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# Airborne Intercept Monitoring

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## *EXECUTIVE SUMMARY*

*The United States Navy has been working to advance the science and technology of sensor integration and communication technologies. This project will leverage an immediately available laser sensor package integrated with a presently operating passive optics sensor system to yield a result that will produce a high-resolution, 3-dimensional trajectory measurement. The integrated system will acquire, track, and record range, range rate, and Doppler imaging data concurrent with passively acquired visible and infrared imagery of Missile Defense Agency objects. The project is a meld of hardware and software from three different programs, the Advanced Airborne Sensor (AAS) from the USAF, Stabilized High-accuracy Optical Tracking System (SHOTS) from the USN, and the Airborne Intercept Monitoring (AIM) system from the USN.*

*The AAS laser is capable of the acquisition and tracking of launched ballistic targets from an airborne platform providing angle, range, range rate, and range-Doppler imaging information.*

*SHOTS is a 0.75 meter aperture telescope that uses a high-precision, GPS-aided inertial navigation unit coupled with a 3-axis, rate gyro stabilized mount to allow precise pointing on land or sea-based platforms.*

*The integration of these two systems under the sponsorship of the AIM program will provide high sensitivity, precision metric capability while maintaining the SHOTS passive sensor suite.*

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AAS Laser in Airborne Platform

SHOTS on board MATSS

## 1. INTRODUCTION

The US Navy is presently conducting Ballistic Missile Defense (BMD) testing at Kauai's Pacific Missile Range Facility (PMRF) in Hawaii. An adjunct to the PMRF optics upgrade program that is being considered is the integration of the AAS laser and the SHOTS optical system. This will produce a system that will provide valuable missile tracking data to the Navy's Aegis Ballistic Missile Defense Program. Both hardware systems were designed, developed and operated by Textron Systems Corporation and include the US Air Force's Advanced Airborne Sensor (AAS) and the US Navy's Stabilized High-accuracy Optical Tracking System (SHOTS). The AAS / SHOTS integration and operation will take place at the Pacific Missile Range Facility under a contract between Textron Systems and the US Navy's Office of Naval Research.

## 2. SHOTS CONFIGURATION

The SHOTS optical configuration consists of the SHOTS Acquisition Telescope (SAT), and the SHOTS Telescope Systems (STS). The two telescope systems are mounted on an elevation over azimuth SHOTS Pointing System (SPS). The STS is a 0.75 meter aperture Mersenne Cassegrain telescope and the SAT is a 0.34 meter aperture 3-mirror anastigmat telescope. The telescopes are controlled by a Stabilized High-accuracy Optical Tracking System which uses a high-precision, GPS-aided inertial navigation unit coupled with a 3-axis, rate gyro stabilized mount to allow precise pointing on land or sea-based platforms. The telescopes' architecture, acquisition, tracking and pointing functionality and methodology meet the missile defense mission data collection requirements. The cameras mounted on the telescopes consist of high frame rate visible and Medium Wavelength Infrared (MWIR) cameras.

The SHOTS pointing system is capable of a maximum azimuth axis angular velocity of 80 degrees / second and an acceleration of 75 degrees / second$^2$. In elevation, it is capable of an angular velocity of 35 degrees / second and an acceleration of 35 degrees / second$^2$. The STS Prime Telescope specifications are

- 0.75 Meter Mersenne, f/8, Afocal system
- Primary mirror of Zerodur with Pilkington 747 coating
- FOV = 0.104 degrees

- Air Flow to Mitigate Thermal "Seeing" Effects
- Light weighted primary mirror to reduce mass

The SAT specifications are

- 0.34 Meter Three Mirror, Anastigmat, Afocal
- Diamond Turned Aluminum
- FOV = 0.56 degrees

The sensor suite consists of

- 30 to 1000 frame per second MWIR and Visible cameras
- Prime Telescope f/8, Resolution ~5 µrad/pixel
- Acquisition Telescope (f/2.6), Resolution ~ 30 µrad/pixel

The Mount Control System performs target acquisition, pointing, and tracking of missiles, satellites and celestial objects. It also has a tracking and pointing subsystem that provides tracking, pointing calibration, trajectory estimation, and outer loop stabilization. The Servo Control Unit provides inner control loop stabilization, which is designed to compensate for shipboard movement to within 100 µradians in a Sea State 5. SHOTS presently represents the largest (0.75 meter) aperture stabilized telescope in the world.

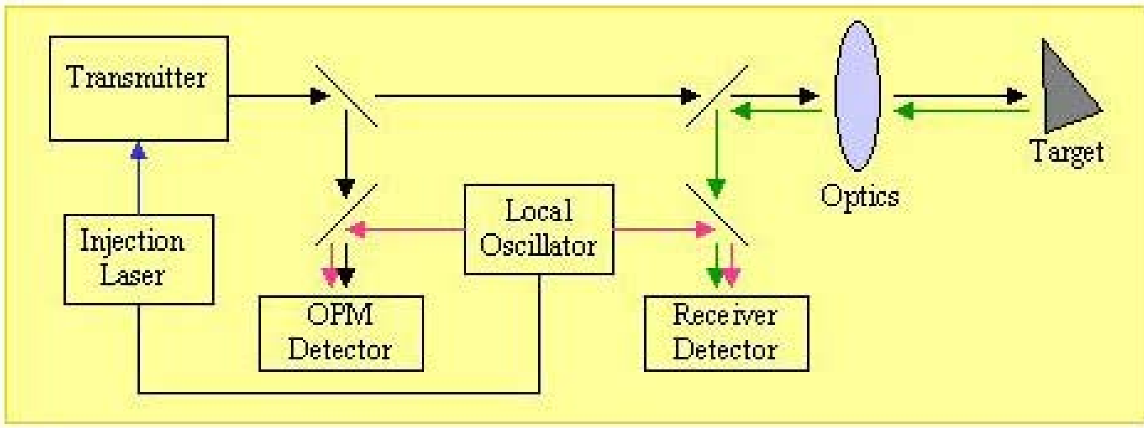
## 3. AAS TECHNICAL SPECIFICATIONS

The Advanced Airborne Sensor (AAS) is capable of acquiring and tracking ballistic targets while mounted on an airborne platform and provides angle, range, range rate, and range-Doppler imaging information. The laser transmitter was developed and built by Textron Systems and consists of a $CO_2$ gas laser using $C_{13}$ isotope, which transmits at a wavelength $\lambda$ = 11.15 µm.. The laser operates in a mode-locked or injection-seeded cavity matched configuration which provides an output power level of 10 Joules at a frequency of 10 Hz. AAS is a closed cycle laser, with a maintenance period (gas replacement) of greater than 2 years.

