

## Tech Brief

# USE OF SMALL UNMANNED AERIAL SYSTEMS FOR BRIDGE INSPECTION

### INTRODUCTION

The capabilities of unmanned aerial systems (UAS) have improved exponentially over the past few years due to advances in the technology; lower prices, which have made UAS more widely available; and greater overall awareness of the technology, which has opened UAS to new uses. This progress has resulted in user-friendly equipment that can fly autonomously, avoid obstacles, and perform repeatable flights in areas that are sometimes difficult to access.

Given these capabilities, the overall use of UAS for infrastructure inspection and condition monitoring activities continues to increase. In a March 2018 survey by the American Association of State Highway and Transportation Officials (AASHTO), 35 of 44 reporting state departments of transportation (DOTs) indicated that they have experience deploying UAS in some capacity (AASHTO 2018a).

Inspection of in-service bridges (Figure 1) are one of the more promising potential uses of UAS.

The agility and overall capabilities of UAS can be leveraged to alleviate several barriers or challenges inherent in the bridge inspection process, including the high cost and limited availability of specialized access equipment, limited inspector access to portions of a bridge, and the cost and safety implications of the traffic restrictions needed for some inspections.

UAS are already used by other industries to capture data in challenging environments, monitor weather, control traffic, support firefighters, map stockpiles, conduct surveys, and perform other tasks.



[https://www.fhwa.dot.gov/innovation/everydaycounts/edc\\_5/docs/uas-factsheet.pdf](https://www.fhwa.dot.gov/innovation/everydaycounts/edc_5/docs/uas-factsheet.pdf)

Figure 1. Use of UAS for in-service bridge inspection



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Current bridge inspection methods rely primarily on visual and hands-on evaluation techniques performed by inspectors. For visual observations to be effective, inspectors must be able to see all of the elements of the bridge to properly assess their conditions. To effectively see some elements, certain types of access equipment may be needed. For a hands-on inspection to investigate suspected deterioration, inspectors rely on a combination of access equipment (ladders, rigging, scaffolds, and rope) and vehicular lifts (man-lifts, bucket trucks, and under-bridge inspection vehicles). UAS have the potential to help inspectors quickly and safely see bridge components that are difficult to reach and provide useful information that can help inspectors determine whether additional, more detailed inspection is needed. UAS can potentially improve the bridge inspection process in several ways:

- Allow inspectors to gain closer access to elements traditionally viewed through binoculars
- Improve safety for inspectors
- Improve safety for the public through fewer lane closures
- Lower overall inspection costs
- Provide unique and cutting-edge deliverables, such as digital image capture and analysis

A large body of local and international research is available on UAS inspections, and DOTs in several states have incorporated UAS into regular activities and sponsored research dating back over a decade. As early as 2008, the California DOT (Caltrans) and the University of California experimented with a tethered electric ducted fan UAS. More recently, the DOTs of Florida, Idaho, Michigan, Minnesota, and Oregon have conducted and/or sponsored studies into the use of various UAS platforms for bridge inspections with varying levels of success.

### ADVANTAGES OF UAS FOR BRIDGE INSPECTIONS

A report requested by the American Association of State Highway and Transportation Officials (AASHTO) and sponsored by the National Cooperative Highway Research Program (NCHRP), *Successful Approaches for the Use of Unmanned Aerial Systems by Surface Transportation Agencies* (Banks et al. 2018), considered a state agency's UAS program successful if it yielded one or more of the following results:

- Increased safety or reduced liability for inspections
- Increased efficiency and productivity of inspections, or reduced impact on the public
- Increased cost savings for inspections
- Increased environmental protection during inspections
- Produced higher quality end products for inspections

Ultimately, a thorough understanding of UAS technology coupled with creative implementation provides an opportunity for UAS to revolutionize the way surface transportation agencies perform bridge inspections.

### BRIDGE INSPECTIONS

The National Bridge Inspection Standards (NBIS), found in the Code of Federal Regulations (23 CFR 650 Subpart C), define the regulations for the inspection and evaluation of all publicly owned bridges. The AASHTO *Manual for Bridge Evaluation* (MBE) (AASHTO 2018b) is incorporated by reference into the NBIS along with other related documents, such as the *Bridge Inspector's Reference Manual* (BIRM) (Ryan et al. 2012). According to the MBE, seven types of formal inspections are conducted on publicly owned in-service bridges: initial/inventory, routine, in-depth, fracture-critical members, underwater, special, and damage.

