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MARYLAND DEPARTMENT OF TRANPORTATION
STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

MDOT CULVERT INSPECTION

JAMES ALEXANDER – PROJECT MANAGER
DARREN ROBEY, JOSH GAUS, GRANT WILLIAMS – TECHNICAL TEAM

UNIVERSITY OF MARYLAND UAS TEST SITE

FINAL REPORT

July 2021

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7. Author(s)
James Alexander, Project Manager, University of Maryland (UMD) UAS Test Site
Darren Robey, Chief Pilot, UMD UAS Test Site
Joshua Gaus, Project Engineer/Pilot, UMD UAS Test Site
Grant Williams, Project Engineer/Pilot, UMD UAS Test Site

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California, MD 20619

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16. Abstract
Concrete/corrugated metal culverts (straight, 50-150 ft long, 12" -48" diameter) are currently inspected visually and less frequently with ground robots by MDOT SHA. The condition of most culverts is unclear due to inspection limitations, which impacts maintenance prioritization. An improved inspection process would allow for a more proactive approach to culvert maintenance. The research team conducted video culvert inspections in St. Mary's County with a small, caged drone (i.e. small Unmanned Aircraft System or sUAS) to compare the results with current inspection methodologies. The drone was a Flyability Elios 2, specifically designed for inspections in confined spaces. Multiple inspections of four culverts along MD-235 were successful and demonstrated a strong proof of concept for video culvert inspection by drone, up to a certain culvert length and in certain conditions. Indications were video inspections by drone were simpler, faster, more reliable, and more thorough than existing procedures under normal conditions. The Elios 2 is now the property of MDOT SHA, so further operational testing and experience is possible.

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Acknowledgements

Matthew Horowitz, Unmanned Aircraft Systems (UAS) Coordinator, MDOT SHA. Mr. Horowitz provided project requirements along with background information on highway culverts and current inspection methodologies and limitations. He also coordinated with other MDOT personnel to help identify suitable highway culverts for research purposes, and was the final approval authority for UAS selection and culvert selection.

James Alexander, Project Manager, University of Maryland UAS Test Site. As Principal Investigator, Mr. Alexander oversaw all aspects of the project including coordination, development, and implementation of research and managing cost, schedule, and performance.

Darren Robey, Chief UAS Pilot, University of Maryland UAS Test Site. Mr. Robey oversaw the UAS flight operations team during the research, to include UAS market study and selection, culvert site survey and selection, UAS training, and research flights.

Joshua Gaus, UAS Engineer/Pilot, University of Maryland UAS Test Site. Mr. Gaus conducted the market study to select a suitable UAS to meet MDOT requirements, and served as one of the research pilots.

Grant Williams, UAS Engineer/Pilot, University of Maryland UAS Test Site. Mr. Williams was the primary UAS pilot.

Executive Summary

Concrete and corrugated metal culverts (straight, 50-150 ft long, 12"-48" diameter) are currently inspected visually and less frequently with ground robots by MDOT SHA. The condition of most culverts is unclear due to inspection limitations, which impacts maintenance prioritization. The goal is to be more proactive vs reactive in culvert maintenance by improving the inspection process. MDOT SHA proposed to use caged drones (small Unmanned Aircraft Systems or sUAS) with video to complement ground robot inspections of culverts and compare results.

The UMD UAS Test Site conducted market research to identify suitable commercially available sUAS and recommended the Flyability Elios 2, a Swiss product which was specifically designed for inspection in confined spaces. With MDOT SHA concurrence and approval, UMD procured the Elios 2 sUAS and following receipt in January 2021, completed manufacturer-provided training and a thorough Airworthiness Evaluation.

Four suitable highway culverts were identified by MDOT SHA for test and evaluation of the culvert inspection process via drone. Suitability was confirmed by UMD site survey. All culverts were located in St. Mary's County, MD and easily accessible along Three Notch Road (MD-235/MD-5) just north of the UMD UAS Test Site.

Test and evaluation flights in the four culverts were completed on May 12th and 13th, 2021 with the Elios 2. UMD UAS Test Site pilots flew flights in all four culverts the first day with MDOT SHA's Matthew Horowitz observing. On the second day, Mr. Horowitz flew flights in two culverts with UMD UAS Test Site guidance. Overall results from both days were very good.

Mr. Horowitz's overall assessment was "…the tests were very successful and provided a strong proof of concept that the Elios drone can be used for video inspections of culverts, up to a certain length and in certain conditions." The test and evaluation flights clearly indicated that video culvert inspection by sUAS such as the Elios 2 can be thorough and highly effective. Such inspections are a viable option for MDOT to determine condition and status of many typical highway culverts. This information could then be utilized to determine where to best prioritize and utilize limited resources.