The laser's local oscillator is a Howden CM3054 Waveguide Laser, with < 80 kHz fluctuation in a 4 millisecond time period. It is frequency locked to the injection laser and frequency shifted to + / - 500MHz by an Acousto-optic modulator.

The system's Receiver Detector is a liquid nitrogen cooled HgCdTe sensor. The method used to sense the received signal is called coherent heterodyne detection, which increases the sensitivity of the detector by reducing the shot noise of the detector.

An Output Pulse Monitor (OPM) detector is used for matched filtering and diagnostics, which also uses a liquid nitrogen cooled HgCdTe Photomixer.




The AAS laser operates several passive sensors for tracking purposes. The Acquisition Sensor consists of a Medium Wavelength Infra Red (MWIR), 22˚ x 22˚ field of view single camera with a 256 x 256 pixel InSb array, and a digital video interface. AAS also carries a visible tracking sensor with an interchangeable standard CCD, 1000 x 510 Si array, a digital video interface or an intensified CCD with a GaAs Photocathode, 760 x 490 array, and a RS-170 Analog interface (640x480). Also available but not normally used is an MWIR Track Sensor with a 256 x 256 InSb array and a digital video interface.

The AAS Electronics are housed in several racks.

- Two Bay Rack
  - Chillers, Frequency Control Electronics, Laser Trigger, Mode-locker Driver
- Pulsed Power Rack
  - HV Power Supply, Thyratrons, PFN Electronics
- Receiver Rack
  - Synthesizer, Digitizer, Receiver Electronics
- Three Bay Rack
  - System Operator Station, Laser Operator Station, Processor Electronics

The AAS Angle and Range Track Capability and the Range Standoff Capability are extremely robust.

Whole Body

| Parameter | Value |
|---|---|
| Angle Resolution | 10 μRadian |
| Range Accuracy | 15 meters |
| Velocity Accuracy | 1 meter/sec |
| Frame Rate | 10 Hertz |

Range Doppler Imaging

| Parameter | Value |
|---|---|
| Range Resolution | 0.25 meters |
| Velocity (Cross Range) Res. | 0.7 meters/sec |
| Frame Rate | 10 Hertz |

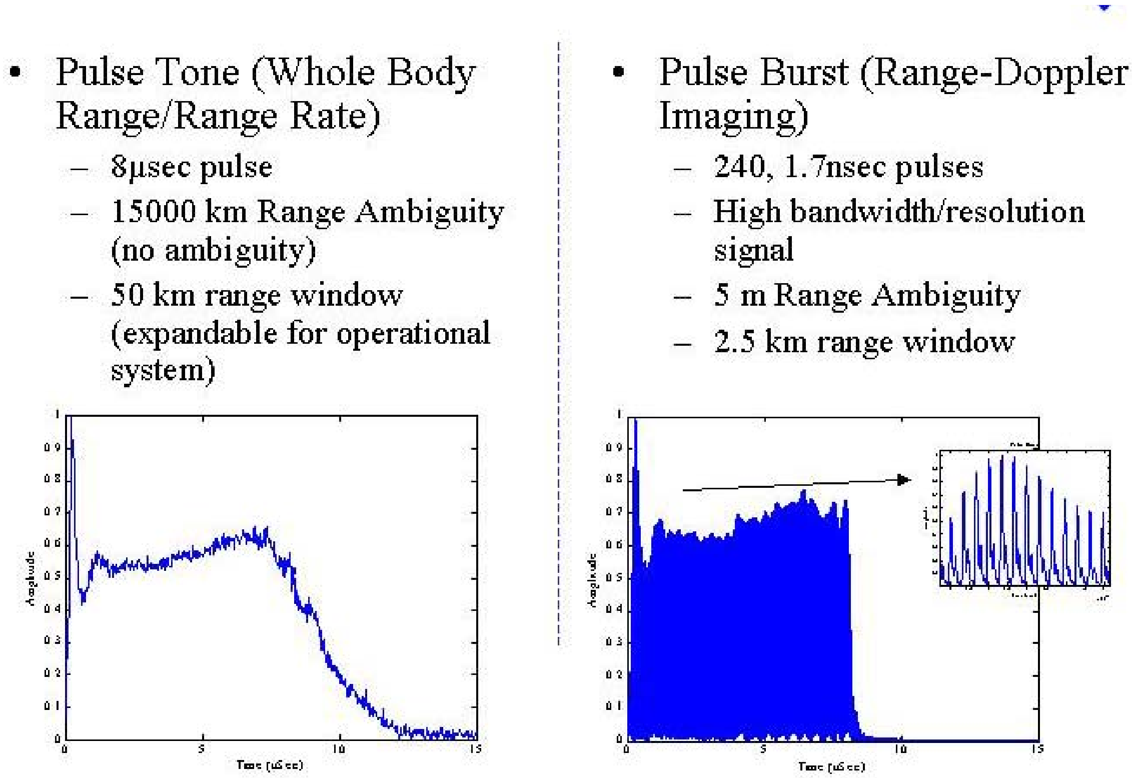
Demonstrated system Performance of Angle and Range Track Capability

| Target | Current Capability | Upgraded Capability |
|---|---|---|
| Re-entry Vehicle | 250km | 500km – 800km |
| Booster | 500km | 1000km – 1600km |

Range Standoff Capability

The AAS laser system has demonstrated its performance in angle and range measurements through various testing scenarios. One test scenario used a retro reflector at a distance of 50 km to measure range resolution, which was demonstrated to be accurate to 25 cm. Another testing scenario used helicopter rotors to demonstrate range rate resolution and tracking jitter. The range rate resolution was measured to less than 0.7 meters / second and the tracking jitter was measured to be within 7 to 10 microradians. Another testing scenario used a satellite to measure range accuracy, range rate and stand off pointing. The range accuracy was measured to be 16 meters, the range rate was measured to be 0.2 meters per second, and the stand off pointing was demonstrated to be 1500 plus km.

