## EPIC Final Report

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| Program | Electric Program Investment Charge (EPIC) |
| Administrator | San Diego Gas & Electric Company |
| Project Number | EPIC-3, Project 5 |
| Project Name | Unmanned Aircraft Systems (UAS) With Advanced Image Processing for Electric Utility Inspection and Operations |
| Date | December 20, 2021 |

# Attribution

This comprehensive final report documents work done in Electric Program Investment Charge (EPIC) 3, Project 5. The project team that contributed to the project definition, execution, and reporting included the following individuals:

**San Diego Gas and Electric (SDG&E)**

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# Executive Summary

SDG&E's Project 5, Unmanned Aircraft Systems (UAS) with Advanced Image Processing for Electric Utility Inspection and Operations, under the third triennial cycle of the Electric Program Investment Charge (EPIC-3), has been completed. The objective of this project was to define, demonstrate, and evaluate concepts for instrumentation and monitoring of the power system equipment using enhanced imaging and sensor technology on UAS.

UAS provides a unique opportunity for SDG&E to obtain, disseminate and use aerial sensor data that provides benefits such as cost savings to its ratepayers and lower physical risks to SDG&E personnel while increasing public safety.

The project focus areas were to demonstrate practical applications of UAS and to evaluate platforms that could integrate UAS applications with existing and future SDG&E infrastructure, software applications and legacy data sets with the ability to ingest, store, analyze and report on SDG&E assets derived from collected data.

The project examined which sensors best supply a necessary file format and metadata to deliver data for ingestion and processing within a future artificial intelligence (AI) platform. For assessment of infrastructure (i.e., equipment, lines, and structures), the project sought to determine the compatible sensors needed for collecting data, the AI platform, and the acceptable file types.

At the early stage of the project work, the project team held a series of meetings and fact-finding workshops with various stakeholders from the operation and engineering departments within SDG&E. The early research gave the project group insight into what technology to evaluate to improve the current work methods regarding time savings, efficiencies, innovation, and safety.

The project demonstrated seven use cases with the following outcomes:

- Aerial Telepresence: Issues were identified that may be resolved with the new 5G network.
- Public Safety Power Shutoff (PSPS)/Wildfire Mitigation Program (WMP): Adopted for commercial use; seven hard-to-access areas were identified for PSPS patrols using UAS.
- Coronal Camera: Licensed thermographers trained on UAS with integrated coronal camera.
- Tethering: Successful demonstration of use case; adopted for commercial use.
- Sense and Avoid: Two units with sense and avoidance of thin power lines and guy wires as well as confined space indoor inspection. Both use cases were determined as high-value and are now in commercial use.
- Line Pulling: Determined a high value use case and is in commercial use.
- Vertical Take Off and Landing (VTOL) - Fixed Wing/Beyond Visual Line of Sight (BVLOS): Due to the difficulty with launch and land procedures, this unit was not purchased, and the use case will not be pursued.

This project successfully demonstrated the value proposition for UAS and the newly mounted sensors that were tested. Based on the findings and results in the demonstrations, it was determined that the

use cases for aerial telepresence and vertical take-off and landing are not yet ready for commercial adoption in SDG&E's applications. The remaining use cases however, including PSPS/WMP, coronal camera, sense and avoid, confined space indoor inspections and line pulling, proved the UAS could perform the tasks intended, and those technologies are now in commercial use at SDG&E. This EPIC project is now completed. Given the successes of this EPIC project, it is recommended that additional work be done to further evaluate and expand use of these UAS technologies and use cases to identify others that can be used commercially in future utility system operations. It is also recommended that the appropriate internal stakeholder group within SDG&E be identified to lead the commercialization and operational use of the technologies that were demonstrated in the EPIC project.

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## List of Tables

## List of Acronyms

| Acronym | Definition |
|---|---|
| 4D | Four Dimensional |
| AGL | Above Ground Level |
| AI | Artificial Intelligence |
| ASD | Aviation Services Department |
| BVLOS | Beyond Visual Line of Sight |
| CNF | Cleveland National Forest |
| COA | Certificate of Authorization |
| CPUC | California Public Utilities Commission |
| DAC | Disadvantaged Communities |
| DER | Distributed Energy Resources |
| DIAR | Drone Investigative and Repair |
| EDE | Electric Distribution Engineering |
| EOC | Emergency Operations Center |
| EPIC | Electric Program Investment Charge |
| ERO | Electric Regional Operations |
| FAA | Federal Aviation Administration |
| FiRM | Fire Risk Mitigation |
| FPV | First Person View |
| FOB | Flight Operations Base |
| GIS | Geographic Information System |
| IOU | Investor-Owned Utility |
| IPP | Integration Pilot Program |
| IR | Infrared |
| ISV | Incident Support Vehicle |
| KMZ | Keyhole Markup Language |
| ME | Mountain Empire |

| Acronym | Definition |
|---|---|
| NOTAM | Notice To Airmen |
| NTR | None to Report |
| O&E | Operations & Engineering |
| PSPS | Public Safety Power Shutoff |
| QAQC | Quality Assurance Quality Control |
| QEW | Qualified Electric Worker |
| RC | Remote Control |
| RFP | Request for Proposal |
| RFW | Red Flag Warning |
| RPIC | Remote Pilot in Command |
| SD | Secure Digital |
| SDG&E | San Diego Gas and Electric Company |
| SOCRE | South Orange County Reliability Enhancement |
| TCM | Transmission, Construction and Maintenance |
| TFR | Temporary Flight Restriction |
| UAS | Unmanned Aircraft System |
| UV | Ultraviolet |
| VTOL | Vertical Take Off and Landing |
| WMP | Wildfire Mitigation Program |

# 1.0 Introduction and Objectives

This report documents the work performed in SDG&E's Project 5, Unmanned Aircraft Systems (UAS) with Advanced Image Processing for Electric Utility Inspection and Operations, under the third triennial cycle of the Electric Program Investment Charge (EPIC-3). The objective of this project was to define, demonstrate, and evaluate concepts for instrumentation and monitoring of the power system equipment using enhanced imaging and sensor technology on UAS.

The focus of EPIC-3, Project 5 was to demonstrate new applications of UAS, including those with enhanced image processing capabilities for electric inspection and operations. This project sought to expand on the extensive work previously conducted by SDG&E on UAS applications resulting in the analysis of high-quality images and data from UAS in aiding time-sensitive decisions in its operations. This project sought to explore the capabilities of UAS to assist in asset aging issues, vegetation management, support for power system operations and wildfire mitigation.

The combination of UAS monitoring and analysis with utility inspection capabilities is designed to improve service reliability, reduce costs, and increase employee and public safety. Specific benefit targets include early identification of failing assets, avoidance of catastrophic events, data for future predictive analytics, and improved engineering practices. Demonstrated uses of UAS in the utility space have the potential to benefit customers by avoiding more costly solutions, thereby lowering operating costs and ultimately reducing ratepayer costs.

The pre-commercial demonstrations documented in this report include the following use cases:

1) Aerial Telepresence
2) Night Flights/Public Safety Power Shutoff (PSPS)/Wildfire Mitigation Program (WMP)
3) Corona Camera
4) Tethering
5) Sense and Avoid Technology/Indoor Confined Space Inspections
6) Line Pulling
7) Vertical Take Off and Landing – Fixed Wing/Beyond Visual Line of Sight (BVLOS)

The project sought to determine the best sensor technologies to meet metadata (latitude/longitude, time/date stamps, position of sensor, position of aircraft) and file format requirements for ingestion and processing within a future intelligence platform.

The project generated valuable lessons learned when traditional methods of assessment are replaced or enhanced by UAS, as demonstrated through execution of the use cases mentioned above. These lessons and other project results have been distributed to the broader utility community and other stakeholders through this report filed with the California Public Utilities Commission (CPUC) and released on SDG&E's EPIC public website. The project endeavored to determine the potential of UAS for increasing reliability, safety, and cost efficiency in power system operations.

