Use of Unmanned Air Vehicles (UAV) for Pipeline Surveillance to Improve Safety and Lower Cost

2nd QUARTERLY PUBLIC REPORT

Period: July through September 2005

Consolidated Research and Development for Pipeline Safety

DTPH56-05-T-0004

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Background

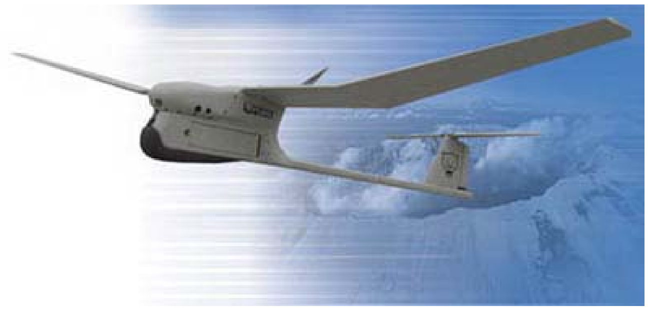

Figure 1: AeroVironment "Puma" Small Unmanned Aerial Vehicle

This project tests available Small Unmanned Aerial Vehicles (SUAVs) and commercial sensor technologies to rapidly converge on a cost effective system solution to conduct aerial surveillance for pipeline monitoring and leak detection. The SUAV and sensor suite will be used to determine the feasibility of the application airborne remote sensing system for detecting leaks associated with natural gas and hazardous liquid pipelines, and identifying and recording encroachment violations in pipeline rights of way. Significant reduction in survey costs of aerial pipeline surveillance is an important aspect of this program. These practical solutions will address Department of Transportation priorities to close gaps in safety, inspection and enforcement while reducing the cost of state-of-the-art pipeline surveillance.

The program team has assessed commercially available payload technology to determine the options available to meet mission requirements. Sensors, digital imagery and data processing options were reviewed. All options were screened for feasibility of use on remotely piloted flight. Sensors available, but not adequate for use to meet mission requirements without further technical development, were documented as well.

Summary of Progress this Quarter

Work this quarter focused on identifying and assessing commercially available payload technology to determine the options available to meet the mission requirements. Sensors, digital imagery and data processing options were reviewed. All options were screened for feasibility of use on remotely piloted flight. Sensors available, but not adequate for use to meet mission requirements without further technical development, were documented as well.

Additionally, significant progress was made on the planning for the test phase of the program. The conceptual test plan for the payload proof of principal and system demonstration are complete and the finalized test plan with metrics will be submitted at the end of October 2005.

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Results

Payload Constraints

Payloads must be capable of integration into the SUAV. The weight must not exceed two pounds (2 lbs) for the "Consolidated Research and Development for Pipeline Safety Unmanned Air Vehicle Program" demonstration. The volume available to house the payload is somewhat flexible; however, the stock payload is 175 cubic inches. The power available for all payloads is 50 Watts nominal (during regular discharge, approximately one hour of flight) and 42 Watts available near the end of battery discharge.

The system is capable of carrying a range of commercially available payloads including black and white, color and infrared still and video digital imaging cameras, a host of environmental sensors, and a Global Positioning System (GPS).

Sensor and Data Requirements for Selected Missions

The mission profiles identified in the Mission Requirements report require the following specific sensor and data payloads:

- Detection of pipeline right of way encroachments, map their location on a GPS map and provide a real-time visual image of the problem area
  - ◊ Record min 1,000 feet on either side of the right of way
  - ◊ A combination of visual (color video camera) and infrared imaging (forward and side looking payloads will be employed)
  - ◊ Images, along with GPS coordinates, will be captured digitally.

- Determine the system's reliability and accuracy in locating and mapping leaks associated with pipelines, map their location on a GPS map and provide a real-time visual image of the problem area:
  - ◊ Potential airborne leak detection methods include:
    - odor
    - vegetation
  - ◊ Potential airborne liquid leak detection methods include:
    - electro-optical cameras
    - infrared imaging
    - other advanced technologies that are applicable, but not necessarily suitable for small airborne missions without further development, include LIDAR, RADAR and chemical/biological sensors.