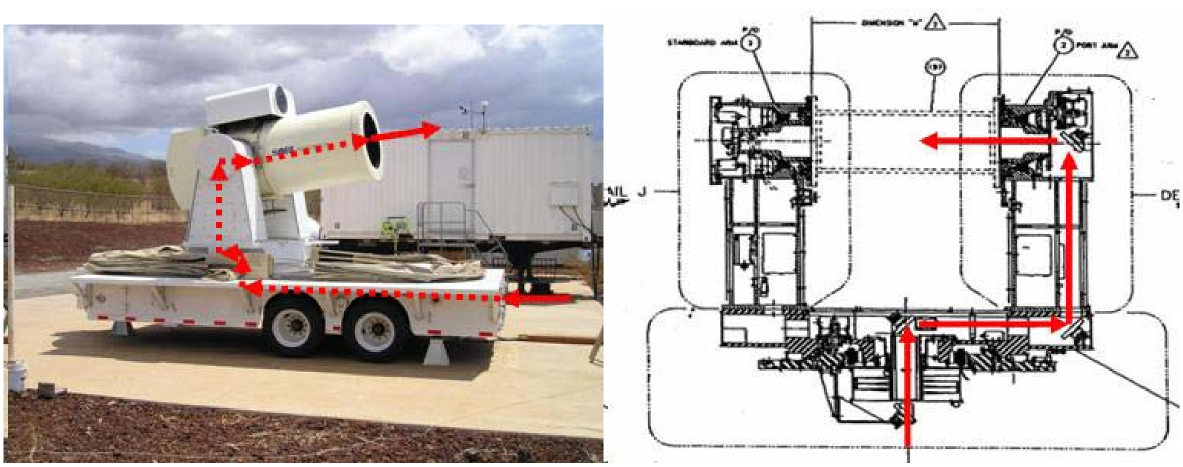
The AAS uses two Waveforms to make range measurements. One waveform is called the Pulse Tone waveform which measures range and range rate. The second waveform is called the Pulse Burst waveform, which measures range Doppler and imaging.




AAS Waveforms

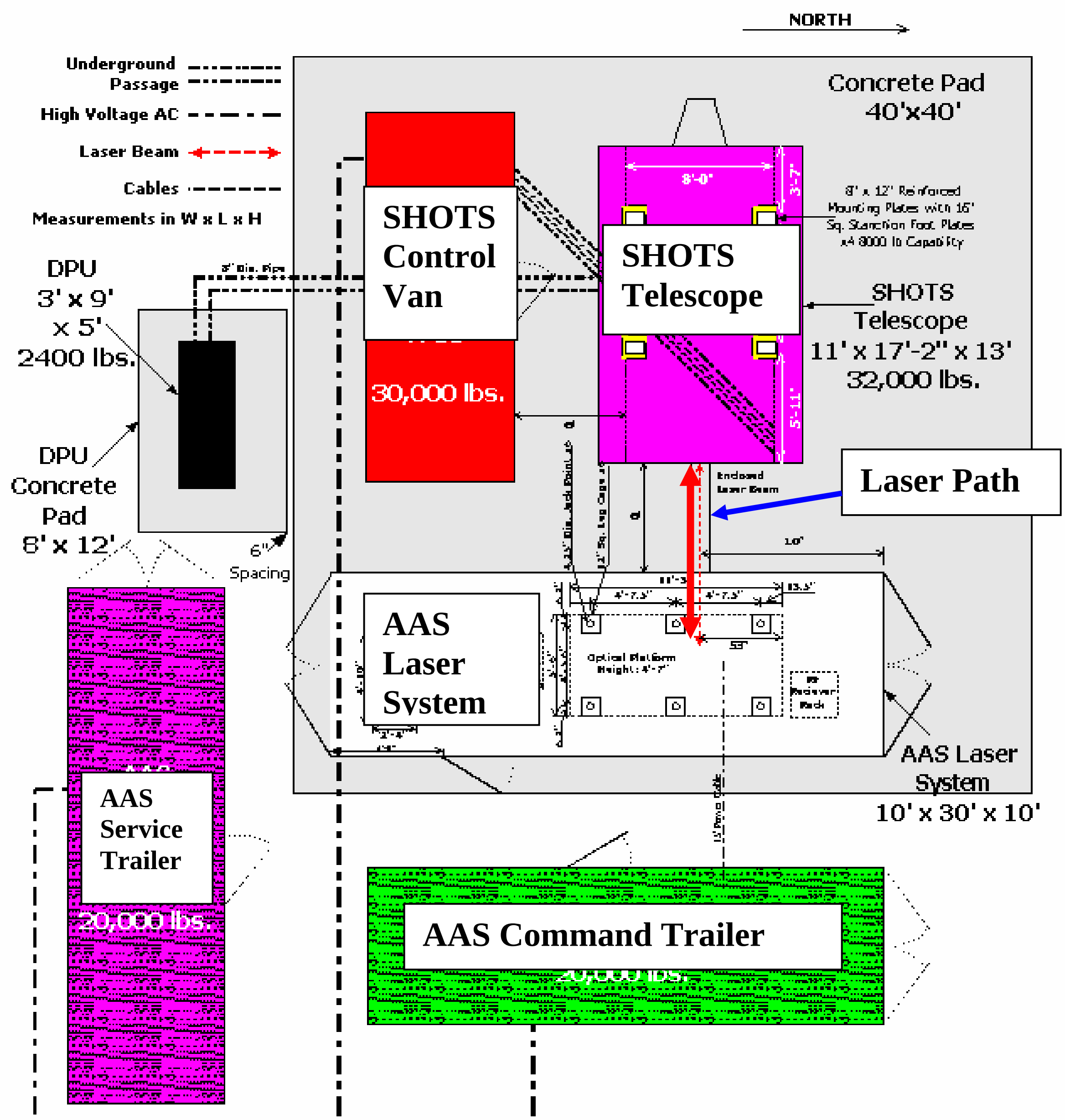
## 4. INTEGRATION OF SHOTS AND AAS LASER

The integration of SHOTS and the AAS laser under the sponsorship of the AIM program will produce a sensor that draws on lessons learned from its predecessors on Haleakala, Maui, Hawaii. SHOTS provides a Coudé path for the laser beam, out the barrel of its main telescope (STS).



