NASA – Ames Research Center and Pipeline Research Council International, Inc.

Automated Monitoring of Pipeline Rights-of-Way

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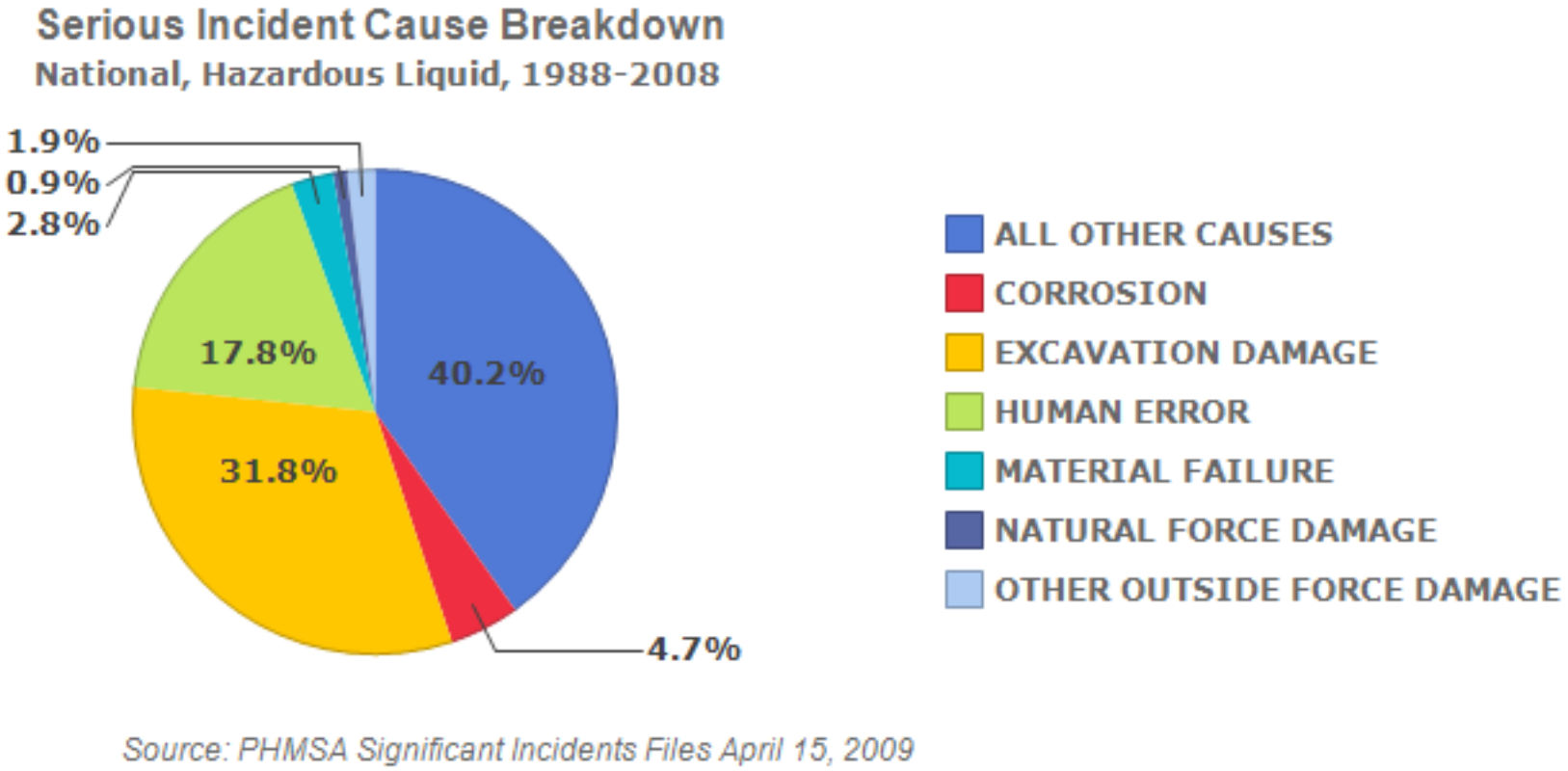
Presentation Topics and Overview

- Damage Prevention – Drivers & Challenges
- Successes of Current Research Programs
- Building on the Successes & Addressing the Next Series of Challenges for the R&D Community

Causes of Damage to Pipelines



Source: PHMSA Significant Incidents Files April 15, 2009

Outside force damage is the single greatest cause of pipeline failures

Mechanical Damage is single largest cause of on-shore pipeline damage

Damage Prevention – Why is This so Challenging?