Table 1.0 outlines commonly used ground-based leak detection methods and their application on the "Consolidated Research and Development for Pipeline Safety Unmanned Air Vehicle Program":

Table 1.0 – Sensor Methods & Applications

Method	Ground Vehicle	SUAV	On Foot
Odor	Possible	Possible	Yes
Vegetation Discoloration	Yes	Yes	Yes
Insect Infestitation	Yes	No	Yes
Fungus Growth	No	No	Yes
Sound	Yes	No	Yes
Unaccounted Gas	No	No	No
Electro-optical Camera	Yes	Yes	Yes
Infra-red Camera	Yes	Yes	Yes
LIDAR	Yes	Possible	Yes
RADAR	No	Possible	No
Chemical/Biological Sensors	Yes	Possible	Yes

- Reduce the cost of aerial surveillance. Examples of operational missions conducted by pipeline owners/operators include:
  - ◊ Annual counting of houses adjacent to pipelines
  - ◊ Monitoring for current and previous excavation in right of way areas
  - ◊ Identifying pipeline washouts
  - ◊ Documenting construction errors

  A review of Land Surveyors offerings resulted in a group of surveying missions in demand by operations (not due to regulations):
  - ◊ Boundary Survey – locating corners and boundary lines of a parcel of land
  - ◊ Topographic Survey – natural and man-made topographical feature mapping
  - ◊ Site Planning Survey – combination of boundary and topographic surveys for improvements
  - ◊ Control Survey – horizontal position and elevation points for use in mapping, including GIS
  - ◊ Court Exhibit Survey – visual displays for use in court proceedings
  - ◊ Construction Survey – layout of control for construction purposes.

  Other possible surveying missions include:
  - ◊ Photogrammetry – to acquire imagery, data and spatial information
  - ◊ Airborne Remote Sensing – including photography (see below); remote sensing derives information about an object, area or phenomenon from a distance
  - ◊ Aerial Photography – from simple out-of-the-window photography to precision oblique and vertical photography using special cameras and modified airplanes
  - ◊ Hydrographic, Aerial Image Processing, Spatial Data and GIS Data Collection.

A number of commercially available sensors are available to address operational missions. Table 2.0 identifies payloads and their characteristics along with applicability to the "Consolidated Research and Development for Pipeline Safety Unmanned Air Vehicle Program".

Table 2.0 – Available Sensors, Characteristics and Applicability to Program Available Sensors

Payload/Technology	Appropriate for SUAV?	Manufacturer	Power Source	Benefits	Drawbacks	Approx Price	Comments
Altimeter	Yes	Various	Vehicle				
Compass	Yes	Various	Vehicle				
Electro-optic color camera	No	Swiss Federal Institute of Technology System Config		Day use.	Contrast dependent.	$ 100,000	Large scale photogrammetry. Used in conjunction with GPS/INS. Used for mapping of landslides/avalanches.
Electro-optic color camera	Yes	Various	Vehicle	Used in vehicle now. Day use.	Resolution not adequate for surveying.		Spectral Sensitivity 300-700nm, Resolution NTSC, Illumination 2.0 Lux min.
Electro-optic low light, black & white camera	Yes	Various	Vehicle	Used in vehicle now. Low light usage.	Resolution not adequate for surveying.		Spectral Sensitivity 300-700nm, Resolution NTSC, Illumination 0.2 Lux min.
Global Positioning System	Yes	Various	Vehicle	Used in vehilce now.			
LIDAR - Light Detection and Ranging	No	Swiss Federal Institute of Technology System Config		Day and night use.		$ 1,500,000	LIDAR integrated with GPS/INS
LIDAR - Light Detection and Ranging	No		7A	Measures topographical differences.	Cost. Weight. Volume. Cost.		LIDAR integrated with GPS/INS
LIDAR - Light Detection and Ranging	No	ITT		Airborne detection feasible	Weight, volume and cost require additional development.		
RADAR	No	Various	Vehicle		Weight		
Thermal camera, uncooled	Yes	Raytheon Corp	Independent, battery powered	Day and night use.	Designed for handheld use.	$ 20,000	Model PalmIR Pro. Tested in use for harbor spills.
Thermal camera, uncooled, passive, mid IR, multi spectral scanning.	No	En'Urga, Inc.			Designed for use within 50 ft of leak		Tested by DOT
Thermal camera, uncooled, passive, mid IR, multi spectral scanning.	Yes	Various	Vehicle	Day and night use.			Spectral Sensitivity 8000-13000nm, Resolution 320x240.
Chem/Bio Sensors	No	SRI, Intl.		Day and night use.	Weight. Prototype System	Very Expensive	
Methane Sensor	Possible	Univ of Glasgow	Independent, battery powered	Day and night use.	Senses methane only. Prototype only.		
Methane Sensor	Possible	Physical Sciences Inc.	Independent, battery powered	Day and night use.	Sensing up to 100 to 150 ft		Tested by DOT
Combustible Gas Indicator	No	Various	Independent, battery powered	Low cost. Developed technology. Day and night use. Broadly adopted for use.	For use in confined spaces.		