## 2.0 Issues and Policies Addressed

Technology advancements in monitoring, measurement and inspection help reduce labor-intensive efforts to maintain and operate the power system infrastructure. Asset monitoring and inspection using UAS has emerged as a possible solution for remote asset inspections. An operator of a UAS can assess conditions through a live high-definition feed or still images taken during flight. The technology offers a safer, less time consuming and less labor-intensive approach than traditional methods. Traditional methods including manned aircraft, are expensive and require specific locations for safe take-offs and landings. UAS can reach remote areas at a lower cost and can be operated in complex terrains that ensure flight safety without compromising data accuracy.

Additionally, with natural disasters increasing, the impact on aging critical energy infrastructure becomes more severe. UAS for preventative and reactive storm response and mitigation has proven a useful and verifiable tool. UAS improves worker safety by providing remote visualization to affected areas without exposing crews to potentially dangerous conditions.

## 3.0 Project Focus

The focus of this project was to demonstrate practical applications of UAS that have strong implications for worker safety, system reliability, data collection and storage, and improved decision making in operations. The project followed a simple formula to capture, process, analyze, and share information using UAS.

The project examined which sensors best supply a necessary file format and metadata to deliver data for ingestion and processing within a future artificial intelligence (AI) platform. For assessment of infrastructure (i.e., equipment, lines, and structures), within a specific environment with autonomous features that can be leveraged, the project sought to determine the compatible sensors needed for collecting data, the AI platform, and the acceptable file types.

Examples of activities included in the project were:

- Demonstration and evaluation of multi-spectral sensors for high-definition imagery, ultraviolet (UV)/reflectivity, and infrared for detailed inspections.
- Use of UAS to identify various levels of corrosion on distribution equipment along coastal areas.
- Analysis to categorize corrosion levels to identify potential risks and associated operational plans.
- Demonstration and evaluation of capabilities of advanced imaging enabled UAS for disaster response and re-energization of patrols.
- Demonstration of UAS capabilities to support vegetation management and wildfire mitigation.

# 4.0 Project Scope Summary

This project scope was to define, demonstrate and evaluate concepts for instrumentation and monitoring of the power system equipment using UAS imaging and sensor technology.

To perform the use case demonstrations, a trained remote pilot in command (RPIC) conducted multiple flights for each use case in the field with the appropriate SDG&E department. The RPIC recorded the results providing raw data and analysis of each pre-commercial concept demonstrated.

Primary outcomes include:

- Demonstrations of the defined use cases using various UAS technologies comparing to traditional methods.
- Identification of lessons learned for distribution to the wider utility community.
- Recommendations for transitioning use cases to commercial adoption.
- Support to SDG&E in determining costs and benefits for adoption into commercial practice.
- A comprehensive final project report for public dissemination of the project approach, findings, and recommendations.

# 5.0 Project Approach

The project approach was comprised of the following tasks and sub-tasks.

*Task 1 - Initiation of Project Plan*

### Task 1a – Identification of Stakeholders and Formation of Stakeholder Steering Committee, Technical Advisory Committee, and Project Team

The following steps were taken to identify and engage the key stakeholders in this project.

**Objective:** This task objective was to identify prospective users and other internal clients impacted by the project results and acquire internal stakeholder steering committee and advisory committee representation from these groups. The goal was to identify stakeholders with the necessary skill sets and technical expertise to help assess the strategic value of the work; and assist the inter-group coordination and staffing required to perform the project work. The steering committee was chaired by the Champion Director for the project and was the governing body.

**Approach:** The first action was the identification of key stakeholders and prospective project team members including members of Aviation Services Department (ASD), Electric Distribution Engineering (EDE), Distributed Energy Resources (DER), Fire Risk Mitigation (FiRM), Fire Science & Coordination, Transmission, Construction and Maintenance (TCM) and District Operations and Engineering (O&E). Also completed during this task was the establishment of the Stakeholder Steering Committee and Technical Advisory Committee and presentation of progress reports to stakeholders.

### Task 1b - Project Kick-off and Development of Project Plan

**Objective:** The focus of this sub-task was to complete the project kick-off, develop the project plan, identify resource requirements, and further develop the internal project team.

**Approach:** Working with the stakeholders identified in Task 1.a., the following steps were taken to identify additional internal staff resources and any contractors required to undertake the actual demonstration project work.

The focus of this project was identified during a project strategy session in Fall 2018. Based on stakeholder input, the team proceeded to write a project plan around the chosen focus. During the project planning phase, the writing team compiled a detailed description of the benefits estimate, technical scope, deliverables, resource requirements, expected budget and project schedule.

Weekly recurring meetings with the project plan writing team were scheduled to lay the groundwork for this project. As part of the project plan writing effort, the core project team was assembled based on task categories identified. The stakeholder steering committee secured the necessary project team members and the requirements for contractors were assessed and later procured using established company procurement business practices.

## Task 2 – Development of Project Requirements

### Task 2a. - Fact Finding

**Objective:** The goal of this task was to explore the availability of existing UAS technology and identify the most suitable products for the selected use cases.

**Approach:** Initial steps in this task included the investigation of UAS solutions available for purchase or contract, followed by evaluation of technical capabilities of industry products from potential vendors through site visits and attending industry conferences as needed. Examining past commercial projects at SDG&E, a review was completed to determine which sensors would deliver the best results for data ingestion and processing. After the project plan and scenario tasks were selected, vendor/contractor solicitations were planned to occur further downstream in the project schedule.

Internal teams investigated UAS solutions and identified vendor/contractor candidates. Upon identifying potential candidates, coordination of meetings to support the development of bidders lists and other procurement activities was performed. The following SDG&E groups were involved in these investigations:

- ASD – Aviation Services Department
- FiRM – Fire Risk Mitigation
- DER – Distributed Energy Resources
- EDE – Electric Distribution Engineering
- Fire Science & Coordination
- TCM – Transmission, Construction and Maintenance
- O&E – Operations & Engineering

#### Task 2.b. – Baselining Current Condition and Practices

Objective: The focus of this task was to determine the existing applications, conditions, and best practices for UAS within the utility industry.

Approach: This task consisted of a review of existing SDG&E UAS practices, including leveraging of innovative technology to safely inspect power lines and gas pipelines in environments that are off-limits to helicopters or difficult to access by road or other means.

For example, during daylight inspections, UAS can be used to:

- Locate the cause of power outages
- Inspect power and gas lines
- Access infrastructure in remote areas that are difficult to access by ground crews or helicopters
- Improve situational awareness during emergencies through monitoring of fires
- Achieve cost savings, noise reductions and environmental protection by avoiding the use of helicopters and other heavy machinery
- Support vegetation management and wildfire risk mitigation
- Capture images of fire breaks

### *Task 3 – Development of Funding Base and Collaborative Funding and In-Kind Services*

Objective: The purpose of this task was to seek opportunities for partnering and cost sharing to allow expansion of work potential for this project.

Approach: This task included the inquiry into leveraging collaborative funding opportunities with SDG&E's FiRM department to piggyback on their commercial activities for centralized data collection to perform data processing and analytics. Prospective collaboration with other investor-owned utilities (IOU), the Federal Aviation Administration (FAA), Integration Pilot Program (IPP) and other potential partners was also explored. In competitive procurement of the contractor and vendor resources for the project, dollar cost sharing and in-kind services (such as equipment loans) were requested.

### *Task 4 – Contractor Procurement:*

Objective: This task focused on the competitive procurement of qualified contractors.

Approach: Established SDG&E procurement business practices were used to select successful vendors and negotiate contracts for equipment procurement and support for task areas that could not be performed solely by SDG&E staff. Both the internal project team and the project stakeholder steering committee were engaged in the decision processes. Working with Supply Management, the vendors were soul sourced as they had uniquely qualifying systems/services. Following the selection of vendors, the vendor list and capabilities were reviewed with the stakeholder steering committee.