- **Substantial mileage of all SYSTEMS**
  - 170,000 miles of hazardous liquid lines
  - 295,000 miles of gas transmission lines
  - 1,900,000 miles of natural gas distribution lines
- **Varying needs - unique conditions for each operator**
- **Monitoring Frequency and timing; resource limitations**
- **Accuracy and reliability of databases (upkeep)**
- **Sensitivity of Measurement systems**
- **Inherent difficulty in effective communication with multiple stakeholders and existing databases – DIRT, One Call, etc.**
- **“If You Build it They Will Come” – Increasing Encroachment**

Damage Prevention – Desired Solution

- **No single technology can address all pipeline issues**
  - Tiered approach
  - Combination of multiple technologies

- **GOAL: Develop one single, automated system, service or suite of technologies developed to apply over the entire pipeline system network to address:**
  - **Damage Prevention**
  - Leak detection
  - Changed Conditions

→ **RAM Program**

Current Operational Practice

- Light aircraft (ex. Cessna 172)
- Flown low-and-slow (~500 ft AGL, 100 kts)
- Single pilot, sometimes with an observer
- No automation – pilot/observer looks out the window
- Calls in any threats observed

Photo credit: Prasetyo, M. Ector

Benefits:

- Reliable
- "Real-time"

Costs:

- Safety of pilot, aircraft
- Time-consuming
- Only "sensors" are pilot's eyes
- No documentation of ROW state
- Coverage of ROW is not continuous

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RAM Program Vision

Realize enhanced aerial surveillance of the ROW through a suite of cost-effective sensors and technologies to prevent infrastructure damage.

Project Objective

- Identify, validate and advance automated monitoring technology
- Implement near term solutions on manned aircraft - long term view to satellite and unmanned surveillance

Scope – Automated Detection

- ROW Encroachments/intrusions
- Machinery/spills underneath tree canopy
- Ground disturbances, erosion, etc
- ROW Leak Detection – Gas & Liquid Hydrocarbons

Integrate sensors and technologies:

- ✓Airborne Threat detection systems
- ✓Near real-time detection & reporting
- ✓Long range communications
- ✓Multiple data systems
- ✓Image archiving & management
- ✓Predictive Modeling