Ownership of the Flyability Elios 2 sUAS used in the test and evaluation flights was transferred to MDOT SHA on June 4th, 2021. UMD recommends that MDOT SHA continue to conduct video culvert inspections with the Elios 2 under varying conditions to build their operational experience and further determine use cases, limitations, and overall value. The Elios 2 sUAS can complement and possibly replace some culvert inspections done by ground robots or people.

Introduction

MDOT SHA contacted the UMD UAS Test Site in December 2019 to discuss a research project that the Test Site would be in a good position to support. The “MDOT SHA UAS Caged Drone Research Request: Analysis of Asset Condition and Rating” document provided the following:

Problem Statement

“MDOT SHA is currently unclear of the condition and operational effectiveness of most of its culverts. MDOT SHA must establish the most efficient method possible to capture this information in order to prioritize maintenance efforts across the State.”

Current Process

“Currently, MDOT SHA visually inspects culverts when performing construction and maintenance activities in the area of the culvert. MDOT SHA also owns and inconsistently operates Robotic land pipe inspection units across the State. The drawback of these units has been the weight and length of cable not being long enough. Additionally, the units are prone to getting stuck under certain conditions.”

“Currently MDOT SHA is mostly retroactive in maintenance of culverts. However, when a video pipe inspection is done the resulting data is viewed by an HHD liaison. Most of the pipes are corrugated metal and concrete with plastic now being installed. When inspecting the video feed liaisons are looking at:

- Pipe joints that are separated vertically or horizontally
- Cracks in concrete
- Metal pipes are more susceptible to rust and holes, so the degree of corrosion is evaluated
- Amount of accumulated sediment or debris”

“The items above are usually noted during the video pipe inspection by typing what was found at the time of inspection. This captures how far in the unit was when the item was located. The Pipe Condition Rating Form provides additional details of the inspections and is in the Appendix.” (See Appendix 1.)

Research Project

“MDOT SHA is looking for a research partner to help identify the most efficient and effective way to capture asset condition of culverts throughout the State. MDOT SHA wonders whether the use of UAS equipment including potentially LIDAR (light detection and ranging) could expedite capturing asset quality across the State.”

“Specifically, MDOT SHA is looking to obtain the following:

- Video feed from a flight so that it can be compared to that of the current land unit
- Time it takes to capture video for comparison to land unit
- Identification of where along the culvert, hopefully in feet, an item of interest is located
- LIDAR capture of flight if possible
- Breakdown of parts/costs for the solution should MDOT SHA look to acquire future systems

- MDOT SHA is interested in joint or sole ownership of any system acquired as part of this research project if possible"

Special Requirements

"After looking at the form in the Appendix UMD will see the process isn't entirely quantitative and the primary driver seems to be identifying obvious existing and potential structural failures through reviewing the video. Perhaps part of this effort could include assisting MDOT SHA in establishing specific quantitative criteria for evaluation. If so, that criteria could assist MDOT SHA in applying Machine Learning (ML), to the video/LIDAR acquired in the culverts."

UMD Recommended Approach

Subsequent discussion between the UMD UAS Test Site and MDOT SHA indicated that typical concrete or corrugated metal culverts are straight, 50-150 ft long, and 12" - 48" in diameter. Based on this information and the MDOT SHA research request, UMD proposed the following work plan on May 18th, 2020:

1. Conduct market research for a suitable commercially available UAS and video camera to meet MDOT SHA requirements.
2. Procure selected UAS and video camera upon MDOT approval.
3. Complete Airworthiness Evaluation (AWE) of selected UAS.
4. Complete two flight days of test and evaluation of selected UAS and video camera at local culverts selected by MDOT SHA.
5. Upon project completion, the UAS/camera will become property of MDOT SHA.

UMD's proposal was accepted with formal notice to proceed by MDOT SHA on June 10th, 2020. The proposal did not address the special requirements noted above.

Methodology

UAS Selection

Mr. Joshua Gaus, UAS Engineer/Pilot, completed the market research to identify suitable sUAS to meet MDOT SHA requirements on August 14th, 2020. Four sUAS candidates for culvert inspection were identified:

1. Flyability Elios 2
2. DJI Mavic 2 with Heliguy Cage
3. DJI Mavic Mini with caged prop guards
4. Skypersonic Skycopter Pro

Of the four options, the Flyability Elios 2 (Fig. 1) was the clear front-runner in terms of quality of data, ease of use, inspection-specific features, and overall suitability. It was designed specifically for inspections in confined spaces. More than 90% of the examples of industrial inspections with caged UAS use this system. By far the most mature of the available systems, it was also the only system to include training with the package. The primary negative consideration was cost (approximately $50K), which was about three times the cost of the second most expensive (but less capable) system.

