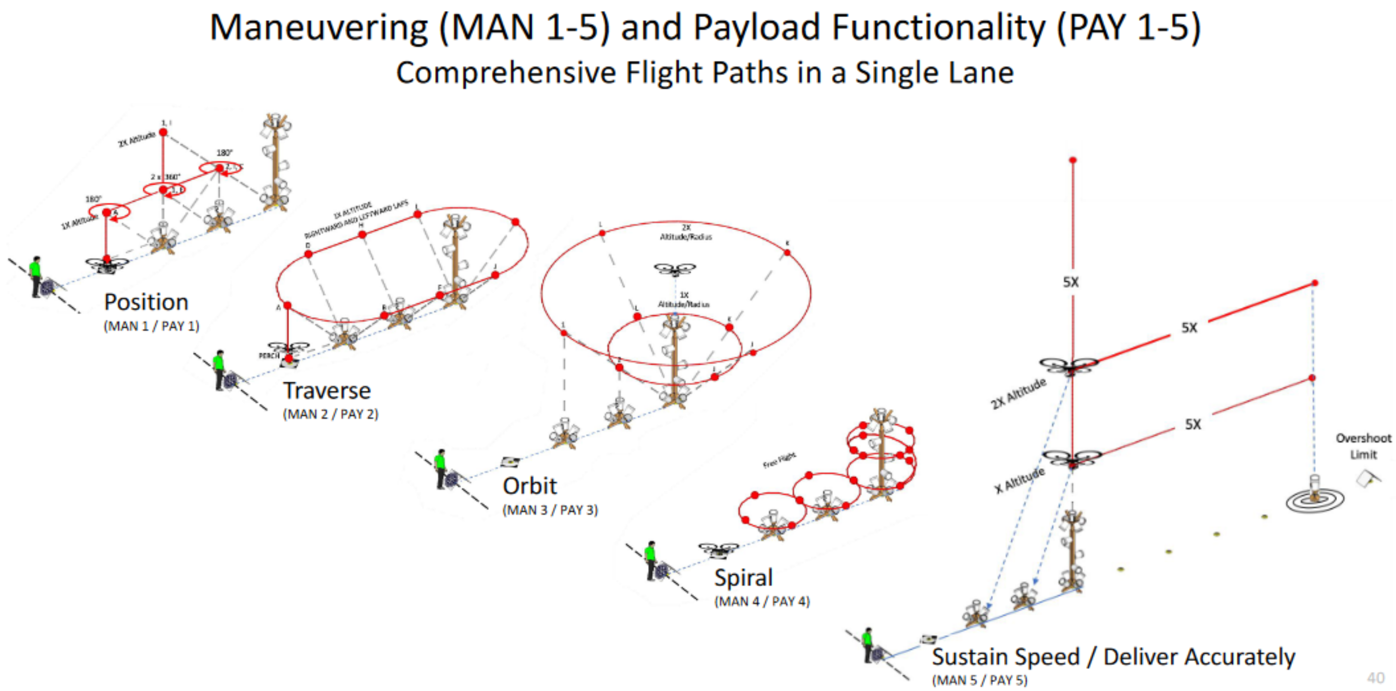

Figure 3-1 NIST MAN/PAY Lanes

Image courtesy of NIST

The primary apparatus used for the standard test methods is the omnidirectional bucket stand (Figure 3-2) in which various target stickers can be placed within the buckets. Remote pilots must align and hold the UAS at each bucket and use the UAS camera to view the target in each bucket. With a series of tasks for each target, the test methods provide a measure of both the pilot's proficiency along with the capabilities of the UAS and its camera payload. Omnidirectional bucket stands were used throughout the familiarization and operational scenarios to provide structured opportunities for performing specific tasks and assessing specific UAS features.

Figure 3-2 NIST Omnidirectional Bucket Stand

This section outlines the activities that were conducted during the assessment. As noted above, each activity was intended to be conducted for a different UAS each day, but weather and equipment availability required some deviations from the planned schedule.

Vendor Overview of UAS: Each vendor provided an overview of their UAS, lasting about 30-45 minutes. The overview included the vendor demonstrating how the UAS is packaged, unpackaged, and assembled. Some vendors used PowerPoint presentations, while others did not. Starting the third day of the assessment, evaluators also used this time to ask questions related to the specification surveys. This Q&A time was added at the suggestion of an evaluator.

Figure 3-3 NIST Test Lane

Vendor Flight Demonstration: Following the overview presentation, participants gathered at the NIST MAN/PAY test lanes (Figure 3-3) for a vendor flight demonstration. For this event, two identical lanes of apparatuses were set up to allow pilots to follow a prescribed series of maneuvers from the NIST Standard Test Methods. Guided by NIST personnel, vendors performed the NIST Basic Maneuvering Procedure. Meanwhile, the UAS video output was relayed from the controller to a larger video monitor so the evaluators could view vendor flight operations. This demonstration also gave evaluators an opportunity to observe aircraft assembly and set-up time.

UAS Hands-On Familiarization: Following the vendor demonstration, evaluators (already split into two teams) familiarized themselves with the UAS by taking turns piloting the UAS on the MAN/PAY lanes according to the NIST Standard Test Methods. The vendor and NIST personnel assisted the evaluators and answered questions about UAS operation and NIST test methods. Each evaluator had approximately 10 minutes to perform as many of the tests as possible before handing off the controller to the next evaluator. Evaluators took additional turns as time allowed. Evaluators switched lanes halfway through to try an alternate model, if available (e.g., FLIR SkyRanger R60 or R70). After each evaluator's turn piloting, NUSTL personnel administered a survey to the evaluators individually to record their feedback on the following evaluation criteria:

- Cache packaging (vendor demonstration)
- Time to deploy (vendor demonstration)
- Wireless video relay (vendor demonstration)
- Ease of battery replacement
- Hot-swappable batteries
- Ease of use, particularly learning to fly the UAS
- Anti-glare screen (i.e., screen visibility in sunlight)
- Intuitive GUI
- Ergonomics of controller

3.1.2 OPERATIONAL SCENARIOS

After they had become familiar with a UAS, evaluators assessed each product in a simulated operational scenario. Assessments were staged in two scenarios: (1) Wide Area Search/Lost Hiker, (2) Post Disaster Search and Rescue. Both scenarios were run once more in order to assess Twilight/Night Operations capacity. One team of evaluators began at the Wide Area Search/Lost Hiker scenario while the other began at the Post Disaster scenario. Each evaluator piloted the UAS through the scenario before the teams switched places to the other scenario. For each scenario, NUSTL data collectors interviewed the evaluators individually after they had piloted the UAS.