*Coudé Path, Conceptual and Schematic*

The AAS laser will be housed in an environmentally controlled fiberglass shelter next to the SHOTS tracking mount. The laser beam will exit the fiberglass shelter and enter the SHOTS tracking mount at the base of the trailer. Four fold mirrors will propagate the AAS laser beam into the optical system of the SHOTS telescope. A dichroic mirror will then inject the 11.15 micron laser beam into the optical path of the telescope and then out the exit of the telescope to the target of interest. The return signal from the target will propagate through the SHOTS tracking mount via the same path through which it was originally sent out.




SHOTS and AAS Laser Conceptual Layout

The layout maximizes the operability and capabilities of the integrated systems and also considers the probable mission scenarios at the Pacific Missile Range Facility.

## 5. CONCEPT OF OPERATIONS

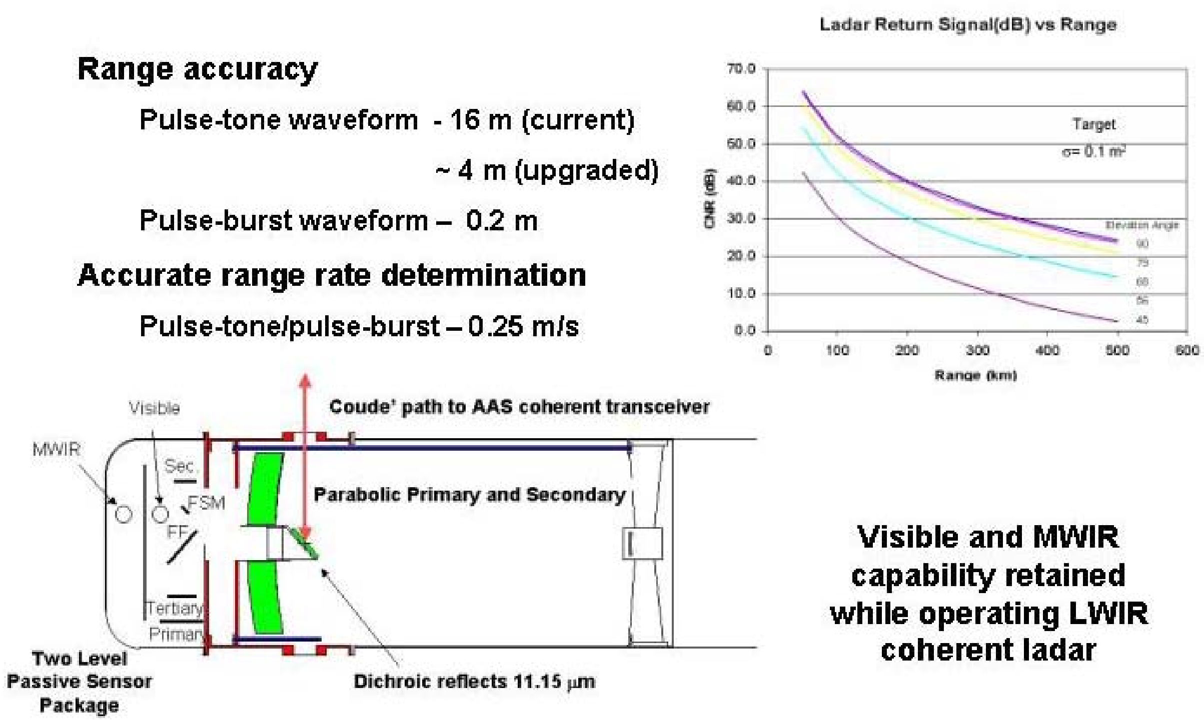
The concept of operations for the project will consist of the following.

- Track and lead-ahead with SHOTS
- Receiver Lag inside AAS
  - map SHOTS angles to detector
- Align AAS to SHOTS
  - internal AAS alignment
  - transfer align AAS visible tracker to SHOTS tracker
- Evaluate alignment stability

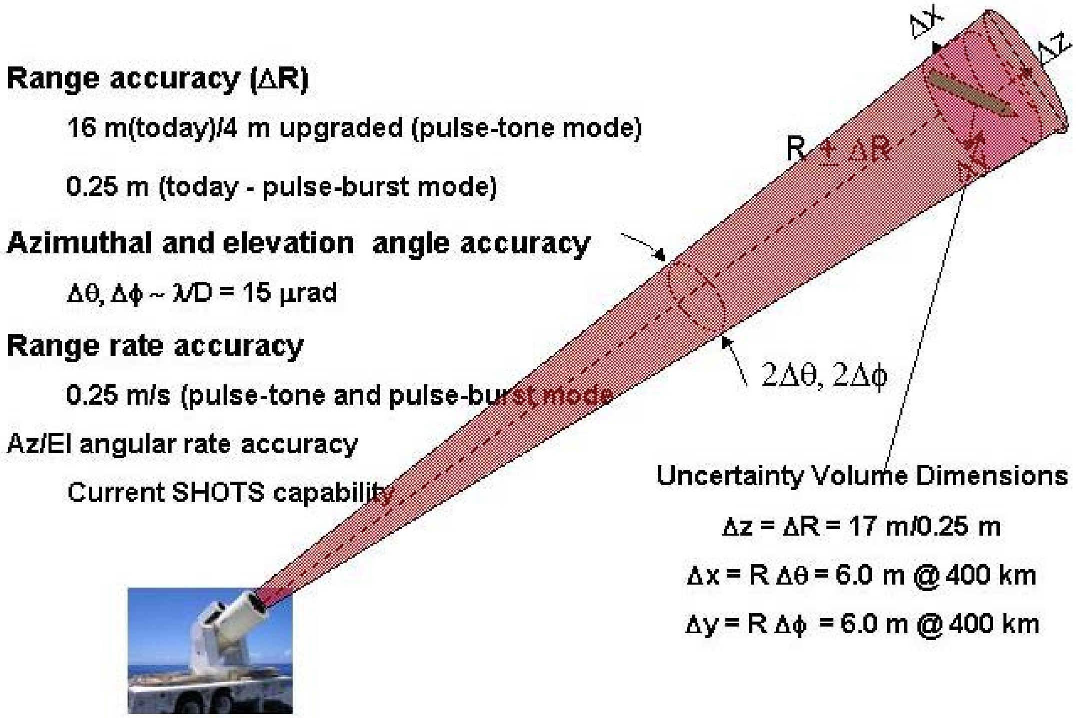
## 6. SHOTS LADAR PERFORMANCE PREDICTIONS

The AAS / SHOTS integration will produce a high-resolution, multi-spectral sensor with 3-D trajectory measurement capability, provide high sensitivity, precision metric capability while maintaining SHOTS passive optics capability, provide a single sensor, high precision, 3-D target position / velocity estimate, and provide, with a wavelength agility upgrade, the ability to detect high altitude chemical agent dispersal.