### *Task 5 – Site Selection and Procurement of UAS Equipment, Hardware, Software, and Licensing*

Objective: This task sought to select a preferred and alternate site for flights to test the best sensors in all environments.

**Approach**: The sensors require massive data streams and a central repository. When procuring equipment, SDG&E rented, purchased, or used from available inventory.

The repository requirements were a separate commercial project at SDG&E and included hardware, software, electric power, climate control, and other site requirements.

Requirements for site selections included obtaining a certificate of authorization (COA) when flying beyond visual line of sight and in restricted airspace. A large, outdoor space that was isolated from the public was required for flight testing.

### *Task 6 – Preparation of Use Cases and Test Plan*

**Objective:** UAS use cases were prepared to define the demonstration process for the project.

**Approach:** A description of use cases was developed with sufficient detail to fully understand the nature of the task. Metrics to define completion of the demonstration were established as well as the determination of data taking requirements to support updating the initial benefits estimate. Steps to finalize use cases and define metrics for demonstration and preparation of a test plan were included in this task. The test plan informed sequential execution of the use cases at the selected sites and recording the raw data. Formal project reviews were conducted with stakeholders.

### *Task 7 – Preparation for Testing*

**Objective**: The objectives of this task were the development of the test set-up for the demonstration work and completion of the supporting modeling work.

**Approach:** This task began with preparation of the test set up for running the demonstrations at the selected sites and running any preliminary modeling needed to maximize the value of the use case runs. The team identified what data would be recorded and ensured the correct infrastructure was ready to ingest the data. Additional actions taken during this task included assuring the right data was collected for updates to the benefit analysis and that all the equipment and software required was ready to meet scheduling requirements of the demonstrations. Accurate evaluation of the overall time, effort, cost, and effectiveness for each use case was achieved during this task.

While conducting this task, a Red Flag Warning (RFW) was an added procedure to UAS operations that dictated an on-call schedule when issued. As Public Safety Power Shutoff (PSPS) events can be identified at least three days before a weather event, RPICs will be on standby two days prior to the event to support potential Pre-PSPS Patrols. After the RFW has expired, the RPICs will standby at the district locations for easy deployment. The expected hours of support are from sunup to sundown. During the PSPS UAS flight, the UAS crews support inspection of overhead power lines to check for debris and equipment damage prior to re-energizing lines. A qualified line checker is on sight and reviewing the live stream data using the second UAS remote.

### *Task 8 - Perform the Pre-Commercial Demonstration*

**Objective**: The goals of this task were to execute the pre-commercial demonstrations and generate data for use in subsequent tasks.

**Approach:** The internal SDG&E team lead the effort in setting up equipment, running tests in concurrence with the use cases, and compiling the data and test results for use in the data analysis task that followed.

*Task 9 – Analysis of Results*

**Objective:** This objective of this task was to analyze the data and results ensuing from the demonstrations to support the development of key findings, conclusions, and recommendations for the project.

**Approach:** The project team reviewed all data to determine which use cases were successful in providing innovative solutions to enhance UAS operations. The following considerations were included in this process:

- Which sensors contributed significant value and should be adopted for commercial use?
- How should the sensors be used?
- What value proposition is associated with the innovative solutions relative to the original baseline of current practice?

The analysis examined how the metrics aligned with the initial benefits estimate. Additional considerations during this task included:

- Were there additional benefit areas that were identified?
- Was the benefit stream greater or less than the original estimate for the benefit areas that were identified at the start of the project?
- What were the key lessons learned and other key findings in the demonstrations?
- What key conclusions and recommendations were derived from the analysis?
- Was the demonstration information complete?
- Were there any gaps that could be filled by running a few more tests, if funds were still available?

*Task 10 – Development of Conclusions and Recommendations*

**Objective**: This focus of this task was to develop the key findings, conclusions, and recommendations for the project.

**Approach:** The project team applied the results of the data analysis task to update the initial benefits analysis and formulate key findings, conclusions, and recommendations for the project. The project team confirmed success or failure of each use case demonstrated and made recommendations for which use cases should be pursued commercially, defining next steps.

*Task 11 – Preparation and Implementation of Tech Transfer Plan*

**Objective**: This task focused on the development and implementation of a technology transfer plan.

**Approach:** The team set out to develop a technology transfer plan to identify a process for transferring project results into practical use at SDG&E and other stakeholder sites. The plan indicates which tech transfer activities took place during the demonstration work, which will be completed at the close of the project, and which will be completed by the stakeholders after the project ends. Example activities are release of this comprehensive final report, preparation of technical papers for presentation at conferences and in journals, participation in CPUC-required events, and a final briefing to the internal SDG&E stakeholders.

*Task 12 - Disposition Plan for Equipment and Software*

**Objective:** The focus of this task was to define and implement a disposition plan for equipment and software used in the project.

**Approach**: Equipment not owned by SDG&E was returned to the owners. Equipment and software owned or licensed by SDG&E was either transferred to the designated internal stakeholder or remained within ASD for potential use as needed. An inventory sheet was created of all UAS, and sensors purchased for asset tracking purposes.

## 5.1 Baseline Studies/Fact Finding

### 5.1.1 Initial Benefit Estimate and Value Proposition

The initial benefit areas focused on the following core areas:

1) Improved sensor technologies and modern methods of data collection will greatly improve worker safety and reduce potential for wildfires, specifically in disadvantaged and low-income communities
2) Increased power system reliability, safety, and cost efficiencies – improved operations and higher cost savings
3) Advanced imaging provides more efficient disaster response times, reporting, and re-energization of patrols after a site is deemed all-clear
4) Improved long-term planning – ability to determine the status of scenarios as-is versus how they should be
5) Supports and increases staff efficiencies of seven departments including Aviation Services Department (ASD); Electric Distribution Engineering (EDE); Distributed Energy Resources (DER); Fire Risk Mitigation (FiRM), Fire Science and Coordination; Transmission, Construction & Maintenance (TCM); and District Operations & Engineering (O&E)

All the use cases demonstrated in the project reduce safety risks in hard-to-reach areas within the SDG&E service territory as their implementation replaces the requirement for manned aircraft and/or field deployments. Benefit estimates and value proposition specific to each use case are provided below.

*Aerial Telepresence*

The potential value of this use case arises from the live stream video capability with no latency of information. Aerial telepresence offers situational awareness during fire, weather, and other emergency events via live video stream to anyone with the web link. The ability to control the UAS via desktop controls ensures correct data is collected and allows for remote assessments, reducing costs, and eliminating potential for safety hazards.

*Public Safety Power Shutoff (PSPS)/Wildfire Mitigation Program (WMP)*

This use case provides the potential to assist in the patrol of pre- and post-PSPS in small hard-to-reach foot patrol segments of the service territory. This helps to reduce duration of assessments and allows photo/video feeds from an aerial perspective capturing metadata (Latitude/Longitude, time captured, etc.) to update records when needed. UAS-assisted patrols may also result in reduced time of de-energization contributing to cost and safety efficiencies.

*Corona Camera*

The use of the hand-held device integrated within the DJI M600 UAS platform can result in reduction of time driving/walking to each tower to capture the four angles required during assessment. The four angles capture the connection points where dirt/damage can be seen only by using the corona camera sensor. Using this tool can help reduce duration of assessments as well as safety risks as the UAS can fly to many structures from one remote location.

*Tethering*

Wire tether eliminates the battery replacement downtime and associated video disturbance, providing live-streaming capabilities for extended periods over a network. This system can provide constant UAS aerial footage as it is tethered to a power source. The UAS has infra-red (IR) and zoom capabilities as well as the ability to live stream data during an emergency. The benefit of using this system is the potential elimination of employee deployment into the field to evaluate conditions during an event.