3.1.3 WIDE AREA SEARCH/LOST HIKER

The Wide Area Search/Lost Hiker scenario included both a field and a wooded area of Camp Shelby (Figure 3-4). The evaluators performed a wide area search for a missing person (a lost hiker, represented by a mannequin) over the field and wooded area and completed embedded NIST tasks. The evaluators took turns flying the UAS while whichever evaluator was next to fly acted as an observer and notetaker.

Figure 3-4 UAS Launch/Landing Pad for Wide Area

Initially, each evaluator configured the UAS in an intelligent flight mode, if available. (The evaluator would consult with the vendor for the appropriate flight mode.) To find a victim represented by a mannequin, the evaluator launched and performed an appropriate flight pattern for the given search direction. If available on the UAS, the pilot tested the camera zoom. When the simulated lost hiker was found, the evaluator activated the altitude hold or 'hold while hovering' feature, if available. Next, the evaluator navigated to a nearby, partially-camouflaged omnidirectional bucket stand (Figure 3-5). The evaluators completed as many maneuvering and payload tests as possible in the remaining flight time, then returned to the launch point for the next evaluator's turn. Evaluators took note of any visual warnings (e.g., low battery) encountered while operating the UAS in this scenario.

Figure 3-5 Omnidirectional Bucket Stand with Visual Acuity Targets Inside

Image courtesy of NIST

The following evaluation criteria were addressed the post-flight NUSTL interviews with the evaluators:

- Intelligent flight modes
- Precision hold while hovering
- Zoomable lens
- Video quality
- Camera pan/tilt capability
- Ease of flight operations (stability and maneuverability)
- Visual warnings
- Communications reliability

3.1.4 POST DISASTER SEARCH AND RESCUE

The Post Disaster Search and Rescue scenario was staged in the mock village area of Camp Shelby. It consisted of bucket targets on a vehicle, on a building rooftop, within building windows, and in a courtyard (Figure 3-6). Inspection of the bucket targets simulated inspections performed in a search for stranded survivors after events such as large-scale flooding or mudslides. Each evaluator flew the UAS while the evaluator who was on-deck as pilot observed and took notes.

In this scenario, the evaluators wore their own gloves in order to evaluate use of the controller with gloved hands. Evaluators could choose to remove the gloves if they believed that using them impeded the safe operation of UAS. Evaluators launched the UAS toward the mock village and inspected a vehicle, starting with a loose identification orbit to determine if further inspection was necessary. They continued to circle in order to identify exterior targets with increasing detail, then completed a detailed inspection spiral of interior targets through open and closed windows. The evaluators also flew over the mock village, which had omnidirectional bucket stands set up on the ground and in window openings. They took note of collision-avoidance features of the UAS and any visual warnings encountered while operating the UAS (e.g., low battery). The following evaluation criteria were addressed by NUSTL's evaluator interviews after this scenario:

- Use of controller with gloves
- Collision avoidance
- Zoomable lens
- Video quality
- Camera pan/tilt capability
- Ease of flight operations (stability and maneuverability)
- Ease of battery replacement
- Visual warnings
- Communications reliability

Figure 3-6 Post Disaster Search and Rescue Scenario

3.1.5 TWILIGHT/NIGHT OPERATIONAL SCENARIOS

The twilight/night scenarios focused on evaluating the thermal imaging features on a UAS, if available, and assessing features related to UAS programming and automated flight. Evaluators took turns flying the UAS while on-deck evaluators served as observers and notetakers.

Figure 3-7 Thermal Image
Note the use of the chemical handwarmer in the left bucket.

Image courtesy of NIST

All evaluators were located at the same launch point, however, flight paths for the two activities differed. Each evaluator had the opportunity to try both activities. For the thermal imaging activity, evaluators launched the UAS toward the village area previously used in the post disaster scenario and repeated an abbreviated version of the building inspection, this time including thermal source targets. Chemical hand warmers were placed inside of buckets and buildings to represent thermal targets in this scenario (Figure 3-7).

For the automated flight activity, the evaluators experimented with programming a search pattern with GPS coordinates; they also set their own alerts or warnings.

Once programmed, the evaluators launched the UAS to carry out the programmed flight pattern. Evaluators experimented with switching between "map view" and "live view" during the flight and took note of any visual warnings encountered. The following evaluation criteria were addressed by NUSTL interviewers after this scenario:

- Thermal imaging
- Programmable GPS flight pattern from tablet
- Movement through waypoints
- Live view capability (switching from map view to live view)
- Reconfigurable alerts
- Video quality
- Visual warnings
- Communications reliability

3.2 DATA GATHERING AND ANALYSIS

At the conclusion of each scenario, evaluators were asked to rate the UAS according to criteria identified in Table 2-1. For each criterion, evaluators rated how the UAS performance would meet their mission needs on a scale from 1 to 5 with values defined as:

1 – Strongly disagree

2 – Disagree

3 – Neither agree nor disagree

4 – Agree

5 – Strongly agree

For those criteria that could be assessed operationally, NUSTL personnel collected feedback in individual interviews after the evaluator piloted the UAS. For criteria evaluated according to manufacturer's specifications, evaluators completed written surveys.

Evaluators were asked to rate certain criteria multiple times over the course of the event. If an evaluator did not have an opportunity to see a feature or capability (e.g., visual warnings, battery change) during one scenario—and therefore could not rate it when first asked—it was likely they would have experience with it in another scenario. Each criterion's ratings were averaged across scenarios and across evaluators to arrive at a final rating. NUSTL personnel also captured any comments about the UAS with respect to the evaluation criteria. Not all criteria had narrative feedback, but what feedback was available is summarized in this report. Additional comments for each UAS and about the assessment process were also collected and are summarized herein.

4.0 ASSESSMENT RESULTS

Evaluators assessed four UAS that varied widely in size, price, and features. They noted the advantages and disadvantages of the assessed products and discussed how certain capabilities would help them in search and rescue missions.