Figure 1. Flyability Elios 2 UAS conducting culvert inspection.

After review and consideration of the options, MDOT SHA reported concurrence from all parties that the Flyability Elios 2 was the best choice for this research. Mr. Matthew Horowitz, MDOT SHA UAS Coordinator, authorized procurement by UMD on September 22nd, 2020. UMD initiated procurement on September 24th, 2020. Further coordination with Mr. Horowitz during the procurement process authorized inclusion of the Range Extender option for the Elios 2 on October 29th, 2020. The Range Extender is an optional accessory for the ground control station that can extend the signal propagation range between the control station and UAS in underground environments. This is particularly valuable if there are any bends in the culverts which would take the UAS beyond visual line of sight (BVLOS).

The Flyability Elios 2 UAS arrived at the UMD UAS Test Site from Switzerland on January 6th, 2021. Manufacturer-provided training and initial indoor flights were completed by the three UMD pilots (Mr. Darren Robey, Mr. Josh Gaus, Mr. Grant Williams) January 19th, 2021.

The Elios 2 Airworthiness Evaluation was substantially completed on March 2nd, 2021. Final approval and signature was completed on April 19th, 2021. There was an administrative delay on completion of the evaluation as UMD recently conducted a major review and update of the airworthiness process in order to achieve an improved, more valuable product.

Culvert Site Selection

On January 6th, 2021, UMD requested MDOT SHA to consider which culverts in St. Mary's County might be appropriate for test and evaluation flights with the Elios 2 UAS. MDOT SHA provided a kmz file of some local candidate culverts on April 9th, 2021. Mr. Darren Robey, UMD Chief Pilot, did a visual inspection of some of the local options on April 13th to assess feasibility, and noted some challenges with MDOT. MDOT provided a list of four additional candidate culverts on April 13th that are newer and more likely to be in better, more accessible shape. Site survey on this last group of four culverts was completed on April 20th, 2021. They were determined to be good candidates and were selected for the test and evaluation flights. Pipes 1, 2, and 4 were in the 24-28" diameter range, while pipe 3 was closer to 48" diameter. All four culverts (Figs. 2-5) were on Three Notch Rd (MD-235/MD-5) within a short drive north of the UMD UAS Test Site located in California, MD.

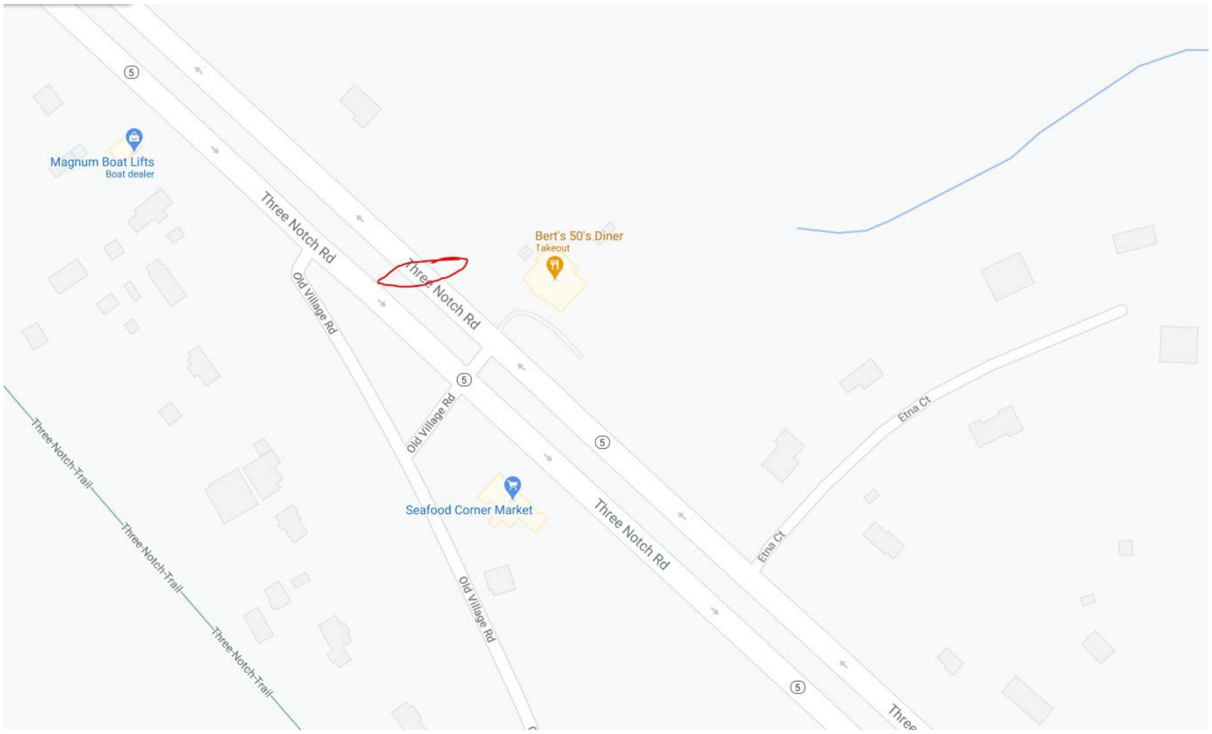

Figure 2. Pipe 1.