Inspection procedures outlined in the MBE require that a team leader who meets minimum qualifications as stated in CFR 650.309 is required to be on site for all the inspection types listed according to the NBIS, except for damage or special inspections, for which qualification is usually dictated by state policy. Because a team leader must be present for all inspections, inspections, they are ideal candidates for UAS remote pilots. These bridge inspectors can take advantage of their technical understanding of bridge structures while also appreciating the limitations of the standard inspection approach.

The following sections describe the roles that UAS might play in each of the seven types of formal bridge inspections listed in the MBE.

#### Initial/Inventory

On completion of bridge construction, a UAS could capture imagery from multiple perspectives to establish a more robust baseline condition of the bridge. Specifically, a three-dimensional (3D) image (Figure 2) and point cloud of the as-built structure can be developed to supplement standard two-dimensional (2D) photographic documentation. Additionally, the UAS can record its own flight paths so that they can be repeated in future inspections for direct comparison.



Wells and Lovelace 2017, MnDOT

**Figure 2.** 3D model created from images of a completed bridge captured by UAS

## Routine

Every 24 months or as required, a UAS could obtain imagery during a routine inspection that cannot otherwise be captured, getting closer to certain areas than would be possible with traditional inspection and repeating previously recorded flight paths while taking images that can be compared with previously acquired images from the same vantage point. Technological advances also allow for the use of thermal cameras to check for subsurface anomalies, all the while minimizing traffic disruptions and improving the safety of the inspector and the public.

## In-Depth and Fracture-Critical Members

The NBIS currently requires hands-on inspections by an inspector for all critical elements of a bridge during a fracture-critical inspection. Although currently available UAS are not yet capable of contributing significantly to hands-on inspections of this nature, technologies such as hyperspectral imaging (Figure 3) are evolving and may soon be available to perform remote nondestructive testing.

Although UAS are not currently acceptable as a replacement for hands-on inspections, at a minimum, UAS can assist in these inspections by providing initial images of difficult access areas and serve to supplement images captured by the bridge inspector performing the hands-on inspection.

## Underwater

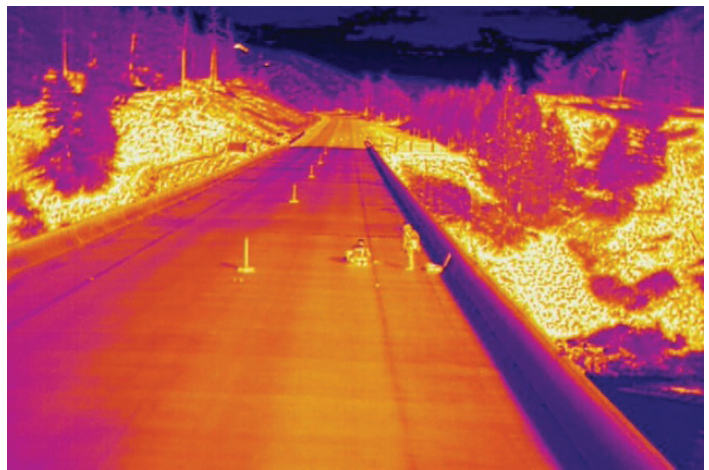
As their capabilities improve, remotely operated underwater vehicles may eventually be used in the field to perform underwater bridge inspections. In limited visibility conditions, underwater divers must manually feel their way around the bridge structure to locate potential deteriorated areas. Underwater vehicles with active sonar capabilities could assist in hazardous situations, such as high flows and poor visibility, by providing better representation of the structure and allowing divers to gather information prior to entering the water and focus on the areas noted. At present, UAS are primarily being used to remotely evaluate water flow around structures, which can assist in inspection planning.

## Special

A UAS could provide an economical means of monitoring a known defect without the need for specialized access equipment and allow for a comparison of imagery on a regular basis.