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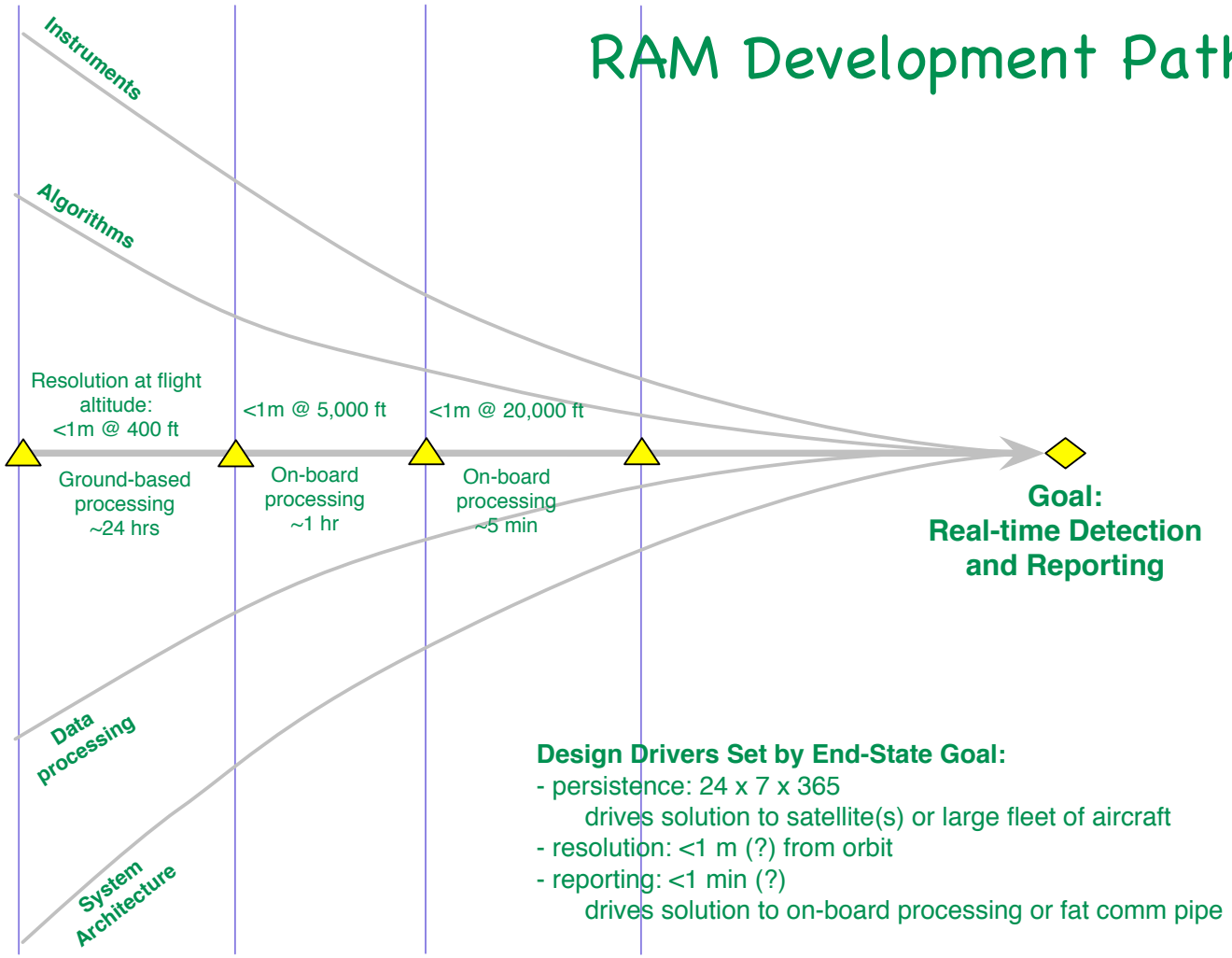
Benefits of RAM and Related R&D

- Enhance community safety and environmental protection
- Increase pilot safety
- Increase pipeline integrity, security and reliability
- Significant improvement to efficiency and effectiveness of monitoring pipeline ROWs
- Augment ability to detect and respond to unauthorized excavations
- Reduce third party encroachments and incidents

RAM Program Overview



Design Drivers Set by End-State Goal:

- persistence: 24 x 7 x 365
  drives solution to satellite(s) or large fleet of aircraft
- resolution: <1 m (?) from orbit
- reporting: <1 min (?)
  drives solution to on-board processing or fat comm pipe

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RAM Program - Concept of Operations

- Suite of sensors mounted on various aerial platforms to detect machinery threats (as well as other threats such as leaks and ROW changes)
- Automated recognition and identification of threats and process data on board aerial platform
- Via communication link (wireless, radio) notify operations center and/or designated field locations of threat with appropriate alarm indicating severity
- Download and archive data

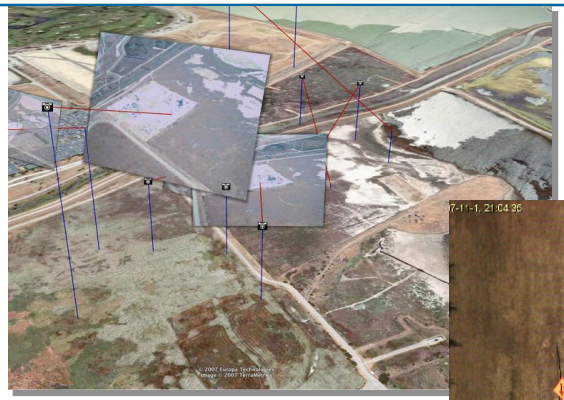
Successes of our

CURRENT RESEARCH

Damage Prevention - Machinery Threat

Objectives

- Develop technology to enhance detection encroachment or intrusion along ROW
- Bulldozers, backhoes, drill/ augers, and scrapers
- Improve efficiency, coverage and cost-effectiveness of patrol



Aerial sensors, geo-referencing, and computer vision

Approach

- Automate documentation and detection tools
- Enhance current practice (manned patrols)
- Develop algorithms and prototypes for future flight systems

Schedule

- Phase 1: Collect data, evaluate sensors, develop algorithms & concept of operations (completed)
- Phase 2: Validate algorithms, prototype and test system in field (current focus)
- Phase 3: Refine, produce, and verify flight system