Sections 4.1 through 4.4 summarize evaluator ratings on how each UAS met their needs for each criterion, as well as their narrative feedback on each UAS. During feedback sessions, evaluators generally expressed preference for lower cost UAS that are simple to use. They noted that their agencies would use UAS assets for a variety of missions.

Many of the evaluators had not operated these four UAS models prior to this assessment. Evaluators found the NIST test methods helpful for familiarization with the UAS. They also stated that the NIST methods would be useful for consistent training within their organizations. They discussed that training and qualifications for UAS pilots currently varies by agency. NIST methods could be used to as a standard metric to quantify a pilot's progress over time or for a comparison of proficiency on different UAS.

4.1 AUTEL ROBOTICS EVO

The Autel Robotics EVO is the smallest, lightest, and least expensive of the UAS assessed during the operational assessment. It was the only model in the assessment with a collision avoidance feature. It has the smallest payload capacity of the assessed models, no IP rating, and no infrared camera.

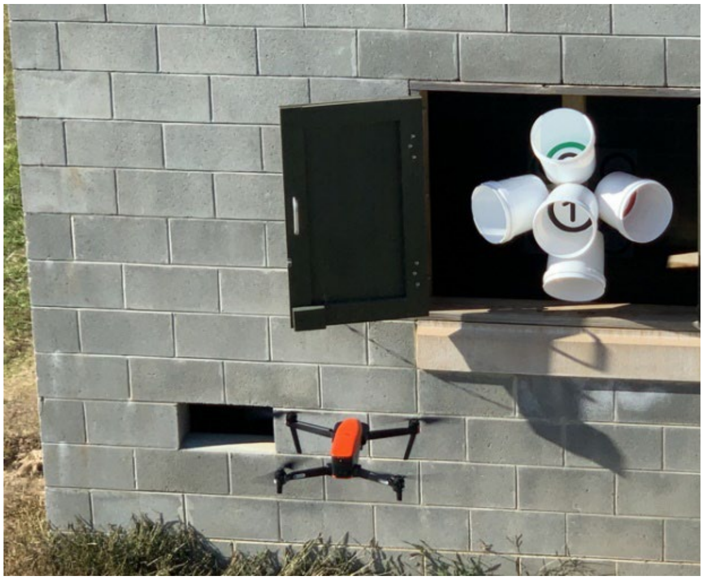

Figure 4-1 EVO in Flight

Image courtesy of NIST

Evaluators stated that the EVO was a good retail model with some public safety applications. They noted that it was limited without an IR camera and expected to prefer the subsequent model, the EVO II which has a HD/Thermal (8x zoom) camera, which had yet to be released at the time of the assessment

Evaluators stated that flying the EVO was easy and intuitive. One evaluator noted some drift when using a high-speed mode and wanted to learn more about the limitations in that mode. Although the EVO controller can be used without an additional screen, one evaluator stated that an additional screen would be needed for optics features like zoom.

Table 4-1 summarizes evaluators' feedback and the average scores for the evaluation criteria. For each criterion, evaluators rated how the UAS performance or capability met their mission needs, where 1 meant "strongly disagree" and 5 meant "strongly agree." Narrative feedback was not provided for every criterion.

Table 4-1 EVO Ratings and Feedback

Autel Robotics EVO		Ratings (1/Lowest → 5/Highest)	
Category	**Evaluation Criteria**	**Average Rating**	**Evaluator Narrative Feedback**
Physical Features	Cache packaging	4.8	• Evaluators liked the size, packaging, and deployment time of the UAS. They described the hard-cased package as portable, compact, and lightweight and the aircraft as compact, easy to handle, lightweight, and very fast to deploy. • Evaluators noted the limitations of the operating temperature range of 32°F to 104°F, with some stating it needed a lower minimum temperature. • Evaluators noted that the UAS has no IP rating. The vendor stated that the UAS can operate in light rain.
	Temperature range	3.1	
	Time to deploy	4.8	
	IP rating	2.4	
	Size	4.7	
Battery Features	Hot-swappable batteries	1.9	• Evaluators noted that the batteries are not hot-swappable, nor self-heating. • Evaluators stated that the batteries were easy and quick to replace. • Evaluators considered the 45- to 70-minute recharge time for aircraft batteries acceptable.
	Batteries for continuous ops	4.0	
	Ease of battery replacement	4.7	
	Recharge time	3.7	
	Self-heating batteries	2.5	
User Interface	Ease of use	4.7	• Evaluators found the UAS easy to use. They described it as intuitive and responsive with good stability and maneuverability. • Evaluators stated that the live view capability is great; and the UAS has good video quality and range. • Evaluators stated that the visual warnings they observed during the assessment were good and easy to understand. One evaluator liked that the collision avoidance warning included distance from the object. Others would have liked a more noticeable warning for weak video signals and more time to react to warnings. • Evaluators stated features were easy to access on the GUI. One evaluator liked the ability to remap the controller buttons to different functions. • Evaluators stated the gimbal controller was relatively easy to use and all the buttons were easy to reach. One evaluator would have preferred a larger controller. Another wanted the ability to adjust the camera's digital zoom on the controller in addition to on the app. One believed some buttons on the controller were too sensitive. • Evaluators noted that a secondary controller could be added by using Autel's Live Deck accessory. • Evaluators stated that they could operate the controller while wearing gloves. • Evaluators noted that the UAS did not have FPV capability.
	Anti-glare screen	3.8	
	Live view capability	4.7	
	Visual warnings	4.2	
	Intuitive GUI	3.8	
	Controller ergonomics	3.8	
	Multiple controllers	4.1	
	Use with gloves	3.7	
	FPV capability	2.9	