*Sense and Avoid Technology*

Utilizing the sense and avoid technology can reduce mishaps during flight in tight spaces as the obstacle avoidance system has proven successful. This is the only unit to date that can sense and avoid thin overhead lines and tree branches known to cause UAS mishaps. The benefit of using this system lies in its ability to fly in areas that many other UAS cannot, allowing for closer inspection and reducing risk of striking obstacles.

For indoor applications, the UAS can save time and inspection costs, as it can complete an inspection within minutes/hours versus days/weeks compared to traditional practices. As an example, one current process requires the construction of scaffolding within a confined space to allow the inspector to access an area required for inspection. The inspection area is 300 feet in height and could cost the company up to $38K annually overall to build the scaffolding required to complete annual inspections. The scaffolding construction process alone takes days with the added labor hours to complete the inspection. During the test case, an actual inspection was tested and successfully completed in one and a half hours. Utilizing this UAS for required and emergency inspections will help with efficiency, cost savings and the overall safety of employees, as the requirement for boots on the ground inspections is removed. This UAS is the first to successfully demonstrate the ability to fly within utility confined spaces to complete required inspections within buildings. Additionally, this UAS has a strong signal allowing control of the UAS in metal and concrete environments expanding its capabilities to various construction types.

*Line Pulling*

Pulling new high voltage power lines during construction is specialized and dangerous work traditionally done by helicopters. This UAS use case saves significant time and money, while reducing risk to employees through the removal of workers exposed to dangerous heights and the elimination of the mobilization of helicopters manned by pilots. Additional benefits beyond the priceless safety factors are the avoided emissions, reduced customer impacts and minimal FAA approval required in comparison to manned flight operations.

*Vertical Take Off and Landing – Fixed Wing/BVLOS*

This technology offers the advantages of flexibility and maneuverability as the UAS can launch and land almost anywhere and is able to perform actions that are impossible for conventional planes. The need for large open areas is removed, contributing to cost reduction in operations.

This use case also includes operations flown beyond the pilot's line of sight, allowing for greater distances, and maximizing efficiency. The ability to map larger areas quickly and efficiently or survey remote and/or hazardous sites improves safety, saves time, costs, and greenhouse gas emissions, by removing the need for employees driving long distances to perform these tasks.

### 5.1.2 Initial Selection of Metrics

The metrics common to all use cases are the immeasurable time and safety implications of performing a task using the UAS versus traditional means. Measurable metrics for each of the use cases were defined at the onset of the demonstrations and are provided below.

*Use Case 1: Aerial Telepresence*

The ability of an interested party to view livestream footage from a tablet, desktop, or phone without being onsite is the primary metric of this use case.

*Use Case 2: PSPS Wildfire Mitigation Program & Fixed-Wing*

Two metrics were identified for this use case: The first metric measured use of UAS compared to foot patrols and the second metric measured use of UAS compared to helicopter patrols.

*Use Case 3: Corona Camera*

Two metrics were identified for this use case. The first metric compared the gain and resolution from the handheld camera currently used by the inspectors to the gain and resolution captured with the camera mounted on the UAS. The second metric compared how long it would take to complete the inspection using current methods, via truck and walking, versus how long it would take using the UAS with the integrated corona camera.

*Use Case 4: Tethering*

The measurable goals of this use case included:

- Testing of the extended use of the tethered drone
- Evaluation of the video zoom and infrared (IR) capabilities
- Evaluation of the livestreaming capability of the tethered drone
- Testing of the radio repeater technology.

*Use Case 5: Sense and Avoid*

The measurable goals of this use case included:

- Complete operations near critical infrastructure with assurance to avoid collisions
- Confirm the capability of the use case to eliminate setup time for complex site access requirements
- Completion of three confined space inspections annually
- Completion of hazardous environment inspection, eliminating the need for scaffolding
- Ability to conduct troubleshooting of outages or faults

*Use Case 6: Line Pulling*

Three metrics were identified for this use case including, comparison of the time required for the UAS crew to pull the line compared to the helicopter, the comparative impact to customers when evacuation and relocation was required if a helicopter was used to perform the project, and the comparison of the time required to obtain FAA approval for a Congested Airspace Plan when using a helicopter instead of UAS.

*Use Case 7: Vertical Take Off and Landing*

The metric defined for the use case was the verification of the processing time expectations to obtain approval for airspace for BVLOS.

## 5.2 Description of Pre-Commercial Demonstration

Pre-commercial demonstration showed initial validation of UAS projects relating to advanced image processing for electric utility inspection and operations. Key project sensitivities included the timing of relevant permits and approvals for demonstration and full field commercialization.

### 5.2.1 Location

Locations of demonstrations by use case are provided in Table 1 below.

*Table 1. Demonstration Locations by Use Case*

| Use Case | Demonstration Location |
|---|---|
| Aerial Telepresence | Mission Valley, Valley Center and La Mesa |
| PSPS Wildfire Mitigation Program and Fixed Wing | Northeast, Eastern, and North Coast Districts |

| Use Case | Demonstration Location |
|---|---|
| Corona Camera | Carlsbad, Mission Valley, Jacumba, and Chula Vista |
| Tethering | Mission Valley Skills Training Center, Chula Vista Salt Creek Golf Course, Mt. Miguel Mountaintop, and Mt. Laguna |
| Sense and Avoid Technology/Confined Space Indoor Inspections | Mission Valley Skills Training Center, Palomar Energy Center, and Miguel Synchronous Condenser |
| Line Pulling | San Juan Capistrano for the South Orange County Reliability Enhancement (SOCRE) Project, in Santa Ysabel, Mt. Laguna, and Carlsbad |
| Vertical Take Off and Landing/BVLOS | Chula Vista Salt Creek Golf course for demonstration flights of aircraft. A temporary flight restriction (TFR) shown in Figure 1 for BVLOS, was in effect for the test period in a 2.5-mile radius area in the Warner Springs area. |

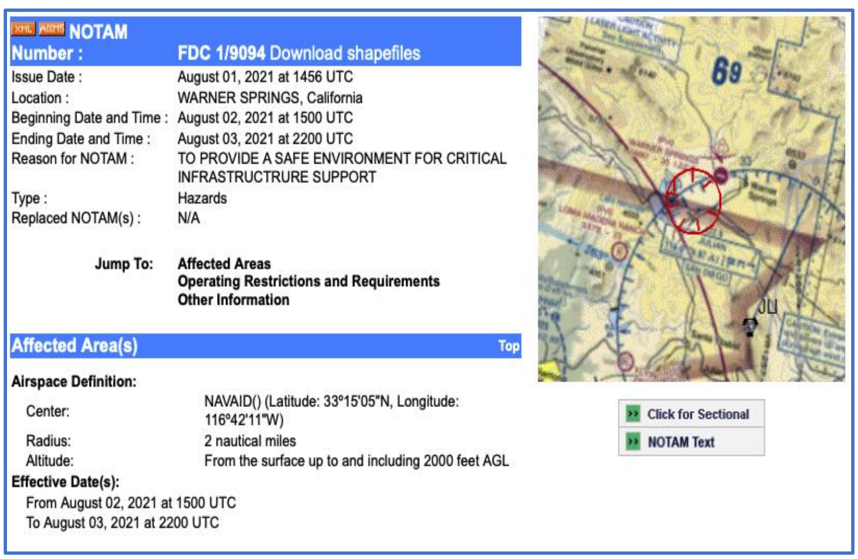



*Figure 1. August 1, 2021, Notice to Airmen (NOTAM)*

### 5.2.2 Equipment Requirements

Equipment required by use is provided in Table 2 below.