Threat Detection: Status

- Developed an easily modifiable end-to-end proof-of-concept system for collecting imagery, consistently finding most threats, and objectively evaluating the system performance
- Developed prototype image collection system, using COTS camera with custom firmware and in-wing mount
- Worked with BP to conduct flight activities: collected ROW and Threat imagery, demonstrated system capabilities
- Threat detection algorithms were significantly improved, with most of the threats due to heavy digging equipment being correctly tagged (however, the false alarm rate is high)

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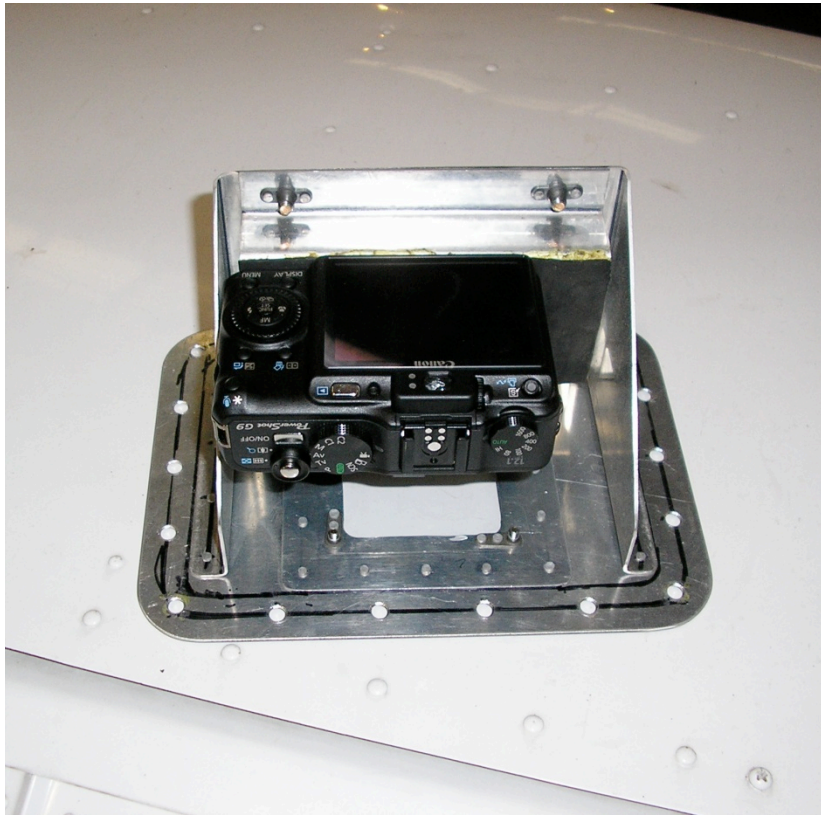
Threat Imaging Technology Demonstrated



Wing-mounted visual imaging camera – configure for current platform

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Algorithm Successfully Identifies Threats

Algorithm accurately identifies threats at high rate of detection

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A good test case – no false positives!

Damage Prevention – Leak Detection

- Technologies for detection above ground are commercially available

- Project focused on *underground* detection

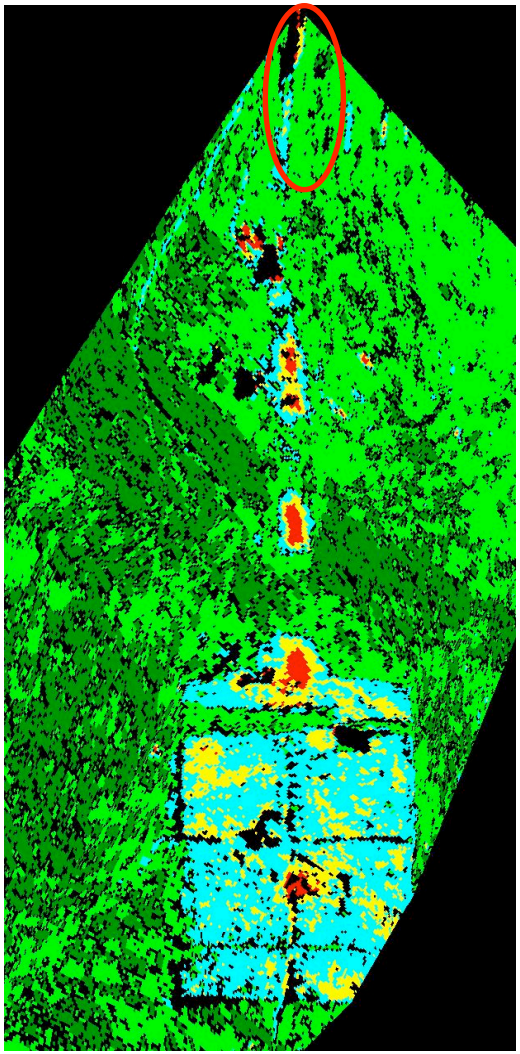
  - Developed an algorithm that automates hyperspectral airborne image analysis for underground gas leak detection utilizing plant stress response to CO2