Autel Robotics EVO		Ratings (1/Lowest → 5/Highest)	
Category	**Evaluation Criteria**	**Average Rating**	**Evaluator Narrative Feedback**
Camera/Video	Video quality	4.2	• Evaluators stated that the optics and interface were user-friendly, and the video quality was good. One noted they could see the logo on the NIST bucket at 120 feet away. One noted video latency and lag when the UAS was about 600 yards from the controller. Another noted shake in the video at one point during the assessment. • Evaluators described the camera's pan/tilt functions as good, smooth, and very responsive. They noted the functions were able to be controlled from a phone. One evaluator liked that he could control the speed of the pan/tilt functions, while another would have liked to have side to side movement. • Evaluators noted that video can be stored onboard the aircraft using a standard SD card. • Evaluators noted the UAS had 8x digital zoom. One evaluator stated that optical zoom would be preferable over digital zoom. Multiple evaluators stated that 8x zoom was good for a UAS of this size. Evaluators noted that the zoom was controlled from the app, but no similar capability is on the controller. • Evaluators noted that the UAS does not have a swappable camera payload. • Evaluators noted that video could be relayed to an external display or a remote server using Autel's Live Deck, a video output accessory with HDMI, Ethernet, and USB connections. Many thought it would meet their needs; one would have preferred a hosted solution and another noted that it could not directly live stream video to an IP address. *Although the unit under evaluation does not have a dual optical/IR camera, nor thermal imaging capability, the vendor demonstrated the subsequent model (EVO II) which has an IR camera. Evaluators based the "Thermal Imaging" rating on that model. • Evaluators considered the IR capability impressive for the UAS's size, with a good zoom, and very clear outputs. • One evaluator stated the thermal color palettes were clunky, and the detail was not great.
	Omnidirectional pan/tilt capability	4.1	
	Onboard camera recording	4.2	
	Zoomable lens	4.1	
	Thermal imaging	4.7*	
	Non-proprietary recording media	3.8	
	Swappable camera pack	2.8	
	Video relay options	4.2	
	Dual optical/IR camera	2.9	
Capabilities	Flight time	3.8	• Evaluators considered the UAS's flight time of up to 30 minutes fairly standard, and the maximum speed of 45 mph good. • Evaluators rated the UAS's 4.3 mile range from the controller favorably. • Evaluators lost or experienced frozen video at points during the assessment, but no loss of control link. • Evaluators stated that its 0.3 lb payload capacity is too small to be practical. • Evaluators considered the manufacturer-stated wind tolerance of approximately 26 mph to be standard. Evaluators noted that the aircraft was stable in the 5-10 mph winds during the assessment period. • Evaluators noted that the UAS operated on the 2.4GHz - 2.4835GHz frequencies.
	Range from controller	4.2	
	Communications reliability	4.0	
	Maximum speed	4.2	
	Payload capacity	2.6	
	Wind tolerance	3.7	
	Operating frequencies	3.8	

Autel Robotics EVO		Ratings (1/Lowest → 5/Highest)	
Category	**Evaluation Criteria**	**Average Rating**	**Evaluator Narrative Feedback**
Features	Return home	4.3	• Evaluators positively rated the EVO's return to home and autoland features, noting the aircraft automatically returned at a preset battery level (10%). One evaluator stated he would have liked the ability to override the manual mode for the autoland feature. • Evaluators rated the intelligent flight modes feature favorably, noting that they liked the ability to preplan orbits and change them mid-flight. • Evaluators described the aircraft's hover as stable and consistent with no drift. One noted a minor shudder with no drift during descent. • Evaluators stated that the collision avoidance features were good and successfully detected objects during the assessment. They also noted that collision avoidance can be disabled in "ludicrous mode" (a higher speed mode) while still allowing other alerts. • Evaluators described the ability to program from a tablet as standard and good, and the process to reconfigure alerts as intuitive. • They noted that maps can be downloaded for use offline. • Third party control software cannot be used at this time. • Evaluators also described the waypoint movement as good and smooth. • Evaluators noted telemetry data is stored on and can be downloaded from the aircraft.
	Autoland	4.3	
	Intelligent flight mode	4.4	
	Precision hold/ hover	4.6	
	Collision avoidance	4.2	
	Program from tablet	4.3	
	Download maps for offline use	4.3	
	3rd party software	2.4	
	Waypoint movement	4.2	
	Reconfigurable alerts	4.0	
	Onboard record telemetry	3.8	
Warranty/ Maintenance	Hardware reliability	4.0	• Evaluators noted that service centers operated 7 days per week and UAS servicing has a 3-week turnaround time • Evaluators believed it would be difficult to acquire most parts or to service the UAS in-house. • Evaluators considered the 1-year warranty to be standard.
	Service center ease	3.9	
	In-house serviceability	2.8	
	Warranty	3.7	

4.2 INTEL FALCON 8+

At 4.4 pounds, the Intel Falcon 8+ is the second lightest of the models assessed. It is the only model among those assessed that is designed as a non-networked system with no connections to the internet. UAS video is stored on the SD card in the camera, and flight data on the laptop controller. The Falcon 8+ is designed with triple redundancy of each inside part (not including the sensor). The Falcon 8+ has the shortest battery life of the models assessed but its batteries are hot-swappable. It also has the shortest transmission range (1 km control, 500 m video). The Falcon 8+ uses proprietary Intel Mission Control software that can create three-dimensional models and has the unique capability of saving and recalling flights so paths can be repeated autonomously.

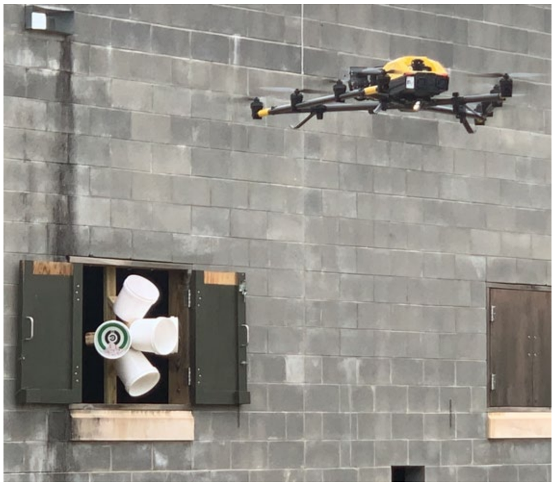

Figure 4-2 Falcon 8+ in Flight

Image courtesy of NIST

Evaluators stated that the Falcon 8+ may not be rapidly deployable nor rugged enough for some of their public safety missions. Some stated that it may be better suited for inspections, fire prevention, brush clearance, GIS/engineering, and pre-deployment planning missions.

Evaluators liked the quality of the images from the 42 MP optical camera and from the thermal camera. They considered the speed of the aircraft very good. Most evaluators liked the aircraft's yellow color. Main concerns discussed were battery life and video transmission distance from the controller.

Table 4-2 summarizes the evaluators' feedback and average scores for the evaluation criteria. For each criterion, evaluators rated how the UAS's performance or capability met their mission needs, where 1 meant "strongly disagree" and 5 meant "strongly agree." Narrative feedback was not provided for every criterion.