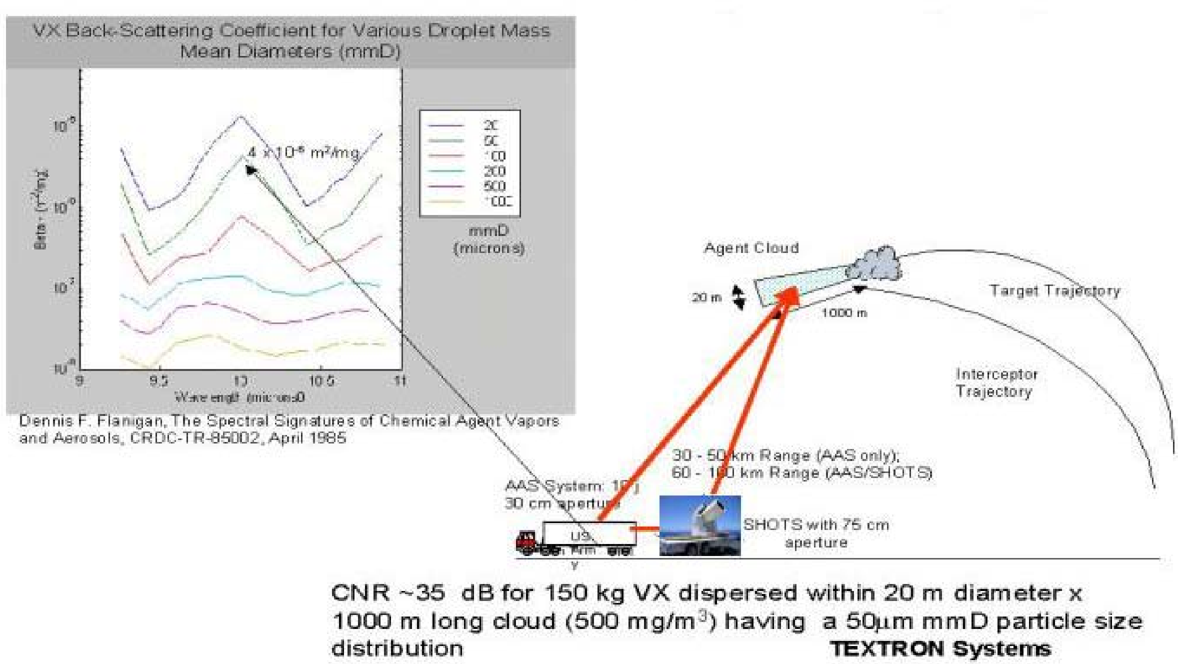
These capabilities are illustrated below.




High Sensitivity, Precision Metric Capability While Maintaining SHOTS Passive Sensor Suite




*Single Sensor, High Precision, 3-D Target Position/Velocity Estimate*




Detect High Altitude Chemical Agent Dispersal

# 7. SUMMARY

The ladar incorporates major hardware components from three programs from two different branches of the US Uniformed Services.

- SHOTS (US Navy)
  - Large aperture (0.75 m) telescope for effective light collection; Coudé path for laser projection
  - Visible and MWIR sensors for acquisition, tracking, and imaging
  - Mount control system for pointing and tracking
- Advanced Airborne Sensor (US Air Force)
  - Dual waveform, $CO_2$ coherent transmitter for precision ranging and imaging
  - Narrow and wideband, Doppler tracking, coherent receiver
  - Transmit-receive switch and "lead ahead/look back" hardware
  - Ladar data acquisition and control system
- AIM (US Navy)
  - Beam transport optics
  - Mount control system modification for ladar "lead ahead/look back" capability

SHOTS is a valuable stand-alone PMRF optical asset to which the AAS laser will add the ability to accurately acquire range, range rate, and Doppler imagery. The system will provide real-time tracking, ranging, and imaging capability, which will enable PMRF to better carry out its Ballistic Missile Defense test objectives.

# AIRBORNE INTERCEPT MONITORING (AIM) SYSTEM

**SET-105/RSM Meeting**
**Maui, Hawaii**
**24-25 April 2006**

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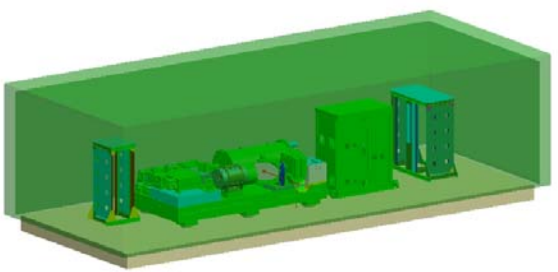
# ADVANCED AIRBORNE SENSOR SYSTEM AND STABILIZED HIGH-ACCURACY OPTICAL TRACKING SYSTEM



**TEXTRON SYSTEMS, PACIFIC MISSILE RANGE FACILITY, AIR FORCE, SPACE AND NAVAL WARFARE SYSTEMS CENTER, OFFICE OF NAVAL RESEARCH**

# Briefing Outline

- Background
- SHOTS Specifications
- AAS Specifications
- Integration of SHOTS and AAS
- Performance predictions of SHOTS/AAS
- Integration Status
- Summary