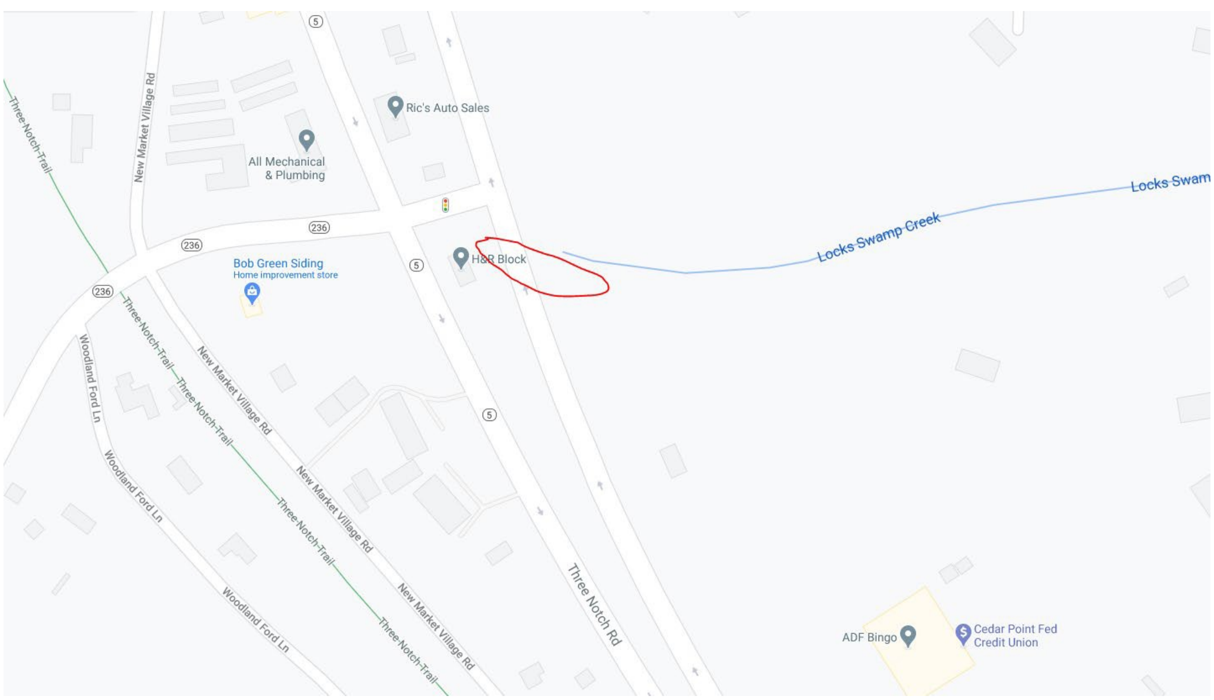

Figure 3. Pipe 2.