Table 4-2 Falcon 8+ Ratings and Feedback

Intel Falcon 8+		Ratings (1 /Lowest → 5 /Highest)	
Category	**Evaluation Criteria**	**Average Rating**	**Evaluator Narrative Feedback**
Physical Features	Cache packaging	2.4	• Evaluators considered the aircraft and its case large. • Some stated that deployment included too many steps and took too long. • Evaluators noted that the UAS did not have an IP rating and gave mixed reviews on the temperature range (23°F to 104°F), with one stating that it needed a lower minimum temperature. • One evaluator mentioned that the 8-rotor design could be a good safety feature if one propeller was damaged.
	Temperature range	3.1	
	Time to deploy	2.9	
	IP rating	2.4	
	Size	3.0	
Battery Features	Hot-swappable batteries	4.7	• Evaluators gave positive feedback about the batteries being hot-swappable and the redundancy of the aircraft's dual battery system. They also found the batteries easy to change. • Evaluators noted that about 8-10 batteries would be required for continuous flight operations; some thought that was too many and that the batteries had to be changed too frequently (after about 17 minutes of flight time). Controller batteries have a 2.5- hour battery life. • Evaluators spoke positively about the 35- to 45-minute battery recharge time and the ability to use the same battery in the controller as is used for the aircraft. • Evaluators noted that the batteries were not self-heating.
	Batteries for continuous operation	3.4	
	Ease of battery Replacement	4.4	
	Recharge time	4.2	
	Self-heating batteries	2.1	
User Interface	Ease of use	3.6	• One evaluator noted the aircraft was stable and maneuverable while another noted too much drift. • Not all evaluators observed UAS visual warnings during operation, but some noted that the low battery warning was good and that they liked the audible alerts. • Some evaluators were concerned that the GUI on the tablet was non-intuitive and limited – the tablet is primarily used as a viewing screen and not for controls. • Evaluators had mixed opinions on the controller: some liked the single joystick, while others found it to be complicated. Some found the controller bulky and said that they had to move their hands a lot to reach controls. • Most evaluators believed they could adequately operate the buttons with gloves. • Evaluators noted that the UAS allows use of multiple controllers using an HDMI connection.
	Anti-glare screen	3.2	
	Live view capability	3.4	
	Visual warnings	4.2	
	Intuitive GUI	2.9	
	Controller ergonomics	3.1	
	Multiple controllers	3.3	
	Use with gloves	3.3	
	FPV capability	3.3	

Intel Falcon 8+		Ratings (1 /Lowest → 5 /Highest)	
Category	**Evaluation Criteria**	**Average Rating**	**Evaluator Narrative Feedback**
Camera/Video	Video quality	3.2	• Evaluators experienced some issues with the video dropping out during the assessment but considered the image quality adequate. • Some evaluators stated that the control for the camera tilt was reversed compared to what they were used to. Others stated that the pan/tilt controls were responsive and had good maneuverability. • Evaluators described the camera zoom capability as good but noted that there is no zoom capability for the thermal camera. • Evaluators found the thermal images clear. They noted that there are four available thermal palettes. • Evaluators noted that video is saved onboard the sensor using a standard SD card. • Evaluators noted there is no option to wirelessly relay video to a remote location or secondary display. • Evaluators stated positive impressions of the dual optical/IR camera, and noted it would be simple to swap the camera.
	Omnidirectional pan/tilt capability	3.9	
	Onboard camera recording	3.8	
	Zoomable lens	3.7	
	Thermal imaging	3.9	
	Non-proprietary recording media	3.7	
	Swappable camera pack	4.3	
	Video relay options	2.1	
	Dual optical/IR camera	3.9	
Capabilities	Flight time	2.2	• Evaluators stated the flight time (~ 17 minutes) and aircraft range from controller (1 km flight, 500 m video link) are too short for many of their missions. • Evaluators noted video degradation and loss of video link at longer distances during the assessment. • Evaluators considered the aircraft's maximum speed (40 mph) very fast. • Evaluators stated the wind tolerance (12 m/s in GPS mode and 16 m/s in height or manual mode) was adequate but thought the image was unstable while the aircraft was moving. • Evaluators considered the 2.4 GHz adaptive FHSS command and control link to be a useful feature when switching among multiple frequencies is needed.
	Range from controller	2.4	
	Communications reliability	3.2	
	Maximum speed	3.9	
	Payload capacity	3.1	
	Wind tolerance	4.1	
	Operating frequencies	3.7	
Features	Return home	3.7	• Evaluators generally liked the "return to home" capability of the aircraft. One evaluator mentioned it would be useful to be able to set an altitude for this feature. • Evaluators noted that the UAS does not have collision avoidance, a feature the evaluators considered useful and some deemed necessary. • Evaluators noted that maps could be downloaded prior to a mission, but it would be difficult on an impromptu basis because the UAS has no wireless connectivity. • Evaluators had positive feedback about programming features and reconfigurable alerts, however they noted that typical public safety pilots may not use those features because of the complexity and number of steps required.
	Autoland	3.1	
	Intelligent flight mode	4.0	
	Precision hold/hover	3.8	
	Collision avoidance	1.5	
	Program from tablet	3.8	

Intel Falcon 8+		Ratings (1 /Lowest → 5 /Highest)	
Category	**Evaluation Criteria**	**Average Rating**	**Evaluator Narrative Feedback**
	Download maps for offline use	3.5	• Evaluators rated the UAS's waypoint movement favorably. They liked the system's ability to record a flight and run the flight path again autonomously. • Evaluators noted that telemetry data and video data is recorded onboard the aircraft and stored on a standard SD card. Data can be downloaded using the proprietary Intel Mission Control software.
	3rd party software	2.4	
	Waypoint movement	4.0	
	Reconfigurable alerts	3.8	
	Onboard record telemetry	3.9	
Warranty/ Maintenance	Hardware reliability	3.3	• Some evaluators stated that the UAS did not appear rugged. • Evaluators noted that service is provided by the vendor (not the manufacturer) with a fast turnaround time. • Evaluators stated that some in-house maintenance was possible and that replacement parts are readily available. Evaluators noted that the one propeller wrench this UAS required came with the unit. • Evaluators considered the warranty to be similar to industry standards (1 year for platform, 6 months for batteries).
	Service center ease	3.6	
	In-house serviceability	3.7	
	Warranty	3.7	

4.3 FLIR SKYRANGER R60/R70

The FLIR SkyRanger R60 and R70, weighing 5.3 and 9.9 pounds respectively, are the second and third heaviest UAS among the models assessed. The SkyRanger models have the widest operating temperature range, highest IP rating, and greatest wind tolerance of the assessed UAS. They are also the only models among the four assessed UAS with integrated strobe lights, self-heating batteries, and the ability to manually select radio frequencies. The R70 has hot-swappable batteries. The R60 and R70 are the most expensive UAS assessed.