*Table 2. Equipment Requirements by Use Case*

| Use Case | Equipment Required |
|---|---|
| Aerial Telepresence | UAS, tablet, cell tower booster, instruction materials, track ball mouse |

| Use Case | Equipment Required |
|---|---|
| PPS Wildfire Mitigation Program and Fixed Wing | Rotorcraft UAS and a fixed wing UAS |
| Corona Camera | UAS and Corona Camera |
| Tethering | Tethered UAS, power source, Toughbook Laptop, radio transceiver |
| Sense and Avoid/Confined Space Indoor Inspections | Two types of UAS for indoor and outdoor applications |
| Line Pulling | UAS with a custom-built line pulling mechanism |
| Vertical Take Off and Landing/BVLOS | Fixed wing UAS and one rotorcraft UAS |

### 5.2.3 Software Requirements

For most of the use cases, software was integrated into the UAS, and no additional software was required. For the tethering use case, vendor proprietary software was needed and for Use Case 1, Aerial Telepresence, and Use Case 2, PSPS Wildfire Mitigation Program; separate mobile applications were required to operate the UAS.

### 5.2.4 Use Case Execution

The seven use cases defined as part of Task 7 of the project plan and discussed in Section 5.0 were executed as follows:

*Use Case 1: Aerial Telepresence*

Comparing the traditional workflow of ground-based field inspections, the telepresence UAS allows construction supervisors and other employees to access sites remotely and virtually. Execution of the use case revealed the construction supervisor was able to take control of the aircraft and complete the inspection without physically travelling to the site location, saving significant travel time. Once testing for the aerial telepresence use case began, over 50 hours of testing in total was performed ensuring the UAS met the use case expectations. The following successes and problems were identified during the initial flights.

- Low video stream latency from remote to web
- Easy flight planning software
- Video/Still Images/IR data collected from remote control (RC) or at desktop
- Inoperable outside of cell range
- Web browser limited to Chrome
- Company-issued mobile data terminals are not equipped with required processing cards
- Higher vantage points to launch the aircraft required
- Only a few UAS are supported by this technology
- Limitations in available supported UAS

- Tablets were subject to overheating
- Constant power supply needed in the field
- Latency from application to UAS control inputs

*Use Case 2: Night Flights, PSPS Wildfire Mitigation Program & Fixed-Wing*

Comparing the traditional method of visual inspection by qualified electric workers (QEW) in difficult-to-access terrain, the PSPS rotorcraft and fixed-wing UAS allow QEW to inspect sites at the site, without traversing difficult-to-access terrain. The rotorcraft and fixed-wing UAS were compared to current practices of visual inspections on foot by QEW. To accomplish the use case demonstration, over 60 hours of testing was performed ensuring the UAS met use case expectations. The following successes and problems were identified during the initial flights.

- Long flight time
- Can fly long distances (miles) without control issues, break in video feed, high altitudes.
- Auto flight or manual flight
- Easy to assemble in field
- No latency in video feed
- Meta data meets ingestion needs
- Video, still, IR data collected
- Using IR camera during night flight helps with seeing the electric lines
- FAA Night Waiver needed for night flights.
- All RPICs must complete Night Flight Training and test before certification for night flights.
- Difficulty finding suitable launch and landing spot for fixed-wing UAS
- Difficulty launching fixed-wing UAS due to challenging launch technique
- Manufacturer offered a limited, six-month warranty on fixed-wing UAS
- Fixed-wing proprietary flight planning software was not user-friendly

*Use Case 3: Corona Camera*

New practices based on innovative technologies were compared to current practices. For Use Case 3 the UAS and the Corona Camera were used instead of the handheld camera. To accomplish the use case demonstration, over 40 hours of testing and inspection of 50 transmission lattice towers were conducted. The following successes and problems were identified during the initial flights.

- Data collected was better than the hand-held result that is used current day
- Can stay in on location and fly many structures without driving to each location
- Easily integrated onto aircraft without issues
- Performed as expected and will be used in hard-to-reach areas
- Micro-secure digital (SD)card must be permanently installed in the UAS, or no corona features are displayed
- Power cable from camera to the drone was getting twisted and disconnected
- Flight telemetry location covered up vital corona camera data
- Camera operator video feed went out intermittently

- UAS did not have a first-person view (FPV) camera, requiring integration of one

*Use Case 4: Tethering*

The tethered drone was compared to helicopter and other UAS practices. The live-stream technology was a unique solution. To accomplish the use case demonstration, over 50 hours of testing the tethered drone and live-streaming capabilities was performed. The following successes and problems were identified during the initial flights.

- Easy set up in field
- Easy to control using tablet or RC
- Still/IR Data Captured
- Live-streaming had low latency (six-second)
- Can fly up to 200 ft above ground level (AGL)
- Low Air recommended maintenance
- No battery changing, powered by generator or electrical source
- The tethered drone cannot be flown within 300 feet of 230 kVA and higher voltage power lines
- The mountaintop repeaters needed to be upgraded to a newer version
- Live streaming required a licensed network
- Live-streaming had a six-second latency
- Corporate firewalls prevented functional live streaming
- Radio repeater too heavy to mount to the tethered UAS

*Use Case 5: Sense and Avoid/Confined Space Indoor Inspections*

Comparing the traditional confined space inspection using scaffolding construction, the sense-and-avoid UAS saves time and provides significant cost reduction. It removes the safety hazards of scaffolding construction and navigating dangerous height environments. To accomplish the use case demonstration, over 10 hours of testing was performed ensuring the UAS met the use case expectations. The following successes and problems were identified during the initial flights.

- Easy to fly
- Quick set up
- Small/portable
- Senses and avoids all objects tested
- Can be flown indoors and in tight spaces
- Portable repeater is used to communicate between RC and aircraft
- Ten-minute flight time per battery, requiring repeated launch and landings to swap batteries
- Maximum of 40 cycles and battery is recommended for decommission; manual tracking required
- High volume especially in confined spaces (109 decibels)
- Limited propeller life (10 hours), requiring repeated launch and landing/manual process to track flight times
- Limited motor life (25 hours), requiring manual process to track flight times

- Low resolution (12 megapixels) resulted in blurry close-up images

*Use Case 6: Line Pulling*

For this use case, the line pulling UAS was used instead of traditional methods of line-pulling using a helicopter, eliminating the need for crews walking the line through environmentally sensitive areas or using a device to shoot the line over canyons or valleys. To accomplish the use case demonstration, over 20 hours of testing to ensure the UAS met use case expectations was conducted. Upon completion of testing, over 15 hours of actual use case flights were performed to include 52 spans (distance between each pole) and over 15,000 linear feet. The following successes and problems were identified during the initial flights.

- Easy set up
- Proven to be time/safety efficient in hard-to-reach terrain
- Avoids disturbing soil and sensitive vegetation
- Release mechanism integrated onto aircraft was successful
- Saves time with flight planning and coordination with the FAA
- Low emissions, both noise and greenhouse
- No customer evacuations needed in the area
- RPICs able to hand-off control for long spanned flights
- Challenges were encountered when there was insufficient jet line to cover the full span
- Communication challenges between the RPICs when spaced too far apart between spans. This was corrected by having a supervisor accompany the RPIC with a radio

*Use Case 7: Vertical Take Off and Landing – Fixed Wing/BVLOS*

To accomplish the use case demonstration, over 40 hours of testing was conducted to ensure the UAS met use case expectations. To accomplish the BVLOS use case demonstration, over six hours researching the process for BVLOS and completing the administrative requirements to acquire a TFR was performed. The following successes and problems were identified during the initial flights.

- Long flight time
- Can fly long distances (miles) without control issues, break in video feed, high altitudes.
- Instant keyhole markup language (KMZ) file creation for instant ingestion into geographic information system (GIS)
- Auto flight, manual override available if needed.
- Easy to assemble in field
- Low latency in video feed
- Metadata meets ingestion needs
- Difficulty finding suitable launch and landing spot for fixed-wing UAS
- Difficulty launching fixed-wing UAS due to challenging launch technique
- Manufacturer offered a limited, six-month warranty on fixed-wing UAS
- Fixed-wing proprietary flight planning software was not user-friendly.