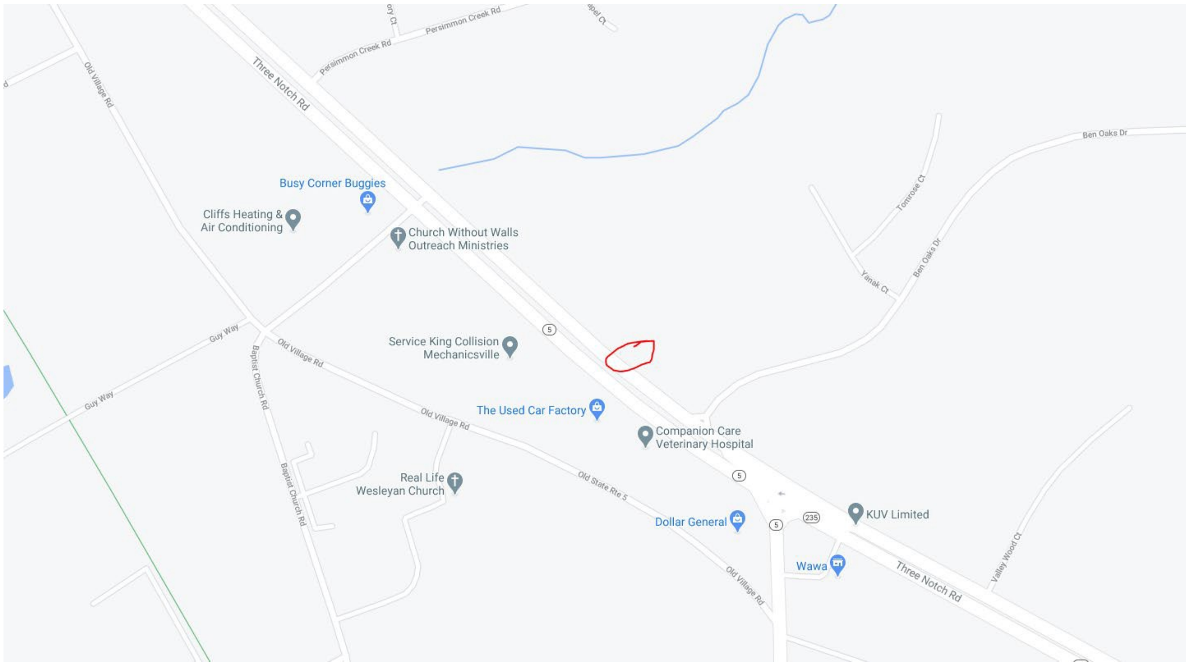

Figure 4. Pipe 3.

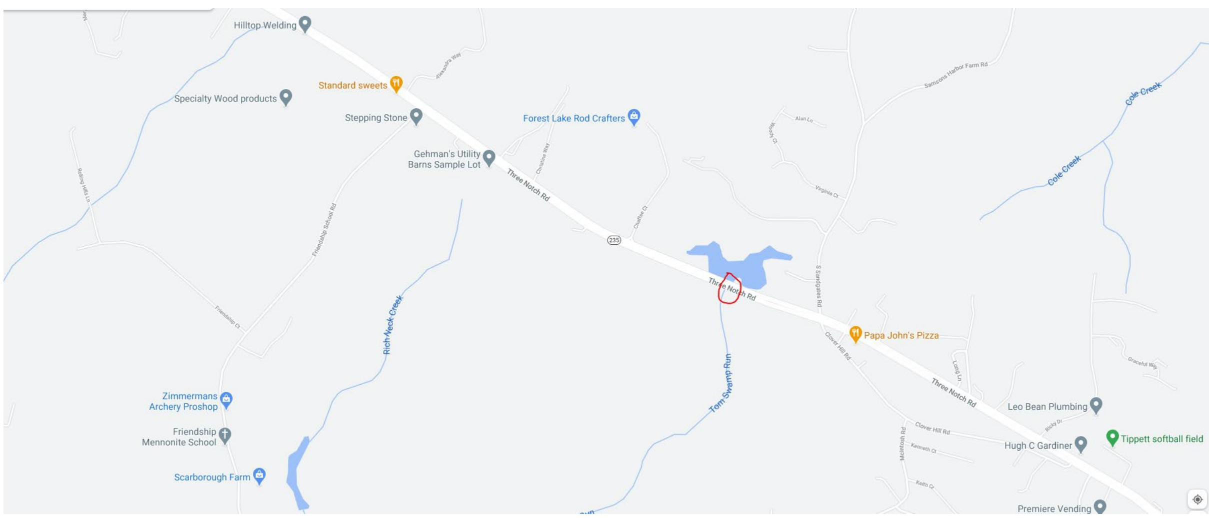

Figure 5. Pipe 4.

Flight Testing

Initial (functional) flight tests were completed on January 19th, 2021, as part of the UMD pilot team's system acceptance and manufacturer training. The training itself consisted of several video walkthroughs covering basic aircraft operations to include flight controls, limitations, and general safety considerations. Although being thoroughly outlined within the videos, actual training flights could not be directly administered by an Elios 2 instructor. As such all initial flights were conducted at the discretion of UMD's Chief Pilot and were completed within existing UAS Test Site operational and safety protocols. These initial flights occurred within the hangar space available at the UAS Test Site whereby the UMD pilot team, beginning with basic flight maneuvers, gradually worked up to the successful navigation of a tight enclosure (Fig. 6) to simulate the dynamic of flying inside a culvert.