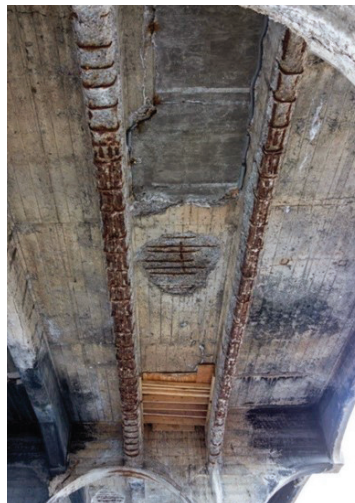
## Damage

An unscheduled inspection to assess structural damage (Figure 4) from either environmental events (e.g., flooding) or human action (e.g., truck impacts) is an excellent use case for a UAS.



Wiss, Janney, Elstner Associates, Inc.

**Figure 3. Infrared image captured by UAS**



Wiss, Janney, Elstner Associates, Inc.

**Figure 4. Damage captured by UAS**

## UAS PLATFORMS AND SENSORS

UAS technology is ever-changing, but the current state of the practice for bridge inspections favors the use of multirotor rather than fixed-wing aircraft. The multirotor aircraft described in the remainder of this tech brief can fly autonomously or be controlled remotely and can be equipped with global positioning system (GPS) sensors, a barometer, and one or more inertial measurement units (IMUs).

A multirotor UAS equipped with an IMU that electronically measures orientation, velocity, and gravitational forces using accelerometers, gyroscopes, and often magnetometers is essential for safe and controllable flight. The aircraft's sensors communicate with the onboard microcontroller, which relays sensor information along with the video feed from the onboard cameras or sensors to the remote pilot, enabling stable, close-range bridge inspections.

The multirotor UAS available to the bridge inspection market can be broken into three categories based on the systems' configurations (and the price ranges shown in Table 1) as follows:

- Compact systems with a fixed camera and sensor suite
- Intermediate systems with interchangeable proprietary cameras, lenses, and sensors
- Advanced systems that are only limited in terms of the possible camera and sensor options by weight, type of use, and unique sensor configuration

Additional information regarding these categories is provided in Table 1.

## CONTROL AND SOFTWARE

UAS operate internally on proprietary firmware but can usually be either controlled remotely by a pilot or pre-programmed with a set flight path. Data can be captured manually or at set intervals using proprietary or third-party software. Most of the branded UAS can be operated using a mobile device through applications that operate on both the Apple iOS and Android platforms.

### Flight Control Software

Most UAS come equipped with their own branded control applications, but many third-party applications that operate as effectively as the branded software can be installed depending on flight requirements or user preferences.

This third-party software can be a substitute for either the existing remote flight control or autonomous flight planning and control software.

### Live Image Processing




The images captured by the UAS are transmitted back to the remote controller, which is typically connected to a mobile data collection device running iOS, Android, or a similar platform. The data collection device allows for live image processing, including but not limited to the simultaneous review of still images either on a separate on-site monitor or via streaming over the internet.

Some applications use the computing power of the remote mobile device to stitch the images together to provide for an overall picture of the area covered by the UAS. Other software allows the pilot (or inspector via a live video feed) to annotate and tag portions of the images in real-time for later automated reporting, which helps reduce the time required for image post-processing.

### Image Post-Processing

For image post-processing, UAS inspections generate a large amount of data and agencies need to plan how to manage these large datasets. A process flow needs to be established by the agency to outline processing, storage, and archival, which may require special expertise within the program.

Table 1. Multirotor UAS available for bridge inspection

Details	Compact	Intermediate	Advanced
Image			
Weight	1–4 lbs	5–10 lbs	2–55 lbs
Rotors/Size	4 rotors; often able to be folded into a small, convenient carrying size	4–6 rotors; typically not foldable and requires dedicated carrycase	4 or more rotors; usually larger than intermediate models
Sensors	3-axis gimbal-mounted camera, with or without zoom capability, using a complementary metal-oxide semiconductor (CMOS) sensor up to 1 in. in size that can store an effective 12–20 million pixels (12–20 megapixels) in still photos or capture up to 4K of video at a maximum bitrate of 100 Mbps	Similar to a compact model with the addition of infrared sensors and additional options for proprietary cameras and lenses for better image capture with CMOS sensors 1 in. or greater; some models have separate controls for flying and image capture, with the cameras utilizing a gimbal that can pan and tilt	Ability to either perform specialist functions or be equipped with a multitude of different cameras and sensors depending on requirements, e.g., light detection and ranging (LIDAR), hyperspectral imaging, and ground penetrating radar
Flight Time	20–30 minutes	15–30 minutes	8–35 minutes
Cost	\$800–\$2,500	\$2,500–\$10,000	\$5,000+