Available Sensors

The following is a list and brief description of the promising payload technologies. For a complete discussion on the payload technologies, please review the "Payload technology Evaluation" report.

1. Electro-Optical Cameras

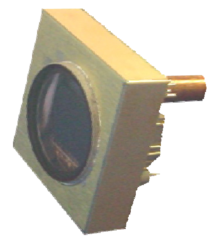
Electro-optical technology is a technology that uses the conversion of optical radiation into electrical signals. Electro-optical cameras should be able to distinguish vegetation discoloration, disturbed soil and some liquid spills. The planned cameras for use include:

- Color Camera
- Low Light Camera (black and white image)

2. Infrared Cameras

An infrared camera is a non-contact device that detects infrared energy (heat) and converts it into an electronic signal, which is then processed to produce a thermal image on a video monitor and perform temperature calculations. Heat sensed by an infrared camera can be very precisely quantified, or measured, allowing the user to not only monitor thermal performance, but also identify and evaluate the relative severity of heat-related problems. The planned IR camera is:

- Uncooled Thermal Camera: The infrared camera planned for use is manufactured by FLIR Systems and their sister company INDIGO. The product brand is named Omega. Omega is the smallest, lightest, fully Integrated, long-wavelength infrared camera available. About 30% (3,000+ Omegas) have been delivered for use in small unmanned aerial vehicles (UAVs). The predominant usage has been as an infrared camera payload on the Raven UAV manufactured by AeroVironment.



3. LIDAR (Light Detection and Ranging)

LIDAR (light detection and ranging) uses the same principle as RADAR. The LIDAR instrument transmits light out to a target. The transmitted light interacts with and is changed by the target. Some of this light is reflected / scattered back to the instrument where it is analyzed. The change in the properties of the light enables some property of the target to be determined. The time for the light to travel out to the target and back to the LIDAR is used to determine the range to the target.

In DOT testing in Wyoming, the most successful location of leaks was displayed by a hand held LIDAR system manufactured by Physical Scientific, Inc. It may be possible to operate the handheld LIDAR in conjunction with a SUAV. Investigation into payload integration will be made in the next phase of this program.

4. GPS – for mapping of areas of concern and documentation of areas of encroachment

The Global Positioning System (GPS) satellites transmit signals to equipment on the ground. GPS receivers passively receive satellite signals. Each GPS satellite transmits data that indicates its location and the current time. When the receiver estimates the distance to at least four GPS satellites, it can calculate its position in three dimensions. The SUAV uses commercial grade GPS signals. At least four satellite inputs are used. Reliability varies depending on the reception and conditions. Typical accuracy of the GPS location for this commercial grade system is within 10 meters.

5. Radar

Radar is short for radio detection and ranging. A transmitter sends out pulses of high frequency radio waves. These waves bounce off objects and return to the dish. A radar echo shows up on a monitor, and a computer measures the time it takes for the signal to bounce off the target and then calculates how far away it is.

Any received signals from the receiver are then sent to a data recorder for storage on a disk or tape. The data can then be processed and interpreted using:

- Broadband vector magnetic field sensors
- Continuous data collection providing coverage with 1 feet horizontal spatial resolution
- DAQ with 14 bits and 1 MS/s per channel
- Precise positioning control
- Visualization and inversion software
- Produce digital map of pipelines.

No feasible radar payloads were located during this investigation effort.

6. Combustible Gas Indicator (CGI)

A Combustible Gas Indicator (CGI) consists of a meter, probe and an aspirator bulb. The bulb is pumped by hand to bring a sample of air into the probe and the instrument. The dial on the instrument indicates the percentage of flammable gas in the air (percent gas scale) or percent of the lower explosive limit (LEL) scale. These instruments must be calibrated for the type of gas in the system. The CGI should be calibrated for natural gas for use on a natural gas system. PHMSA recommends that a two-scale meter be purchased (LEL and percent gas). CGI systems are not suitable for use with a SUAV.