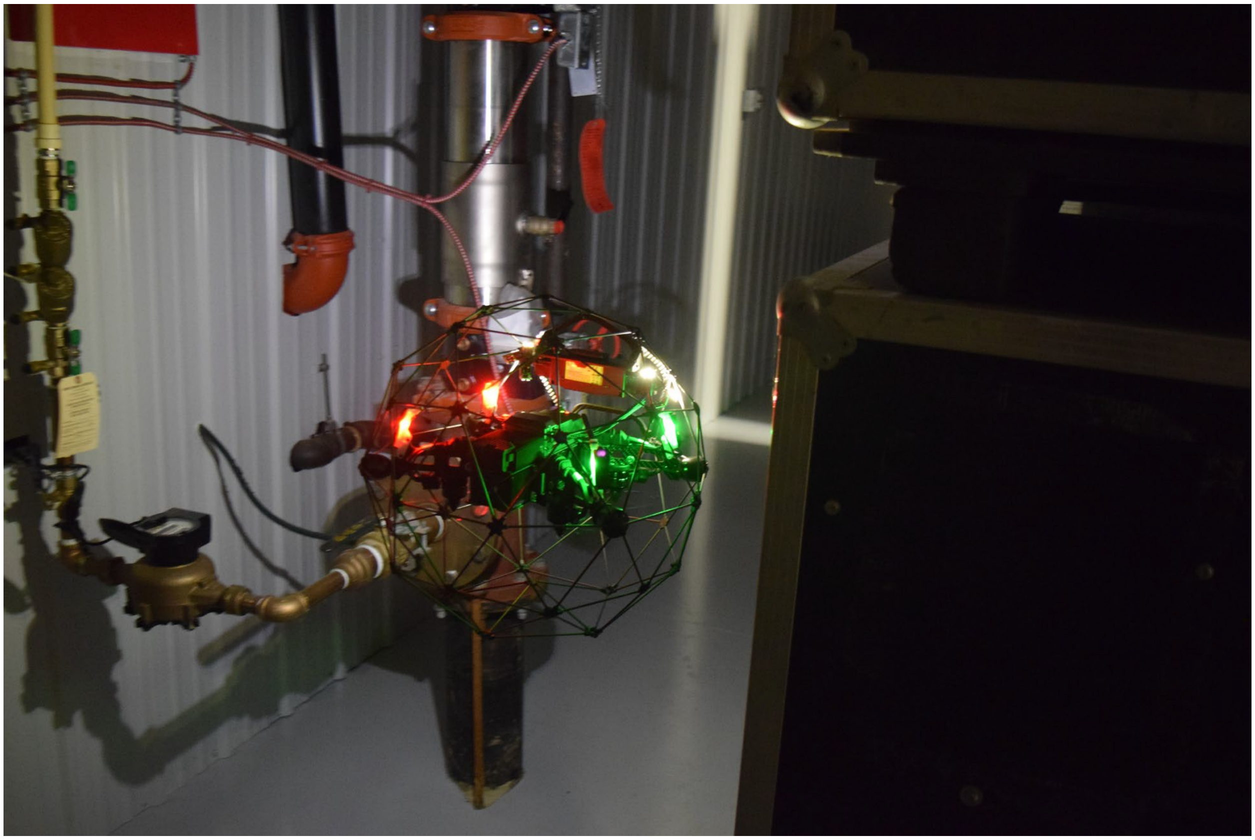

Figure 6. UMD flight tests/training. The Elios 2 navigates through confined space at the UAS Test Site.

Further flight testing was completed at the UAS Test Site as a necessary function of UMD's airworthiness evaluation process. Besides basic structural and operational inspection items, the team's main concern was validating the aircraft's advertised resistance to water (understanding that the intended use case for the Elios 2 involved flight into the confined space of a culvert in which the presence of standing or flowing water was likely). Additionally, the downward force of air created by the aircraft's rotors as it flew within a given culvert could conceivably exacerbate the state of any existing water and potentially create enough displaced droplets to cover the aircraft and obscure the camera. In this case, the overall viability of the system within this given application would be called into question. To effectively evaluate this, the pilot team recreated a culvert environment, complete with standing water. Multiple flights were conducted within this simulated environment during which the Elios 2 performed as advertised. The extent of any displaced water on the system, while present, did not pose a notable threat to proper function of the aircraft, its sensors, or the camera itself. The overall airworthiness evaluation culminated with this test. The Elios 2 was subsequently deemed "airworthy" and ready for practical field testing (Fig. 7).


Figure 7. Elios 2 after confined space water testing.

The practical flight tests were completed on May 12th and 13th, 2021. On the morning of the 12th Mr. Horowitz met the UMD team in the parking lot of a diner near Pipe 1. The UMD team then provided Mr. Horowitz with a general overview of the system to include any notable findings from the preliminary flight tests. A risk assessment was completed at that time and a safety brief was given which preceded the tentative plan for the day. The intent was to begin at Pipe 1 and work chronologically through the remaining three culverts. The team was unsure as to how long each inspection would take so the initial objective was to complete as many of the culverts as possible with any remaining to be completed the following day. In fact, due to the increased efficiencies that were experienced through utilizing the Elios 2, all initial culvert inspections were completed in one day with additional time remaining.