Once the images have been downloaded from the UAS, an extensive array of software is available to process the data for different uses:

- *Photogrammetry*, the science of taking measurements from photographs, allows image data from the UAS to be combined with accurate GPS coordinates to produce extremely accurate measurements from the images. The flight images obtained from the UAS have a large amount of overlap, and algorithms within the image processing software can identify related features in each image that allow the images to be joined (i.e., stitched) together.

In addition to the stitching process, the software geometrically blends the overall image to remove distortions stemming from topographic relief, lens distortions, and camera tilt while creating a uniform scale. These large-format post-corrected images, which are referred to as orthomosaics, provide the bridge inspector or bridge reviewer with accurate measurements and a detailed image of the overall structure while retaining the ability to zoom in on defects.

- *Radiometric infrared* software allows images to be calibrated to identify small differences in surface temperature.
- *Digital terrain modeling* uses algorithms to emulate the terrain while ignoring vegetation, while *digital elevation modeling* operates similarly but incorporates plant life. In both types of modeling, contours can be accurately mapped, stockpiles can be measured, and area and length can be evaluated.
- *Computer-aided design (CAD) file rendering* from point cloud data can be utilized to create drawings, take accurate measurements, and/or capture details of specific components.
- *3D modeling* allows multiple images and/or LIDAR points to be stitched together to form a “lifelike” image of the bridge structure. Software for 3D reality mesh modeling is available as a cloud service or as standalone desktop programs. The images produced by the software can be rotated to provide a greater understanding of the structure’s elements and to help visualize potential issues and identify surface anomalies within the context of the surrounding elements in the structure.

Viewing the structure in three dimensions allows all interested parties to gain a much greater understanding of the complexities involved in bridge structures. Although the current accuracy of aerotriangulation does not consistently allow for perfect visual results, some software packages allow back referencing to the original image or images from which the 3D model was created.

## FAA REGULATIONS REGARDING UAS FOR BRIDGE INSPECTIONS

UAS operators in both the public and private sectors must adhere to statutory and regulatory requirements. Public aircraft operations (including UAS operations) are governed under the statutory requirements for public aircraft established in 49 USC § 40102 and § 40125. Additionally, both public and civil UAS operators may operate under the regulations promulgated by the Federal Aviation Administration (FAA).

The provisions of 14 CFR Part 107 apply to most operations of UAS weighing less than 55 lbs. Operators of UAS weighing greater than 55 lbs may request exemptions to the airworthiness requirements of 14 CFR Part 91 pursuant to 49 USC § 44807.