# 6.0 Results

A summary of results for each of the seven use cases is provided in Table 3 below.

*Table 3. Results Summary by Use Case*

| | Learnings to Date | Problems or Issues Encountered | Transition Plan |
|---|---|---|---|
| Use Case 1 Aerial Telepresence | The software was successfully tested on a hard-to-reach segment of overhead lines which are listed as possible circuits patrolled during a PSPS (pre/post) event for construction districts.<br><br>The flight locations are usually in hard-to-reach areas with limited cell coverage.<br><br>Requires a signal booster.<br><br>Vendor software will only support US-built aircraft. | Incident support vehicle (ISV) Wi-Fi was unreliable and should not be relied upon as the only network.<br><br>During the June 15, 2021, test run, the project team ran into a dead zone and had to relocate to higher ground. This issue is now considered for future PSPS patrols with a successful UAS launch location noted for future flights within this area.<br><br>iPads overheated during the same flight which halted operations for 30 minutes. Need to ensure during high temperatures, the remote-control monitors are shaded and not in direct sunlight. | ASD will need to provide support in the field due to the complexity of the system.<br><br>This technology is available for any company business unit for support with data viewable via the weblink. |

| | Learnings to Date | Problems or Issues Encountered | Transition Plan |
|---|---|---|---|

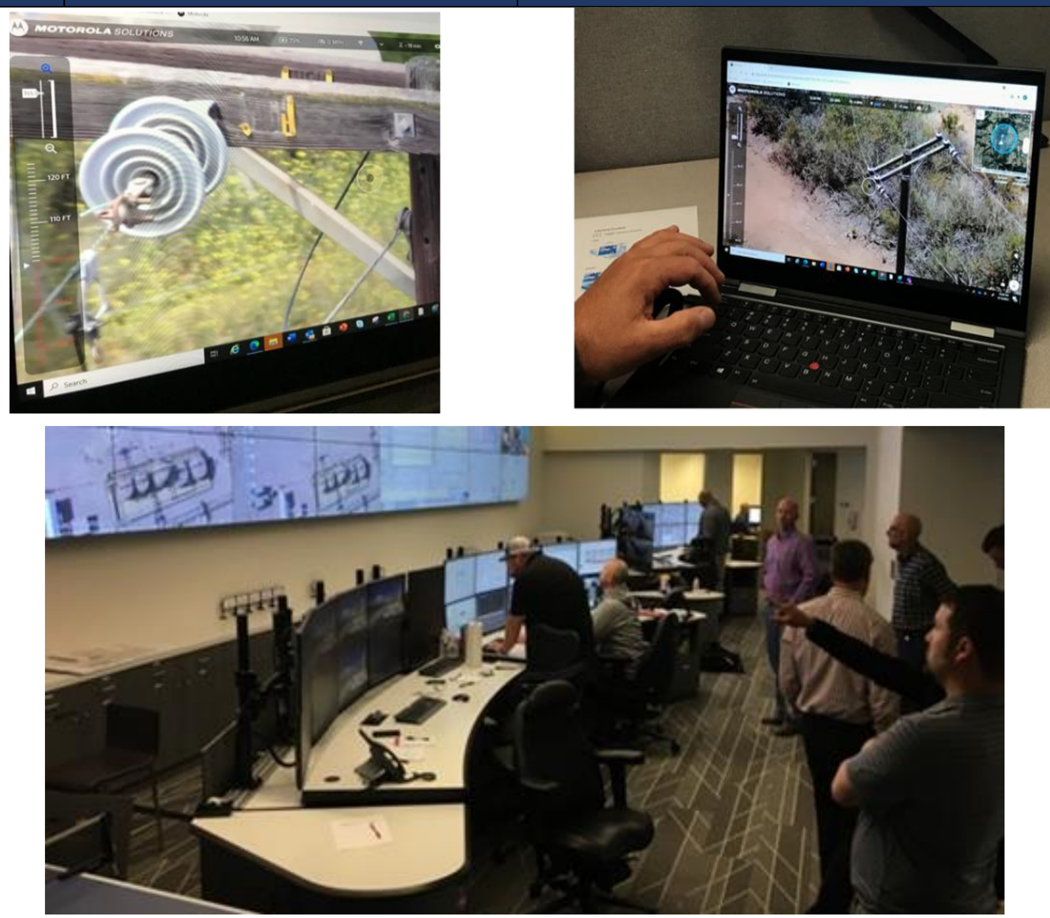



*Figure 2. Aerial Telepresence Imagery*

| | Learnings to Date | Problems or Issues Encountered | Transition Plan |
|---|---|---|---|
| Use Case 2 PSPS/Wildfire Mitigation Program | Aircraft camera performed better than expected but night flights are not supported. | None to report (NTR). | ASD has gathered seven areas to support during a PSPS event for the Northeast and Eastern Districts.<br><br>ASD created PSPS support reports for easy flight planning. |

*Figure 3. Night Flight/PSPS/WMP Imagery*

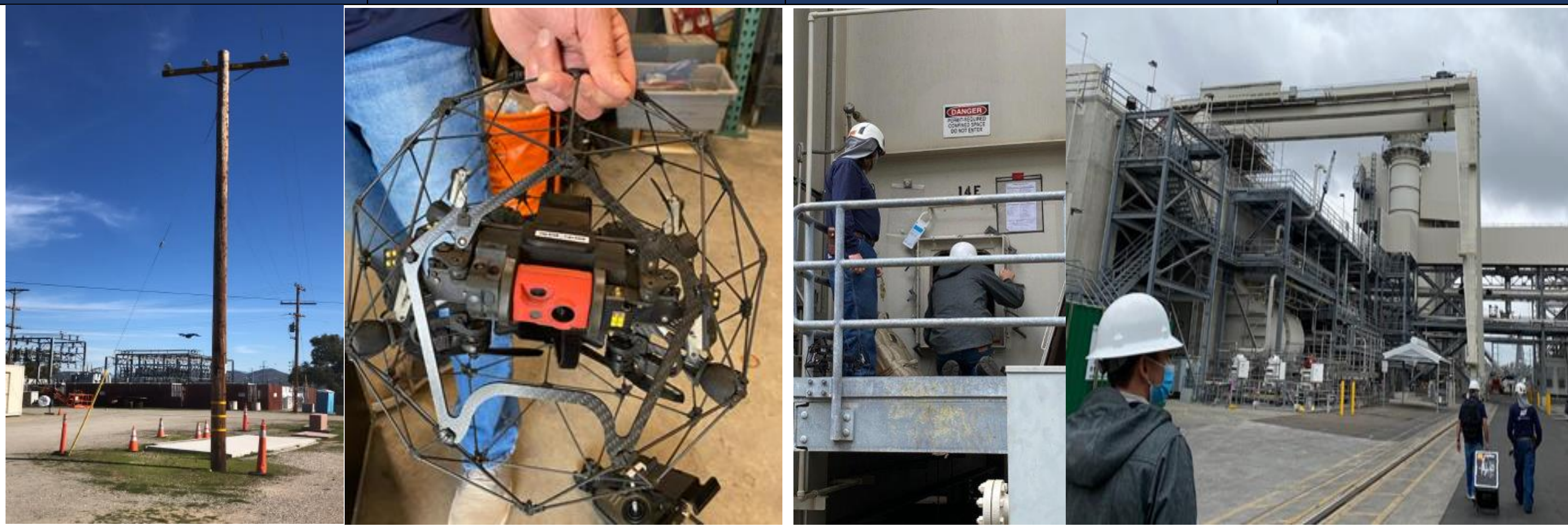
| | | | |
|---|---|---|---|
| Use Case 3 Coronal Camera | Using the UAS cuts down the assessment time by half. | Licensed thermographers are necessary. | The Coronal UAS was transferred to TCM for use and |