Figure 4-3 SkyRanger R70 in Flight

Evaluators stated they learned to use the SkyRanger readily and that the camera images were clear. They had positive reactions to many of the unique features of the aircraft but stated that many agencies would be likely to buy less expensive models.

Table 4-3 summarizes the evaluators' feedback and average scores for the evaluation criteria. For each criterion, evaluators rated how the UAS's" performance or capability met their mission needs, where 1 meant "strongly disagree" and 5 meant "strongly agree." Narrative feedback was not provided for every criterion.

Table 4-3 SkyRanger R60/R70 Ratings and Feedback

FLIR SkyRanger R60/R70		Ratings (1 /Lowest → 5 /Highest)		
Category	**Evaluation Criteria**	**Average Rating R60**	**Average Rating R70**	**Evaluator Narrative Feedback**
Physical Features	Cache packaging	4.2	3.8	• Evaluators described the UAS as reasonably sized for its type. One evaluator called this UAS medium-sized and said its size was appropriate for his operations. One stated that the size of the smaller R60 (weighing 5.3 lbs.) would be preferable to the R70 (weighing 9.9 lbs.). • One evaluator noted it took 2 to 3 minutes to do a pre-flight check while rebooting the R60. Another noted the R70 boots up quicker than the R60. • Evaluators were relatively satisfied with the weather-resistance of the system, noting IP ratings of IP53 for the R60 and IP54 for the R70. • Evaluators favorably rated the operating temperature range of both models (-22°F to 122°F).
	Size	4.0	3.8	
	Time to deploy	3.8	4.2	
	IP rating	3.9	3.9	
	Temperature range	4.5	4.5	
Battery Features	Hot-swappable batteries	2.8	4.6	• Evaluators felt favorably about the capability to hot-swap the battery in the R70. • Evaluators noted that the R60 requires 3 batteries and the R70 requires 12 batteries for continuous operation. Some stated they considered 12 batteries too many to change and charge and that more batteries drive up cost. • Evaluators stated that the battery replacement and battery recharge times were reasonable. R60 batteries recharge in 2 hours and R70 in 1-1.5 hours (for aircraft and controller). • Evaluators rated the self-heating battery feature favorably and noted that was especially important for those living in colder climates.
	Batteries for continuous ops	3.9	3.7	
	Ease of battery replacement	4.0	4.5	
	Recharge time	3.3	3.6	
	Self-heating batteries	4.6	4.6	
User Interface	Ease of use	3.9	4.0	• Some evaluators noted that although they had not flown this UAS before, they were able to learn to use it quickly. One noted that the UAS maneuvered easily. • After examining the display, one evaluator stated that the font sizes for zoom and elevation were a bit small. • Evaluators stated that they did not see many visual warnings during the assessment but noted those warning they did see (e.g. low battery) were acceptable. • Multiple evaluators liked the joystick interface and found the handle and buttons to be useful. One stated that it would be hard to reach buttons while using the joystick.
	Anti-glare screen	4.0	3.9	
	Live view capability	4.0	5.0	
	Visual warnings	3.3	3.3	

FLIR SkyRanger R60/R70		Ratings (1 /Lowest → 5 /Highest)		
Category	**Evaluation Criteria**	**Average Rating R60**	**Average Rating R70**	**Evaluator Narrative Feedback**
	Intuitive GUI	3.7	3.4	• Some evaluators stated that the console was big and bulky and required hands to be too far apart. They noted the console would be hard to hold without a neck strap. • One evaluator stated that the controller is too complicated. • Evaluators rated the ability to use a secondary controller favorably, noting that it can be beneficial for incident command situational awareness. • Evaluators found it useful to be able to switch from tablet to joystick control and noted that the ability to reprogram buttons is good. Multiple evaluators stated they preferred the joystick and button controls over the tablet. • Evaluators noted that they had no problem operating the controls with gloves except for tablet controls. • Evaluators noted that the R70 had a front facing camera that allowed for first person view. They considered this important for spatial awareness and when using a secondary controller.
	Controller ergonomics	3.2	3.4	
	Multiple controllers	4.3	4.3	
	Use with gloves	NR	4.1	
	FPV capability	2.7	4.3	
Camera/Video	Video quality	3.7	4.2	• Evaluators described the video quality as good, clear, and acceptable for search and rescue missions. • Evaluators stated that they would need some time to get used to the camera controls. One noted difficulty using the zoom control. • Evaluators rated the capability to record video on SD cards and directly onto the aircraft favorably. • One evaluator stated the thermal imaging clarity was acceptable for search and rescue targets. Another described the thermal image as good, and another stated that the image could be more detailed. • Evaluators favorably rated the ability to swap camera payloads. • Evaluators noted that video could be relayed from the tablet to a remote user, a feature important for helping decision makers who may not be near the pilot. • Evaluators rated the dual optical/IR camera favorably and noted that the ability to switch between optical and IR imaging without swapping the camera saves time and battery life.
	Omnidirectional pan/tilt ability	3.3	3.8	
	Onboard camera recording	4.6	4.6	
	Zoomable lens	4.3	4.3	
	Thermal imaging	NR	4.3	
	Non-proprietary recording media	4.3	4.3	
	Swappable camera pack	4.4	4.4	
	Video relay options	4.5	4.3	
	Dual optical/IR camera	4.6	4.6	