Once it became clear that operations were ahead of schedule, the team proactively allocated the remaining time to conducting orientation and training flights for Mr. Horowitz back at the UMD UAS Test Site. Up to that point, all operations, to include the culvert inspection flights, had been conducted by a member of the UMD pilot team with Mr. Horowitz observing. This opportunity to provide training in a controlled environment now allowed for a proper handoff of operational responsibilities between UMD and MDOT to occur. The following day (May 13th), Pipes 1 and 3 were inspected again, this time with Mr. Horowitz serving as the system operator with the UMD pilot team there to guide and assist.

Throughout both days, for each culvert inspection, the Elios 2 was placed on level ground near the opening of the pipe. The operator remained nearby within visual line of site of the aircraft. Upon initial takeoff, the operator would slowly position the sUAS into the center of the culvert and begin a forward flight path inside. Once the aircraft was established within the 'tube' the operator would reposition himself to be directly in line with the opening to ensure the radio signal of the hand control unit would have the most direct and unobstructed path to the aircraft. This also allowed the operator to maintain line of site with the aircraft as it advanced further into the pipe. (Note that a Range Extender was provided with the Elios 2. The team employed the extender during the inspection of Pipe 2 but, due to the design of the range extender itself, found no notable benefit for this application.)


Figure 8 (Left). Elios 2 being flown into Pipe 3.
Figure 9 (Right). UMD pilot observes Mr. Horowitz operating at Pipe 1.

Once inside the culvert, the Elios 2's various sensors aid in avoiding obstacles and maintaining a flight path consistent with the center of the tube. The operator's primary job at that point is to mitigate forward velocity and make small adjustments to the flight path as needed. In general, the sUAS maintained a high level of stability and controllability within the culverts. However, if the aircraft got too close to the culvert lining, a vacuum effect seemed to be produced by the rotors which would pull the aircraft toward the wall. In these instances, the aircraft's outer cage would drag along the wall until the operator could successfully reorient it. The aircraft remained unimpeded inside the cage and this scenario presented no tangible impact to the safety of the operation. At times, though, it did negatively affect the quality of the video as the camera angle would change somewhat sporadically each time the cage impacted the wall. This situation could be mitigated to a certain extent by constant and proactive operation/navigation of the aircraft.

Figure 10. Imagery from the Elios 2 inside Pipe 1.

As the team moved from culvert to culvert, it became clear that the Elios 2 was a very capable platform. The video quality was more than adequate for real time inspection work and the aircraft was able to power through any small snags and debris as it slowly floated along. However, certain operational constraints and considerations were observed. First, the aircraft's endurance is limited. The battery only allows for approximately 10-15 minutes of total flight time which translates to just five minutes of flight into a pipe (as the remaining time is needed to safely navigate the aircraft back). This proved to be insufficient to fully exploit the furthest reaches of certain culverts. Additionally, the aircraft performed less efficiently in smaller culverts. For example, while operating in Pipe 4 (Tom Swamp Run Dam, which has a diameter of only 24"), the aircraft was far more likely to get caught in the 'vacuum' effect previously described and would frequently drag along the outer walls. This slowed the progress of the inspection and demanded more performance from the aircraft as it powered through the added friction. Conversely, the added space within larger culverts enabled the operator to achieve higher speeds and more easily avoid any significant obstructions.

Figure 11. Elios 2 operating inside Pipe 3.

Research Findings/Discussion

Flight testing at the four culvert locations on May 12th and 13th, 2021, clearly indicated that video culvert inspection by UAS can be thorough and highly effective. Good results can be obtained quickly, easily, and reliably by a skilled, experienced pilot without the inconveniences of a manual or ground robot inspection.

Following the conclusion of testing, MDOT's Mr. Horowitz made the following assessment: "I think the tests were very successful and provided a strong proof of concept that the Elios drone can be used for video inspections of culverts, up to a certain length and in certain conditions. The drone is not very difficult to fly, but it has a sophisticated control and wall avoidance system that takes time and practice in a controlled environment to understand how to operate it. Setting up the drone is fairly easy and takes only a couple minutes onsite."

"The biggest limitation is the battery life. The battery only lasts about ten minutes, and you need to turn around at around the 60% mark to make it out of the pipe safely, so that limits how far into a pipe you can get. The drone comes with ten batteries however, so it can be flown several times in a row."

Conclusions and Recommendations for Implementation

Video culvert inspection by a capable UAS such as the Flyability Elios 2 is a viable option for MDOT to determine condition and status of many typical highway culverts. This information could then be utilized to determine where to best prioritize and utilize limited resources.