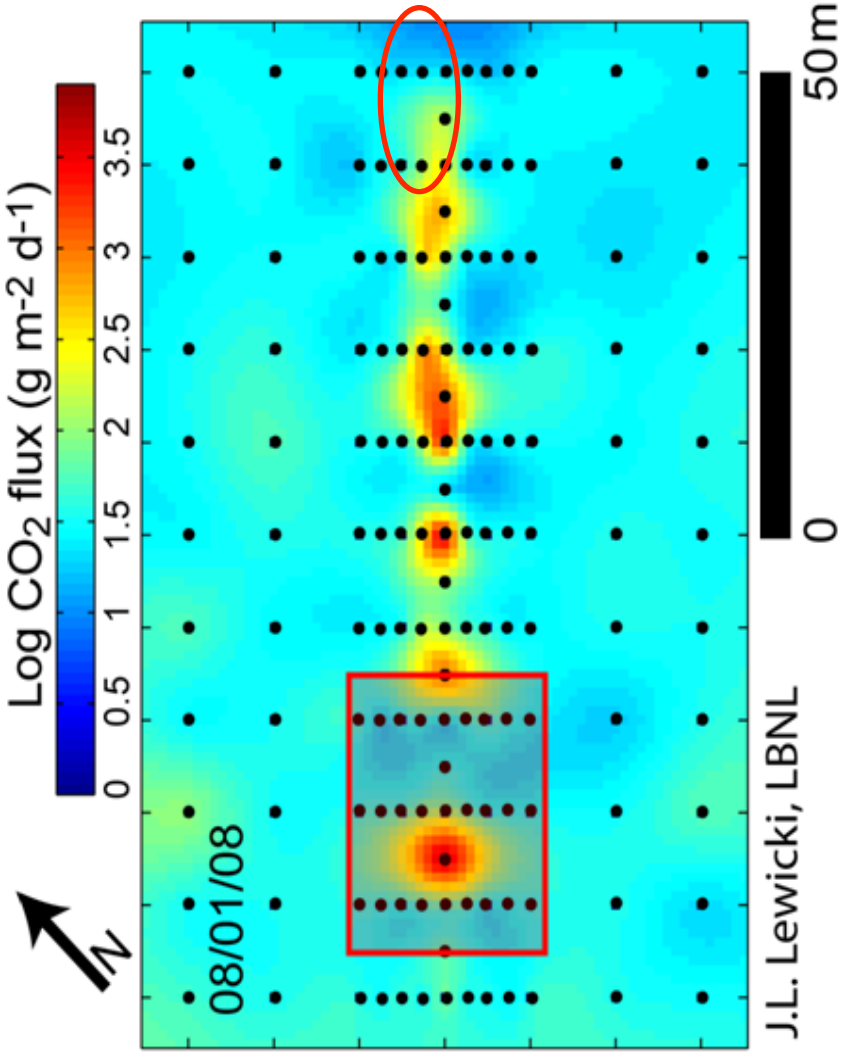
- Automation algorithm matches results of manual analysis (using COTS ENVI software) almost identically