# BACKGROUND

- Advanced Airborne Sensor (AAS) designed, developed and operated by Textron Systems under contract with Air Force
- Stabilized High-accuracy Optical Tracking System (SHOTS) designed, developed and operated by Textron Systems under contract with Space and Naval Warfare Systems Center, San Diego
- AAS / SHOTS integration and operation will take place at Pacific Missile Range Facility by Textron Systems under contract with Office of Naval Research

# AIM

Mobile AT-Sea Sensor (MATSS)


SHOTS SYSTEM SPECIFICATIONS

SHOTS on MATSS

SHOTS Land Based

**TEXTRON Systems**

# SHOTS General Description

- 0.75 meter aperture telescope, Stabilized High-accuracy Optical Tracking System (SHOTS)
- Uses high-precision, GPS-aided inertial navigation unit coupled with a 3-axis, rate gyro stabilized mount to allow precise pointing on land or sea-based platforms
- Architecture, acquisition, tracking and pointing functionality and methodology meet missile defense mission data collection requirements
- High frame rate visible and MWIR sensors

# SHOTS Specifications

- Land or Sea Operation
- Pointing System
  - Gyro Stabilized, Elevation over Azimuth, Trailer Mounted Gimbal
    - Azimuth Axis:  80 deg/sec, 75 deg/sec$^2$
    - Elevation Axis:  35 deg/sec, 35 deg/sec$^2$
- Prime Telescope
  - 0.75 Meter Mersenne, f/8, Afocal system
    - Light weighted Zerodur with Pilkington 747 coating
  - FOV = 0.104 degrees
  - Air Flow to Mitigate Thermal “Seeing” Effects
- Acquisition Telescope
  - 0.30 Meter Three Mirror, Anastigmat, Afocal
  - Diamond Turned Aluminum
  - FOV = 0.56 degrees

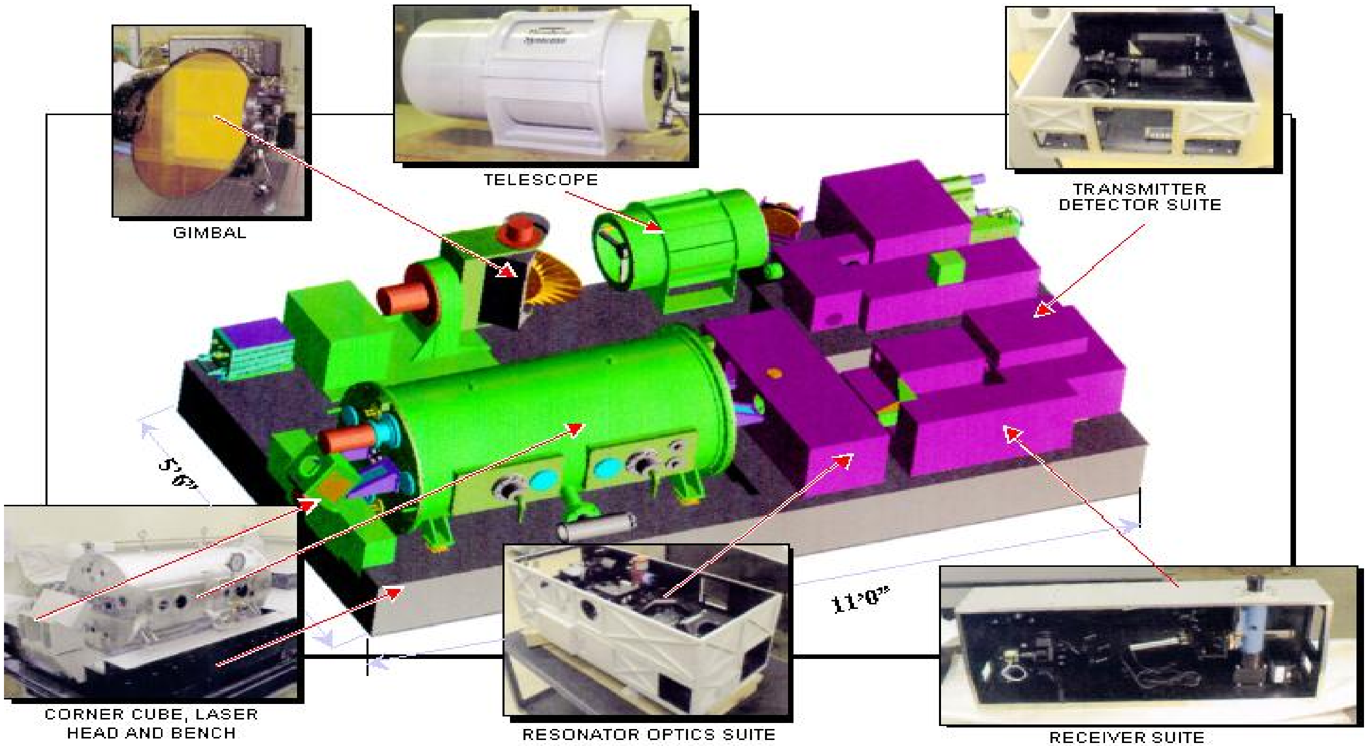
# SHOTS Specifications (cont')

- Sensor Systems
  - 30 to 1000 frames per second MWIR and Visible
    - Prime Telescope f/8, Resolution ~5 µrad/pixel
    - Acquisition Telescope (f/2.6), Resolution ~ 30 µrad/pixel
- Mount Control System
  - Performs target acquisition, pointing, and tracking
  - Tracks missiles, satellites and celestial objects
  - Tracking and Pointing Subsystem
    - Provides tracking, pointing calibration, trajectory estimation, outer loop stabilization
  - Servo Control Unit
    - Provides inner control loop stabilization

# Unique SHOTS Features

- Stabilization system will compensate for shipboard movement to within 100 μradians
- Largest (0.75 meter) aperture stabilized telescope in world
- Light weighted primary mirror to reduce mass