FLIR SkyRanger R60/R70		Ratings (1 /Lowest → 5 /Highest)		
Category	**Evaluation Criteria**	**Average Rating R60**	**Average Rating R70**	**Evaluator Narrative Feedback**
Capabilities	Flight time	4.8	4.9	• Evaluators stated that the flight times of the R60 (30-50 minutes) and of the R70 (40-50 minutes) are good. • Evaluators noted that using the standard base station the R60 aircraft range from the controller is 1.86 miles and the R70 is 5 miles. One evaluator noted that these ranges represent large coverage areas, more than most UAS. • Evaluators had mixed reviews of the communications reliability of the R60 and R70 during the operational assessment. Some evaluators did not experience connection problems, while others experienced loss of video feeds and image pixilation, particularly when the UAS was behind a building. • Evaluators noted that the maximum horizontal speed for both the R60 and R70 is 31 mph. One evaluator stated that the settings for speed adjustments are very helpful. • Evaluators stated that the 4.4 lb payload capacity of the R70 was good. • Evaluators rated the manufacturer-stated wind tolerances of 40 mph sustained and 56 mph gusts (for both the R60 and R70) positively. Evaluators operated the aircraft in windy conditions during the assessment and experienced some instability and drift but noted that the UAS corrects. • Evaluators noted that the UAS operate on 915 MHz, 922 MHz, 2.4 GHz and other frequencies, with the ability to switch between frequencies.
	Range from controller	4.2	4.2	
	Communications reliability	2.3	3.9	
	Maximum speed	4.1	4.1	
	Payload capacity	4.1	4.1	
	Wind tolerance	4.8	4.8	
	Operating frequencies	4.0	4.0	
Features	Return home	4.9	4.9	• Evaluators noted that the UAS has return to home and autolanding features but the autolanding feature must be initially configured. • Evaluators noted that the UAS does not have collision avoidance—a feature that some deem necessary. • Evaluators noted that maps can be downloaded offline and that flights can be preprogrammed. • Evaluators noted that the UAS has proprietary flight controls and that the ability to integrate with other mapping software is limited. They noted that the R60 does not allow 3rd party software and that the R70 allows the use of ATAK. • Evaluators described the R60's waypoint flight as correct and smooth. • Evaluators were positive about the ability to reconfigure alerts and one particularly liked the available audible and vibration alerts.
	Autoland	4.3	4.3	
	Intelligent flight mode	3.5	NR	
	Precision hold/hover	3.0	NR	
	Collision avoidance	2.3	2.5	
	Program from tablet	4.3	4.0	
	Download maps for offline use	4.3	4.3	

FLIR SkyRanger R60/R70		Ratings (1 /Lowest → 5 /Highest)		
Category	**Evaluation Criteria**	**Average Rating R60**	**Average Rating R70**	**Evaluator Narrative Feedback**
	3rd party software	3.1	3.7	• Evaluators noted that telemetry data is recorded onboard the UAS, however, extra software is needed to view it.
	Waypoint movement	4.3	4.0	
	Reconfigurable alerts	3.9	4.0	
	Onboard record telemetry	3.7	3.7	
Warranty/ Maintenance	Hardware reliability	4.0	4.0	• Evaluators noted that the service centers operated from 9am to 5pm Eastern time. One evaluator stated it would be helpful to also have West Coast hours and representatives. • Evaluators noted that a torque wrench is needed and some parts are user-serviceable. One stated that an agency should maintain a supply of parts as ordering parts through the mail could be slow. • Evaluators considered the 1-year warranty standard.
	Service center ease	3.3	3.3	
	In-house serviceability	4.0	4.1	
	Warranty	3.8	3.9	

4.4 SOLUTE UAV AMERICA EAGLE XF

At 71 inches in diameter and 28.5 pounds, the Solute Eagle XF is significantly larger and heavier than the other assessed UAS. It was the only assessed model that required two-person operation (i.e., separate controllers for the aircraft and camera.) It has the slowest top speed and the largest payload capacity of the four aircraft evaluated. It can fly for about 30 minutes with a payload and 58 minutes without a payload.

Figure 4-4 Eagle XF in Flight

Evaluators stated this is a larger and more complex UAS than they would typically want for their search and rescue missions. They stated the Eagle XF may be better suited for long-range/heavy-lift missions (e.g., wildfire fighting) or for industrial applications. They noted that with its high payload capacity, different cameras could be expand its uses.

Some evaluators did not like that the Eagle XF requires two-person operation (both an aircraft and a payload operator). Evaluators stated that while it's beneficial to have the ability to use multiple controllers in some situations, they prefer that it not be required. They noted the interchangeability of the parts and the ease of obtaining parts for repairs as positive features.

Table 4-4 summarizes the evaluators' feedback and average scores for the evaluation criteria. For each criterion, evaluators rated how the UAS's performance or capability met their mission needs, where 1 meant "strongly disagree" and 5 meant "strongly agree." Narrative feedback was not provided for every criterion. As noted above, the evaluators did not fly this UAS: their feedback is based on observing the vendor's flights.

Table 4-4 Eagle XF Ratings and Feedback

Solute Eagle XF		Ratings (1 /Lowest → 5 /Highest)	
Category	**Evaluation Criteria**	**Average Rating**	**Evaluator Narrative Feedback**
Physical Features	Cache packaging	2.3	• Evaluators stated that the UAS was larger than they would need for their missions. One noted that the transport case would fit in the back of a pick-up truck. • Although deemed acceptable for other applications, evaluators stated the deployment was neither simple enough nor fast enough for search and rescue missions. • Evaluators noted that tools are required for assembly. • Evaluators noted the temperature range (20°F to 104°F) is better than average, but the IP rating (IP21) is not.
	Temperature range	3.4	
	Time to deploy	1.9	
	IP rating	2.1	
	Size	1.8	
Battery Features	Hot-swappable batteries	1.3	• Evaluators noted that the aircraft batteries are large, not self-heating, not hot-swappable, and are not “smart batteries.” • Evaluators stated the number and cost of batteries required for continuous flight operations is more than they would like. Continuous flight would require 7-10 sets (or between 14-20 batteries) with each battery’s cost approximately $480. • Evaluators considered the battery replacement procedure relatively easy and straightforward. • Evaluators stated that 2-2.5 hours to recharge aircraft batteries is too long for their purposes.
	Batteries for continuous ops	2.0	
	Ease of battery Replacement	3.3	
	Recharge time	1.9	
	Self-heating batteries	1.5	
User Interface	Ease of use	1.7	• Evaluators stated the UAS was too complicated for their standard missions. It requires 2 operators (pilot and payload/camera operator) and would be more suited to missions requiring a specialized payload. • Evaluators rated the display screen and controller relatively favorably for customizability (i.e., various aftermarket equipment is available for both). • One evaluator noted that the live view image was good. Another noted that during the assessment, the video signal was lost when the aircraft moved beyond 1000 feet away. • Evaluators noted that the system provided no visual warnings. The battery level was accessible through QGroundControl • A laptop using the open-source app QGroundControl served as the user interface during the assessment, primarily for the camera operator. Evaluators had mixed reviews on using this as the GUI. • Some evaluators were satisfied with the standard RC controller used during the assessment; others found it non-intuitive and believed that gloves may get caught on the switches.
	Anti-glare screen	3.3	
	Live view capability	4.0	
	Visual warnings	2.0	
	Intuitive GUI	2.9	
	Controller ergonomics	3.4	
	Multiple controllers	3.8	
	Use with gloves	3.0	
	FPV capability	3.8	