- *The plant stress mapping technology is of high readiness*

Leak detection via plant stress response

Manual analysis results

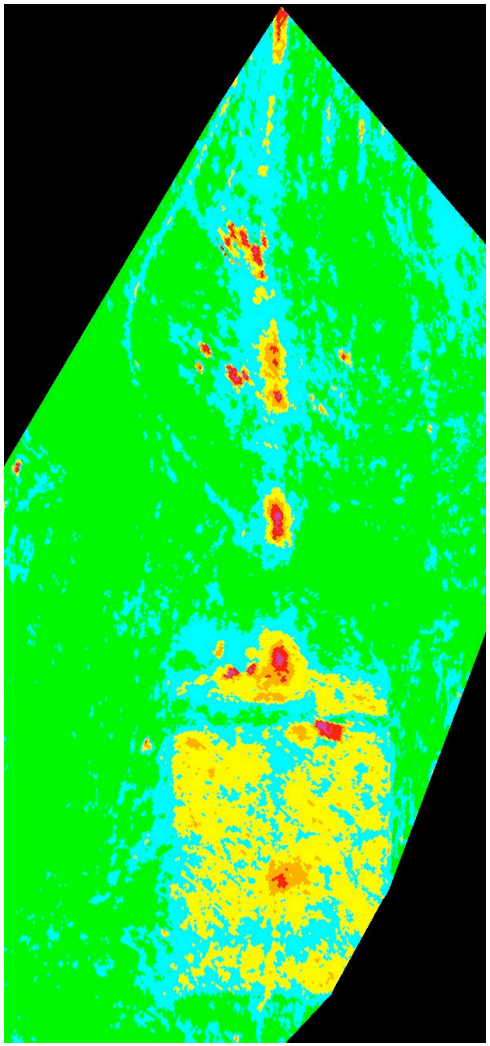




Plant stress spots correspond to measured CO_2 flux maxima

- Pickles UCSC NASA-AMES 12-2-09

Semi-automatic notch depth analysis results



Black and white:

raw results

Colored:

brightness ranges mapped to 6 color set

Red indicates leak or false positive

False positives can be discriminated based on sharpness of edges and/or using high resolution photographs

Information Gathering

- Request for Information, RFI, announced through DOT – PHMSA
- FedBizOps RFI #DTPH56-09-1000001
- Solicited input on available technologies relevant to RAM program
- Has been, and is continuing to be, very successful
- 36 Responses to date, extended through 2010, and possibly through project life cycle
- Responses covered a range of sensors and technologies e.g.,
  - Full spectrum hyperspectral
  - Light Detection and Ranging
    - Morphology measurements (-vs- gas constituent detection via differential absorption)
  - Synthetic Aperture Radar (SAR)
  - Polarimetry
  - Magnetometry
  - Data Fusion / Hybridization
  - Imagery / Hyperspectral / Lidar / SAR
- *Responses are still solicited!*

Building on our successes… addressing the next

CHALLENGES

Challenges and Additional R&D Needs

Sensors

- **What are the *minimum* requirements?**
  - Type
  - Resolution
  - Calibration & maintenance requirements
  - Payload limitations
- **Sensor and computer miniaturization**
- **Automated sensors that detect machinery in various environments, terrains, and background conditions**
  - Snow, grass, dirt, sand
  - Mountain, swamp, forest and variable terrains
  - Under tree canopy
  - Off-shore

Challenges and Additional R&D Needs

Data Processing and Communications

Near-real time to real time

- Detection, analysis & processing; on-board systems
- Multiple sensors
- Dissemination and appropriate notification

Over the horizon, high band-width communications

Full integration with aircraft and ground systems

Data management and archiving challenges

Human factors

Evaluating Multiple Platforms

- **Manned – near term focus**
- **Unmanned – mid to long term goal**
- **Satellite – long term goal**

RAM Program plans

- **In 2010, the program will focus on:**
  - Continued development and validation of machinery threat detection technologies
  - Development of a flyable prototype system
  - Continued evaluation and assessment of elements identified through the RFI process

RAM – Other Potential Benefits

- Enhance localized aerial surveillance
- Focus surveillance during spill/event
  - Marine oil spill, wildfires, hurricanes
- Security surveillance
  - Refinery, tank farm or marine terminals
- Threat detection and security for other linear industries or critical infrastructure
  - Water, electric, highway, rail, communications

RAM Program: Summary

PRCI, in collaboration with NASA, has successfully implemented a research program that is focused on overcoming the key gaps for automated right-of-way monitoring:

- **Developing and testing systems capable of detecting heavy equipment threats and underground leaks**
- **Defining operational requirements**

- **We are *not* focusing on elements that are easily procured**

- **Significant challenges remain to be addressed**

- **The fundamental technologies being developed and tested are of broad value to NASA and the nation**

RAM Program

- Questions