# AIM
# AAS Transmitter and Local Oscillator



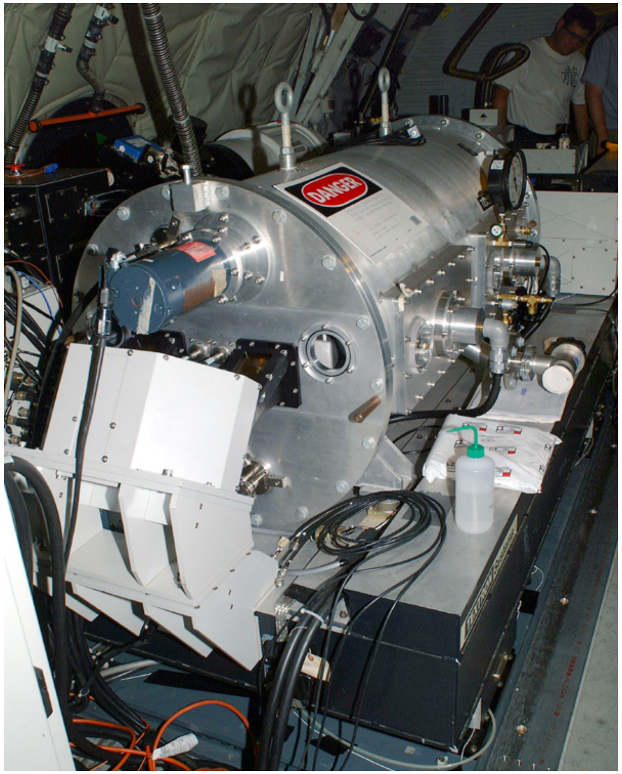

## AAS Program Background

- Mission Capabilities
  - Acquisition and Tracking of Launched and Ballistic Targets from an Airborne Platform.
  - Provide angle, range, range rate, and range-Doppler imaging information.

**TEXTRON Systems**

# AAS Laser Transmitter

- Textron developed and built.
- $CO_2$ gas laser using $C^{13}$ isotope.
  λ=11.15 um (good atmospheric transmission)
- Mode-locked or Injection-seeded & cavity matched.
- 10 Joules @ 10 Hz.
- Closed cycle.
- Maintenance period greater than 2 year.

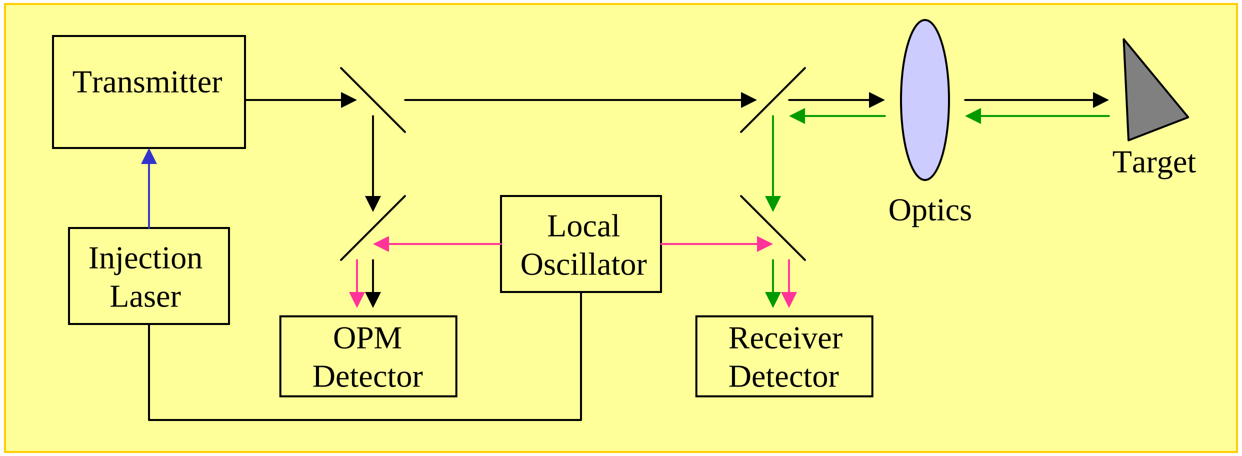


# AAS Local Oscillator

- Howden CM3054 Waveguide Laser
- < 80kHz Fluctuation in 4 msec
- Frequency Locked to the Injection Laser
- Frequency Shifted to +/- 500MHz by Acousto-optic Modulator

# AAS Laser Sensors

- Receiver Detector
  - Coherent Heterodyne Detection
    - Shot noise limited
    - No need to cool the optics
    - High sensitivity
  - $LN_2$ cooled HgCdTe Photomixer
- Output Pulse Monitor (OPM)
  - Used for matched filtering and diagnostics
  - Heterodyne detection
  - $LN_2$ cooled HgCdTe Photomixer



# AIM
# AAS Passive Sensors

- Acquisition Sensor
  - MWIR
  - 22° x 22° FOV (single camera)
  - 256x256 InSb array
  - Digital video interface
- Visible Track Sensor (interchangeable)
  - Standard CCD
    - 1000x510 Si array
    - Digital video interface
  - Intensified CCD
    - GaAs Photocathode
    - 760 x 490 array
    - RS-170 Analog interface (640x480)
- MWIR Track Sensor (available, not used)
  - 256 x 256 InSb array
  - Digital video interface

TEXTRON Systems

# AAS Electronics and Gimbal

- Two Bay Rack
  - Chillers, Frequency Control Electronics, Laser Trigger, Mode-locker Driver
- Pulsed Power Rack
  - HV Power Supply, Thyratrons, PFN Electronics
- Receiver Rack
  - Synthesizer, Digitizer, Receiver Electronics
- Three Bay Rack
  - System Operator Station, Laser Operator Station, Processor Electronics
- Azimuth +/- 25 deg , Elevation -10/+90 deg
- 30 cm diameter clear LOS aperture
- Tracking angular rate 4 deg/sec
- Fast Steering Mirror
  - High Bandwidth LOS stabilization

# AAS Angle/Range Tracking and Standoff Capability

Whole Body

| Parameter | Value |
|---|---|
| Angle Resolution | 10 μRadian |
| Range Accuracy | 15 meters |
| Velocity Accuracy | 1 meter/sec |
| Frame Rate | 10 Hertz |