<table>
<tr><th></th><th>Learnings to Date</th><th>Problems or Issues Encountered</th><th>Transition Plan</th></tr>
<tr><td></td><td></td><td>Communication issues with vendor in different time zone.</td><td>ownership in late 2021. ASD will provide support as needed.</td></tr>
<tr><td colspan="4"><br>*Figure 4. Corona Camera*</td></tr>
<tr><td>Use Case 4 Tethering</td><td>Long flight time was successful with no requirement to change the battery.<br><br>Hoverfly software connected to ISV then stream to the Emergency Operations Center (EOC) or Flight Operations Base (FOB). This testing was</td><td>Battery version issues with the demo unit.<br><br>Communication relay for the fire coordinators using 800 MHz radios. Looking for a solution as the product used is too heavy to carry on the UAS.</td><td>This unit will be available to support various business units as needed during emergencies or various company situations due to zoom/IR camera and the ability to live stream back to ISV</td></tr>
</table>

| | Learnings to Date | Problems or Issues Encountered | Transition Plan |
|---|---|---|---|
| | successful, once with low latency but with significant support by IT and the vendor. | | via cable. The unit has been on display with ISV during many public gatherings and has the attention of many fire and public agencies for added assistance as needed. |

*Figure 5. Tethering Imagery*

| | Learnings to Date | Problems or Issues Encountered | Transition Plan |
|---|---|---|---|
| Use Case 5 Sense and Avoid/Confined Space Indoor Inspections | The unit used for outdoor applications is very small and hard to see at a distance.<br><br>The unit used for the indoor use case had no issues and was easy to fly. | Unable to use the units purchased in June 2020 for Use Case 1 Aerial Telepresence as there is no longer support for the units.<br><br>It was difficult to schedule demonstration for vegetation management.<br><br>Does not seem stable outdoors. | The unit will remain with ASD until a particular business unit has the need for a small sense and avoid aircraft.<br><br>Quality Assurance Quality Control (QAQC) Inspections Group is looking into the indoor use case unit and could be a potential candidate for commercial adoption.<br><br>Committee approved the indoor use case purchase after the last quarterly meeting. The unit was received in August 2021 and transferred to Palomar Energy Center. |

| | Learnings to Date | Problems or Issues Encountered | Transition Plan |
|---|---|---|---|
| <br>*Figure 6. Sense and Avoid Technology/Confined Space Indoor Inspections Imagery* | | | |
| Use Case 6 Line Pulling | Lessons were learned after each mission resulting in continuous improvement.<br>May require a special RPIC skill set for handling off controls to second RPIC during a flight. | Promoting the use case to all districts for use in hard-to-reach areas. | The operation and systems will remain in ASD as this flight type requires special RPIC skills. |
| | | | |

| | Learnings to Date | Problems or Issues Encountered | Transition Plan |
|---|---|---|---|
| <br>*Figure 7. Line Pulling Imagery* | | | |
| Use Case 7 Vertical Take Off and Landing – Fixed Wing/BVLOS | Nothing to report for this use case. | Due to supply issues and no delivery until the unit was fully paid, the unit was borrowed from the vendor to complete the use cases.<br>Local fire agency was understandably hard to reach during fire season. | This unit was not purchased due to the difficult launch and land procedures. |

| | Learnings to Date | Problems or Issues Encountered | Transition Plan |
|---|---|---|---|
| | | Very difficult to launch and land as large clear area is needed. | |

*Figure 8. Fixed Wing Imagery*

## 6.1 Results Discussion

*Aerial Telepresence*

Five test flights were performed with various electric construction districts internally. During each test flight, the UAS aircraft and platform were evaluated to ensure safe flights before streaming the live video or handing off controls to someone offsite. The offsite staff was able to control the camera, zoom in/out as needed and collect footage as desired. Controls were handed off to the offsite staff members who were able to fly the UAS safely. Overall, the flights were successful with the new technology.

*Night Flights/PSPS/Wildfire Mitigation Program*

**Rotorcraft UAS Demonstration:** Three hard-to-reach, short overhead span areas were identified in Escondido and Pine Valley that would have been inspected on foot during a PSPS event. The rotorcraft UAS was used on August 24 and August 25, 2021. The QEW assessed 13 poles in 15 minutes in the Escondido area, and 10 poles in 15 minutes in the Pine Valley area. A second inspection was performed on eight poles in 15 minutes at a separate location in Pine Valley. Using the UAS saved an estimated three hours of time versus performing a hike-in/hike-out inspection in rugged terrain. Any reduction in time reduces impact to the customer during a PSPS event and reduces risk to QEW.

**Fixed-Wing Demonstration:** Fixed-wing flight was demonstrated in the Warner Springs area on August 2nd and 3rd, 2021. Using the UAS saved an estimated 45 minutes of time versus performing a hike-in/hike-out inspection in rugged terrain. As in the rotorcraft demonstration, any reduction in time reduces impact to the customer during a PSPS event and reduces risk to QEW.

*Night Flight Demonstration:*

Two night-flights were conducted once SDG&E obtained the UAS FAA Night Waiver and RPICS passed the FAA required night flight operations training and test. The test successfully demonstrated the ability to safely fly UAS during night hours. Pre-planning of the area in daylight per the FAA regulations helps result in the success of the flights. Night flights will only take place during emergency situations and will be dispatched by SDG&E Emergency Management.

*Corona Camera*

The project team assessed 12- 230 kV tower structures which took about an hour to complete. Normal operation involves the use of a handheld camera requiring travel to each structure taking approximately four hours and about 20 mins per structure to perform the assessment. The typical cost savings is approximately $100 per labor hour with the number of hours varying from site to site.

The project team assessed 20-230 kV and 4-138 kV transmission structures taking a total of 46 minutes of flight time using the UAS. Traditional methods would have taken the thermographer seven hours with some structures inaccessible due to terrain. The typical cost savings is approximately $100 per labor hour with the number of hours varying from site to site.

Comparing the handheld camera and the UAS mounted camera produced the same results 75% of the time. The other 25% was dependent on the altitude of the aircraft and the distance to the structure. For optimum results, the angle and distance does matter, preferably 30 feet away from the object of interest.

#### *Tethering*

Aerial live-streaming capability utilizing UAS, provided efficiency and was safer than helicopter alternatives which have the same capability. Costs using a UAS were significantly lower than a helicopter and did not have the flight time limitations due to fuel capacity.

#### *Sense and Avoid Technology/Indoor Confined Space Inspections*

This use case was applied to an inspection area 300 feet in height and could potentially cost $38K annually to build the scaffolding that is needed to complete this annual inspection. The scaffolding build process alone takes days, and then the inspector will use the scaffolding to inspect the confined space which takes many more labor hours. During the test case, an actual inspection was tested and was successfully completed in one and a half hours. Current practices would have taken an estimated two weeks or more. During the second live test inspection the sense and avoid UAS was flown inside of the communications warehouse that is three stories tall. The UAS was used to inspect pipes, welding points of the building's structural condition and other potential flaws that may have never been inspected. The use of this UAS will continue to grow as it is now commercialized internally.

#### *Line Pulling*

The line pulling UAS provides significant benefit to customers by eliminating the need to evacuate the work area. Homeowner evacuations within a minimum 150-foot radius of the flight operations area are required when using a helicopter. This makes it a challenge to manage the amount of people in an area, so they do not encroach operations.

The UAS also saves time by removing the need to file a congested airspace plan with the FAA. Additional advantages include decrease of environmental impact in confined areas and the reduction of risk to QEW crews as compared to a manned helicopter flying overhead.

Results of Use Case 6 Line Pulling demonstrations are provided in Table 4 below.