Figure 2: Combustible Gas Indicator

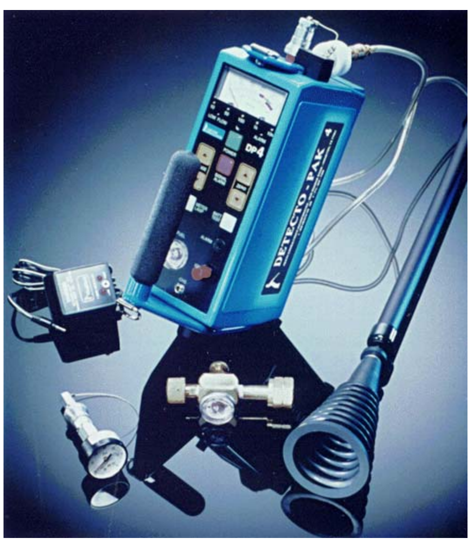


Figure 3: Flame Ionization Detector

7. Flame Ionization

A Flame Ionization (FI) detector uses a hydrogen fuel to power a small flame in a detector cell. A pump or venturi system is used to pass continuous air samples through the detector cell. If the air contains hydrocarbons such as natural gas, they will be burned or ionized in the hydrogen flame. This is detected electronically and displayed on a meter read-out. Leak surveys can be accomplished more rapidly with an FI unit than with a CGI using the bar hole method. FI devices are not yet appropriate for integration into a SUAV.

8. Methane Sensors

Airborne Methane Gas Sensors work by collecting an air sample through an external airborne probe, then passing a laser beam through the sample, focused on a photo-detector. The photo detector receives different levels of light intensity depending on the composition of the air sample. The resulting photo current is transmitted to a signal-processing unit, then available for display. Commercially available systems weigh approximately 16 kg and operate on vehicle power. Recommended speed and altitude varies, but is as low as 60 knots and 150 feet. These operational ranges are feasible for use on SUAV systems. Additional effort will be required to reduce the weight, volume and power consumption of the system before use on a SUAV is possible.

9. Airborne Laser Bathymetry

Airborne Laser Bathymetry systems measure shallow coastal water depths for mapping and other applications. Improvements in techniques have resulted in the ability to create 3D models in shallow water. Size, weight, power consumption and operation speeds make this technology unsuitable for integration into SUAV systems.

Available Digital Imagery

The SUAV utilizes a NTSC (National Television System Committee) standard analog signal to download information from the air vehicle to the ground control unit. The ground control unit displays the data and provides a video feed to either a videocassette-recording device or to a personal computer. The standard computer is a military issued "Tough Book." The computer digitizes the image and displays them on the computer screen. The digitized image may then be used in conjunction with commercially available software packages for real time and interactive mapping and geographic information systems.

Photographs will be taken with GPS coordinates to demonstrate recording capabilities for use in addressing violations. Available imagery will be obtained to determine success in the following tasks:

- Video and still images of encroachment violations
- Enough information to determine the resolution of imagery and the scale of the images
- Conduct house counts – GPS coordinates and mapping of area
- Video with GPS coordinates
- Ability to identify structures through tree cover
- Capture and store images for review and analysis
- Interface to GIS systems.

Payloads Requiring Further Technical Development

The payload proof of principle and demonstration phases of the program will identify the capabilities and limitations for each of the payload sensor packages. This information will be used to establish a baseline for the ability of current payloads to meet the mission requirements, as well as identify technology gaps requiring further development. The team will review all first phase efforts and make recommendations to the DOT (as part of Task 7: Data Analysis) on further development efforts required to achieve the DOT's pipeline monitoring requirements. Several payloads have already been identified as possible technologies for future development. These payloads include:

- Handheld LIDAR
- Miniature RADAR

LIDAR and RADAR technologies may be useful in bridging any gaps in leak detection and aerial surveillance.

Future Activities

Planned activity over the next 90 days will include work on all subtasks related to the third milestone identified in the agreement. These include:

- Develop test plan and metrics.
- Conduct payload proof of principal.

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