Ownership of the Flyability Elios 2 UAS used in the test and evaluation flights was transferred to MDOT SHA on June 4th, 2021. UMD recommends that MDOT SHA continue to conduct video culvert inspections with the Elios 2 under varying conditions to build their operational experience and further determine use cases, limitations, and overall value. The Elios 2 UAS can complement and possibly replace some culvert inspections done by ground robots or people.

Appendix 1

Pipe Condition Rating Form

Date: ______ District & Inspectors: ______
Location: ______

Upstream Structure Number: ______
Downstream Structure Number: ______

Instructions: Check all that apply and circle number of rating given. The worst defect along the individual storm drain length is used to give a single condition grade for that particular pipe length. The grade is based on the highest (worst) internal condition grade along the pipe length.

5 Collapsed or Collapse Imminent (pipe has failed):

- ☐ Road severely sagging/caving due to settlement and/or closed to traffic
- ☐ Partial or complete collapse of pipe
- ☐ Deformation >10% and pipe is broken or fractured
- ☐ Pipe invert completely deteriorated
- ☐ Extensive areas of pipe material missing and/or extensive perforations in pipe
- ☐ Partial or complete collapse of endwall/headwall structure with embankment failure encroaching on roadway shoulder
- ☐ Embankment failure near pipe encroaching on roadway shoulder
- ☐ Multiple sections are out of alignment; pipe is not functioning

Other ______

4 Collapse likely in foreseeable future (pipe will probably fail within 0-5 years):

- ☐ Evidence of roadway settlement or previous patching; depressions in roadway
- ☐ Deformation up to 10% and pipe is broken
- ☐ Pipe broken or has multiple fractures; seams cracked 3 inches or more at bolts; evidence of efflorescence(crystalline whitish deposit on surface of concrete)
- ☐ Fracture with 5-10% deformation
- ☐ Misalignment and/or ponding from sagging segments shifted more than pipe thickness (significant infiltration/exfiltration at joints; fill visible
- ☐ Major undermining of pipe/structure; evidence of piping (runoff along outside of pipe eroding soil around and beneath(
- ☐ Pipe exposed behind endwall/structure
- ☐ Partial or complete collapse of endwall/headwall structure with embankment failure **NOT** encroaching on roadway shoulder
- ☐ Embankment failure near pipe **NOT** encroaching on roadway shoulder
- ☐ Extensive areas of spalling (chipping/splintering concrete) or slabbing (large slabs of concrete peeling) with exposed corroding reinforcing stee
- ☐ Extensive areas of corrosion/rust with scattered perforations and deep pitting
- ☐ Large areas of wearing greater than 0.5 inch deep (removal and deformation of surface material in pipe)

Other ______

3 Collapse unlikely in near future but further deterioration likely (pipe may fail in 5-10 years):

- ☐ Longitudinal cracking, multiple cracks or significant seam cracking near bolts on metal pipes
- ☐ Fracture with <5% deformation
- ☐ Minor horizontal or vertical displacement of pipe segments (less than pipe thickness); alignment beginning to change
- ☐ Minor to moderate perforations in pipe, scattered heavy rust and/or deep pitting
- ☐ Large open joints or medium joint displacement (over 1 times the pipe wall thickness) allowing backfill or water infiltration at joint:
- ☐ Minor undermining of pipe/structure; possible piping
- ☐ End structure separated from pipe segments
- ☐ Significant cracks or spalling and/or large areas of scaling (peeling or flaking less than 0.25 inches deep); isolated locations of exposed reinforcing steel
- ☐ Medium areas of wearing less than 0.5 inch deep

Other ______

2 Minimum collapse risk in short term but potential for further deterioration (pipe unlikely to fail for atleast 10-20 years):

- ☐ Moderate rust with no perforations; slight pitting
- ☐ Minor pipe distortion or misalignment due to settlement or excessive loads
- ☐ Minor joint defects; medium open joint or small joint separation (less than 1.0 times pipe thickness), joints deteriorated at isolated locations
- ☐ Minor hairline cracks or minor cracking at bolt holes
- ☐ Small areas of wearing, spalling or scaling (finished concrete surface chunks cracking off) on invert present

Other ______

1 Adequate Condition:

- ☐ No structural defects/in good condition

Other ______

0 No Rating:

- ☐ Pipe not accessible (Comments Required)
- ☐ Pipe submerged
- ☐ Pipe buried
- ☐ Overgrown vegetation
- ☐ Pipe could not be located
- ☐ Pipe full of sediment/debris- needs to be cleaned

Other ______

Overall Rating Comments: ______

Number of Additional Photos: ______

08-31-2015
Form 1