Solute Eagle XF		Ratings (1 /Lowest → 5 /Highest)	
Category	**Evaluation Criteria**	**Average Rating**	**Evaluator Narrative Feedback**
Camera/Video	Video quality	4.3	• Evaluators stated that the camera was high quality and the images and video were clear. • They stated that the pan/tilt capability of the camera worked well with smooth movement and was truly omni-directional. • Evaluators noted that video is recorded on the payload and that a standard SD card is used. • Evaluators generally liked the thermal imaging capability, calling the quality and clarity of the image good. One evaluator would like more adjustments and greater zoom on the thermal camera. • Evaluators considered the system very adaptable to swapping cameras and payloads. • Evaluators considered the video relay options limited: remote streaming of video requires an HDMI connection.
	Omnidirectional pan/tilt capability	4.1	
	Onboard camera recording	4.0	
	Zoomable lens	4.1	
	Thermal imaging	4.0	
	Non-proprietary recording media	4.0	
	Swappable camera pack	4.4	
	Video relay options	3.0	
	Dual optical/IR camera	4.3	
Capabilities	Flight time	4.1	• Evaluators considered the 28- to 55- minute flight time (depending on payload weight) and the 7-pound payload capacity better than most systems. • They noted that the manufacturer-stated value for aircraft range from the controller is 2 km (1.25 mile). • Evaluators found the communications reliability to be acceptable with no communications link loss during the assessment. Evaluators did observe loss of the video link when the aircraft was beyond 1000 feet. • Evaluators consider the maximum speed of 34.5 mph very fast. • Evaluators stated the UAS would be unstable in windy conditions. The manufacturer-stated wind tolerance is 15 – 18 knots (17-21 mph). • Evaluators noted that the UAS operated on 2.4 GHz and 900 MHz frequencies with no ability to manually change frequency.
	Range from controller	3.6	
	Communications reliability	3.3	
	Maximum speed	3.4	
	Payload capacity	3.6	
	Wind tolerance	2.6	
	Operating frequencies	3.6	

Solute Eagle XF		Ratings (1 /Lowest → 5 /Highest)	
Category	**Evaluation Criteria**	**Average Rating**	**Evaluator Narrative Feedback**
Features	Return home	3.6	• The UAS has a return home feature in one mode. Evaluators noted that the UAS has no collision avoidance features and no autolanding feature except in lost link situations. • Evaluators found the ability to switch to hold-position mode useful, and the aircraft hover to be stable. • Evaluators noted that programming (e.g. configuring alerts) can be accomplished on a laptop, but not on the controller. • Evaluators liked the ability to use 3rd party and open source software for the UAS. They noted that it can use Pixhawk 2 flight controller software. • Evaluators considered the waypoint flight to be accurate and smooth. • Evaluators noted that flight telemetry information could be recorded onboard the aircraft and later downloaded.
	Autoland	2.7	
	Intelligent flight mode	3.0	
	Precision hold/hover	4.0	
	Collision avoidance	1.9	
	Program from tablet	3.7	
	Download maps for offline use	4.1	
	3rd party software	3.8	
	Waypoint movement	4.3	
	Reconfigurable alerts	3.0	
	Onboard record telemetry	4.1	
Warranty/ Maintenance	Hardware reliability	3.6	• Evaluators considered the manufacturer-stated hardware reliability of 200 hours to be good. • Evaluators stated the in-house serviceability of the UAS was limited but noted that some parts were readily available and that only standard tools would be required. • Evaluators considered the 30-day warranty too short.
	Service center ease	2.9	
	In-house serviceability	3.0	
	Warranty	1.6	

5.0 SUMMARY

Over four days in November 2019, nine experienced UAS pilots from emergency response agencies nationwide assessed four different small UAS in simulated search and rescue scenarios. The UAS varied widely in features and cost. Evaluators rated how different criteria for each UAS would meet their mission needs. Evaluator feedback on the most and least favorably rated criteria for each UAS are highlighted in Table 5-1. First responder agencies that consider purchasing UAS for search and rescue missions should carefully research each product's overall capabilities and limitations in relation to their agency's operational needs.

Table 5-1 Product Advantages and Disadvantages

Manufacturer/Product	Advantages	Disadvantages
 **Autel Robotics EVO**	• packaging is portable, compact and lightweight • fast and simple to deploy • quick and easy battery replacement • easy to use; intuitive and responsive • good live view capability	• is not IP rated • does not have hot-swappable or self-heating batteries • does not have a swappable camera payload or good payload capacity • no third-party control software
 **Intel Falcon 8+**	• hot-swappable and easy to change batteries • 35 to 45-minute battery recharge time • good visual warnings and audible alerts • easily swappable camera pack	• does not have self-heating batteries • no option to wirelessly relay video to a remote location or secondary display • short flight time and short range from controller • does not have collision avoidance feature
 **FLIR SkyRanger R60/R70**	• hot-swappable batteries (R70) and self-heating batteries • good live view capability (R70) • 30-50-minute flight times • wind tolerances of 40 mph sustained and 56 mph gusts • good return to home capability	• does not have hot-swappable batteries (R60) • lack of first-person view (R60) • difficulty with reliability of video feed during the assessment (R60) • does not have collision avoidance feature
 **Solute Eagle XF**	• clear image and video • good omnidirectional pan/tilt capability of camera • adaptable to swapping cameras and payloads • good dual optical and infrared camera • accurate and smooth waypoint flight	• larger than evaluators need • lengthy deployment time • does not have hot-swappable or self-heating batteries • complicated to use • short 30-day warranty

6.0 REFERENCES

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