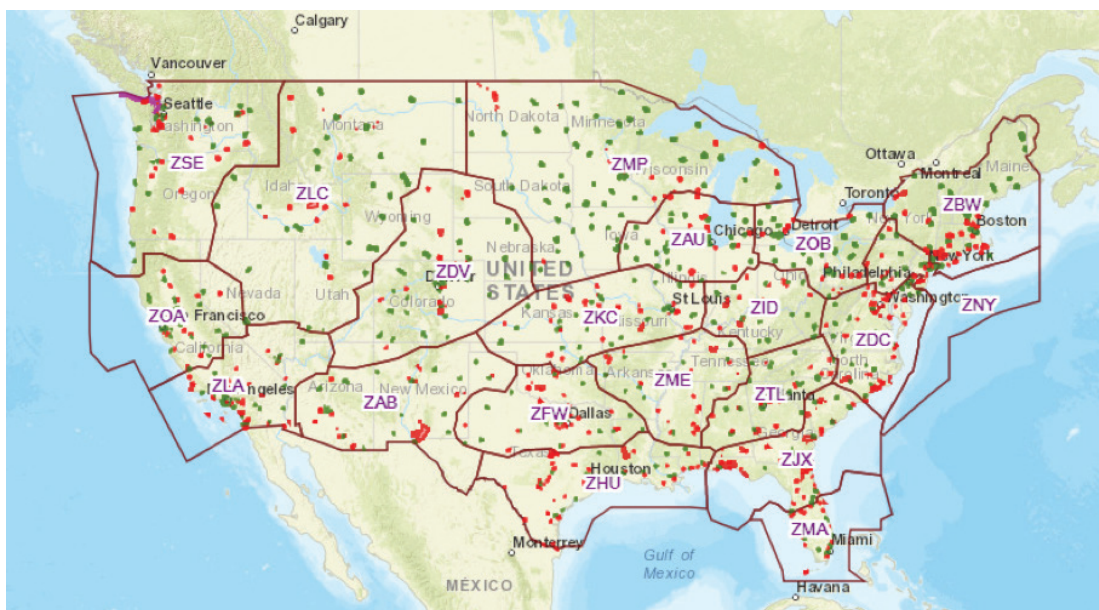
UAS operators should also be aware of the requirements of the airspace in which they wish to fly. The FAA provides extensive resources and information to help guide UAS operators in determining which laws, rules, and regulations apply to a particular UAS operation. For more information, please see <https://www.faa.gov/uas/>.

Because the height of a bridge above ground level seldom exceeds 400 ft, altitude is not the primary limitation; many bridges are located in controlled or restricted airspace, and it is the responsibility of the UAS pilot to understand and follow the regulations set by the FAA, including the UAS registration requirements, airspace authorizations, and specific waiver requests.

### Airspace Authorizations

The National Airspace System (NAS) is the network of US airspace, navigation facilities, services, and airports with their associated technical information, rules, regulations, policies, procedures, personnel, and equipment, which is shared jointly between the FAA and the military. The use of a UAS within this system requires knowledge and understanding to safely operate within the requirements. Most airspace is unrestricted, but to assist UAS operators, the FAA and its partners provide the following resources:

- Low Altitude Authorization and Notification Capability (LAANC) system ([https://www.faa.gov/uas/programs\\_partnerships/data\\_exchange/](https://www.faa.gov/uas/programs_partnerships/data_exchange/))
- FAADroneZone unmanned aircraft registration and links to forms (<https://faadronezone.faa.gov>)
- UAS Facility Maps ([https://www.faa.gov/uas/commercial\\_operators/uas\\_facility\\_maps/](https://www.faa.gov/uas/commercial_operators/uas_facility_maps/))
- B4UFLY mobile application for drone operators ([https://www.faa.gov/uas/recreational\\_fliers/where\\_can\\_i\\_fly/b4ufly/](https://www.faa.gov/uas/recreational_fliers/where_can_i_fly/b4ufly/))



Green dots = airports participating in the LAANC; Red dots = airspace that requires a manual or online application

**Figure 5. FAA UAS facilities map**

Under the FAA UAS Data Exchange umbrella, LAANC is a collaboration between the FAA and industry that directly supports UAS integration into the airspace. It provides access to controlled airspace near airports through near-real-time processing of airspace authorizations below approved altitudes in the controlled airspace.

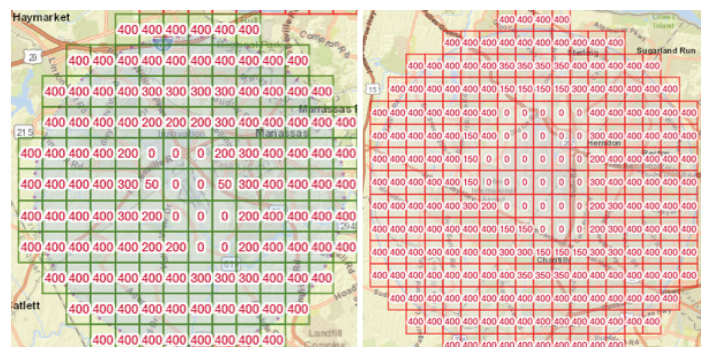
Through its platform partners, LAANC provides UAS pilots with the ability to apply for and receive online approval to fly up to the prescribed altitudes under 400 ft according to the grid pattern in the controlled airspace and to request permission to fly above the altitude ceiling in a particular grid, which is coordinated manually by the local air traffic control (ATC). This authority can be sought up to 90 days prior to the flight date.