*Table 4. Line Pulling Results*

| Date | Project Location | Spans | Lines per span | Linear Feet | # of Pulls | Time | RPIC Position | Lineman on Pole | Notes |
|---|---|---|---|---|---|---|---|---|---|
| 7/23/2020 | CNF - Pine Valley | 7 | 5 | 1600 | 35 | 4 hours | Ground | Y | Individual pulls from pole to pole. RPICs ground based, lineman in bucket |

| Date | Project Location | Spans | Lines per span | Linear Feet | # of Pulls | Time | RPIC Position | Lineman on Pole | Notes |
|---|---|---|---|---|---|---|---|---|---|
| 11/9/2020 | SOCRE - San Clemente | 3 | 1 | 3000 | 2 | 1hr or less | Bucket | Y | The line used during operation came free and wrapped around the nearby transmission line |
| 11/19/2020 | FiRM - Santa Ysabel | 35 | 1 | 10000 | 35 | 6-7 hours | Bucket | Y | Divided into two separate sections |
| 3/29/2021 | ERO ME - Mt Laguna | 6 | 4 | 1200 | 8 | 1 hour | Bucket | Y | Long continuous pull |
| 4/6/2021 | ERO NC - Carlsbad | 1 | 4 | ~250 ft | 4 | 45 minutes | Ground | N | Pulled mule tape from base of pole to base of pole |
| 11/1/2021 - 12/1/2021 | Ramon | 96 | 1 | 573, 919 | 96 | 159 hours | Ground & Bucket | At times | Pulled jet line for a future fiber optic job from sub to sub |

#### *Vertical Take Off and Landing – Fixed Wing/BVLOS*

Comparing traditional operation of UAS within line of sight of the RPIC, the BVLOS UAS offered more efficiency with less landings and takeoffs due to relocating saving time and money.

**Flight No. 1**: Fixed wing flight demonstrated the fixed wing UAS to travel three miles beyond visual line of sight with no connectivity problems.

**Flight No. 2**: Rotorcraft flight demonstrated the rotorcraft UAS to travel four miles beyond visual line of sight with no battery or connectivity issues.

**Flight No. 3:** Attempted third flight with fixed-wing UAS but could not find suitable takeoff area.

## 6.2 Updated Benefits Analysis

The demonstrated use cases provided significant insights into the potential of UAS to increase reliability, safety, and cost efficiency in power system operations. A summary of confirmed benefit highlights include:

- Increased Safety - Unmanned Aircraft Systems can access environments that are hazardous to humans
- Effective tool for use in vegetation management, situation awareness during emergency, public safety, and wildfire mitigation
- Avoided emissions and need for public evacuations that are associated with helicopter flights
- Time savings in flight planning and authorizations

- Avoided costs and risks of human travel into isolated and/or distant locations
- Cost savings for confined space inspections
- Operating cost savings flow through to lower ratepayer costs

## 6.3 Commercialization Cost Estimate

*Aerial Telepresence*

The cost of the software is approximately $80,000 for an annual subscription for six aircrafts. No other items are required to support this use case. Commercializing internally requires reassessment as there are peaks and valleys of interest. Live streaming data from an aircraft is not practiced by SDG&E to date.

*Night Flights/Public Safety Power Shutoff (PSPS)/Wildfire Mitigation Program (WMP)*

No other reoccurring costs are required, other than employee time to support it. During such events there is a charge order that covers the employee's labor expenses. WMP is currently funded by the project team with internal discussions taking place about conducting SDG&E Drone Investigation and Repair (DIAR) UAS assessments in-house and not by contractors.

*Corona Camera*

The cost per corona camera is approximately $58,000 per camera. The number of UAS and corona cameras needed is left to the commercializing stakeholder group to determine.

*Tethering*

The cost per tethering unit is approximately $100,000. No other outside costs are required once the UAS is purchased. The number of tether units needed will be determined by the stakeholder group to as the use case matures internally.

*Sense and Avoid/Indoor Confined Space Inspections*

The cost per sense and avoid UAS is from $2,000 - $50,000 per unit, depending on which UAS. A four-dimensional (4D) mapping license may be added at a cost of $8,000.

*Line Pulling*

The complete cost per UAS kit is approximately $35,000. This includes extra batteries and a battery charging station. Additional cost for the line pulling system mechanism is approximately $500. The drop system is estimated at approximately $1,000.

*Vertical Take Off and Landing – Fixed Wing/BVLOS*

Acquiring BVLOS authorization from the FAA is free of charge. It takes less than an hour to complete the required paperwork once familiar with the process. The complete cost for a full rotorcraft UAS kit is approximately $35,000.

# 7.0 Conclusions

*Aerial Telepresence*

While this demonstration confirmed the ability to operate the aircraft and perform an inspection manually, issues were identified with the technology requiring ASD support in the field. The technology is available for internal business use with expected improvements on performance with the 5G network.

*PSPS Wildfire Mitigation Program, WMP & Night Flights*

The use case was adopted for commercial use. Seven hard-to-access areas for public safety power shutoff were identified with patrols now using UAS. WMP UAS flights are currently being conducted via the SDG&E (DIAR) Program and have proven successful. The DIAR Program was implemented after EPIC-3 Project 5 was kicked off for testing. Night flights will not be conducted for PSPS as the patrols are not conducted after sunset.

*Corona Camera*

The demonstrated technology performed its intended functions successfully. This technology is ready for commercialization for use within a utility to complete corona inspections by a certified thermographer.

*Tethering*

This technology performed its intended functions successfully and was adopted for commercial use.

*Sense and Avoid/Confined Space Indoor Inspections*

The demonstrated outdoor use case proved the technology can sense and avoid thin power lines and guy wires. The indoor use case was also successfully executed through demonstration of actual confined space inspections. Both were determined as high-value solutions and are in commercial use.

*Line Pulling*

Successful demonstration of this use case was determined as high-value and is in commercial use.

*Vertical Take Off and Landing – Fixed Wing/Beyond Visual Line of Sight (BVLOS)*

Due to the difficulty with launch and land procedures, the fixed wing unit was not purchased, and the associated use case will not be pursued commercially. BVLOS was verified with a quadcopter UAS, and the FAA approval process was easily obtainable. (A quadcopter is defined as a type of helicopter with four rotors.)

# 8.0 Tech Transfer Plan

## 8.1 Project Result Dissemination

The results of this project will be disseminated throughout the industry in the following ways

*SDG&E Website*

This comprehensive final project report is the main tech transfer documentation for the project. All EPIC final project reports are posted to the SDG&E website at: https://www.sdge.com/epic. The website also includes annual updates that were made over the life of the projects. These documents are also filed with the CPUC.

*EPIC Symposium*

The project results were shared with California Investor-Owned Utilities through the annual EPIC symposiums and other EPIC workshops. During these meetings, information on various EPIC projects is shared with public audiences.

*Industry Conferences and Publications*

SDG&E personnel worked with the product vendors to develop presentation material outlining the results of this report. These presentations are offered, as may be appropriate, for inclusion at industry conferences such as DISTRIBUTECH, IEEE conferences, Utility Week, Grid Modernization Forum, and others.

# 9.0 Recommendations

This project successfully demonstrated the value proposition for UAS and the newly mounted sensors that were tested. Based on the findings and results in the demonstrations, it was determined that the use cases for aerial telepresence and vertical take-off and landing are not yet ready for commercial adoption in SDG&E's applications. The remaining use cases however, including PSPS/WMP, coronal camera, sense and avoid, confined space indoor inspections and line pulling, proved the UAS could perform the tasks intended, and those technologies are now in commercial use at SDG&E. This EPIC project is now completed. Given the successes of this EPIC project, it is recommended that additional work be done to further evaluate and expand use of these UAS technologies and use cases to identify others that can be used commercially in future utility system operations. It is also recommended that the appropriate internal stakeholder group within SDG&E be identified to lead the commercialization and operational use of the technologies that were demonstrated in the EPIC project.