In order to assist operators in controlled airspaces, the FAA publishes facility maps with details on towered airport locations (see Figure 5) where the FAA may grant permission to fly at maximum altitudes.

A facility map provides pilots with information concerning specific restricted airspace. A closer view of any of the green or red dots in Figure 5 reveals the five-mile radius around an airport, laid out in a grid pattern, as shown in Figure 6.

Around the runway and adjacent to the airport, the grid altitude is 0 ft. As the radius increases, the allowable altitude a UAS may fly increases in 50 to 100 ft increments, depending on aircraft flight paths and other requirements specific to the airport.

LAANC is available at nearly 300 air traffic facilities covering about 500 airports. If pilots need to fly in controlled airspaces near airports not offering LAANC, they can use the manual process to apply online for an authorization via the website.



Green = permission obtained through LAANC; Red = permission obtained through a manual or online application

**Figure 6. Example of FAA UAS facilities map data**

The B4UFLY mobile app gives all UAS operators a comprehensive overview of all airspace and other limitations that apply to recreational as well as commercial operators. It includes information that may not limit flight, but that could be of use to commercial operators.

## UAS LIMITATIONS

A UAS is an aircraft that is usually electromechanical powered; lightweight (.55 to 55 lbs); limited in terms of flight time (unless tethered) and distance; sensitive to weather (including difficulty in higher winds, not to mention inclement conditions), stray currents, and magnetic or radio frequency interference; controlled by radio frequencies or pre-programmed GPS flight coordinates that require contact with the controller and the GPS and/or global navigation satellite system (GNSS) signal; and restricted in its use by federal and local law.

UAS inspections of bridge structures has its challenges that need to be considered when planning an inspection. At a minimum, the following limitations should be reviewed:

- Pedestrian and vehicular traffic need to be considered as well as other safety and flight restrictions.
- While recognizing the complexities of flying in congested areas such as trusses or under bridge structures, flight paths need to be carefully considered to accommodate single battery flight times, which are generally about 20–30 minutes.
- An unaided visual line of site of the UAS by the remote pilot or visual observer is required at all times during inspections, so understanding site access and other limitations to visual lines of site should be considered (see the FAA Fact Sheet on Small Unmanned Aircraft Regulations [Part107] Operating Requirements section at [https://www.faa.gov/news/fact\\_sheets/news\\_story.cfm?newsId=22615](https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=22615)).

Recognizing the limitations of UAS is as important as understanding the benefits they provide to bridge inspections.

## CONCLUSIONS

UAS offer a number of potential advantages for some bridge inspection activities, in that they can make it easier for inspectors and engineers to see the most difficult to reach sections of bridges at almost any time with a little planning and preparation, but on relatively short notice. Moreover, the use of UAS puts fewer workers at risk because it reduces the need for workers to climb to high, dangerous, and difficult-to-reach bridge areas as frequently.

UAS are not intended to replace bridge inspectors, but rather can be used as a tool to supplement the information available to inspectors and bridge owners and provide better access to information on the condition of a bridge and its elements.

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Wells, J. and B. Lovelace. 2017. *Unmanned Aircraft System Bridge Inspection Demonstration Project Phase II*. Minnesota Department of Transportation, St. Paul, MN.

## ASTM RESOURCES

*ASTM F3178-16 Standard Practice for Operational Risk Assessment of Small Unmanned Aircraft Systems (sUAS)*.

*ASTM F2909-14 Standard Practice for Maintenance and Continued Airworthiness of Small Unmanned Aircraft Systems (sUAS)*.

## For Personnel

*ASTM F3266-18 Standard Guide for Training for Remote Pilot in Command of Unmanned Aircraft Systems (UAS) Endorsement*, which, in addition to the FAA knowledge test, advocates which practical skills should be able to be demonstrated for proficiency.

## Proposed New Standards under Development

*ASTM WK62741 Guide for Training UAS Visual Observers*.

*ASTM WK61764 Training for Public Safety Remote Pilot of Unmanned Aircraft Systems (UAS) Endorsement*.

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