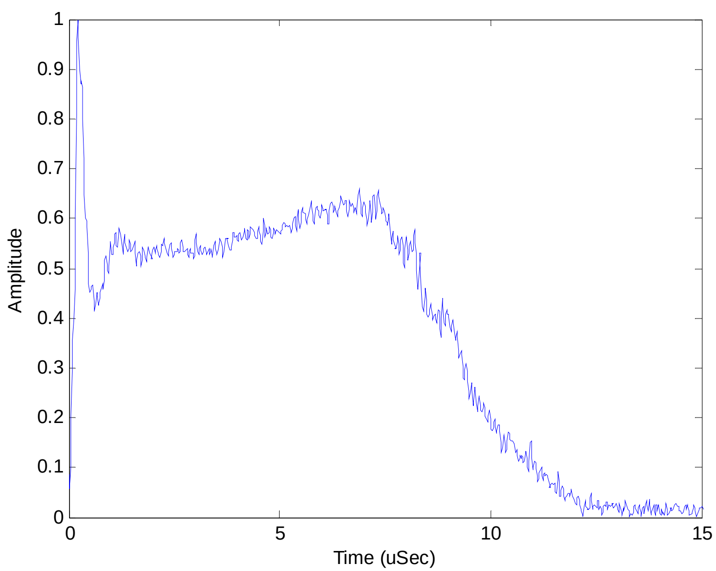
Range Doppler Imaging

| Parameter | Value |
|---|---|
| Range Resolution | 0.25 meters |
| Velocity (Cross Range) Res. | 0.7 meters/sec |
| Frame Rate | 10 Hertz |

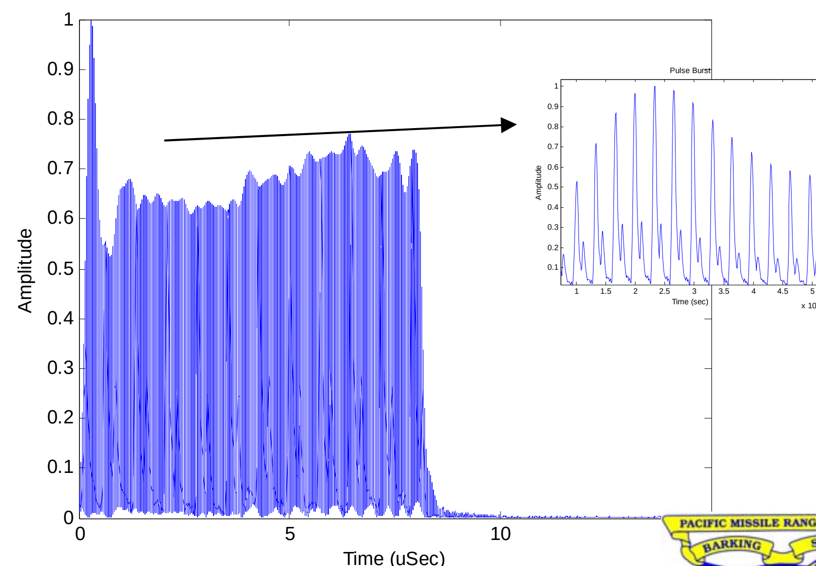
| Target | Current Capability | Upgraded Capability |
|---|---|---|
| Re-entry Vehicle | 250km | 500km – 800km |
| Booster | 500km | 1000km – 1600km |

# AAS Waveforms

- Pulse Tone (Whole Body Range/Range Rate)
  - 8μsec pulse
  - 15000 km Range Ambiguity (no ambiguity)
  - 50 km range window (expandable for operational system)




- Pulse Burst (Range-Doppler Imaging)
  - 240, 1.7nsec pulses
  - High bandwidth/resolution signal
  - 5 m Range Ambiguity
  - 2.5 km range window




TEXTRON Systems

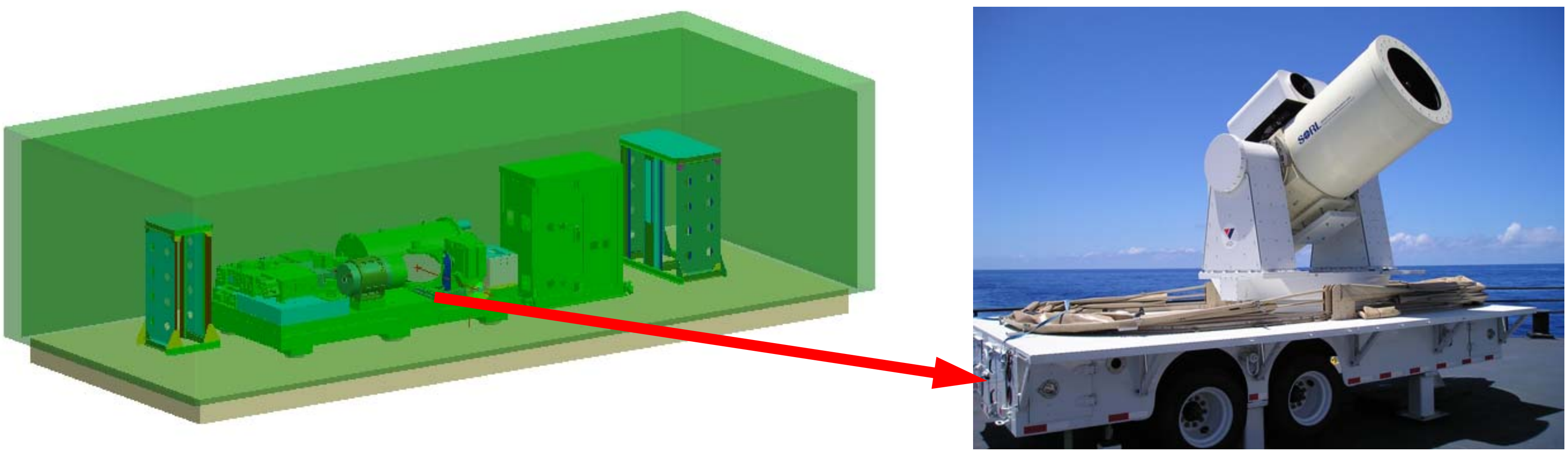
# Demonstrated System Performance

| ANGLE TRACK | DEMONSTRATED | TEST TARGET |
|---|---|---|
| AIM POINT ACCURACY | 10 – 15 mrad | LOCAL BORESIGHT<br>10KM, 50KM |
| STAND-OFF (POINTING) | 1500+ KM | SATELLITE |
| TRACKING JITTER | 7-10 mrad | HELICOPTER<br>SATELLITES |

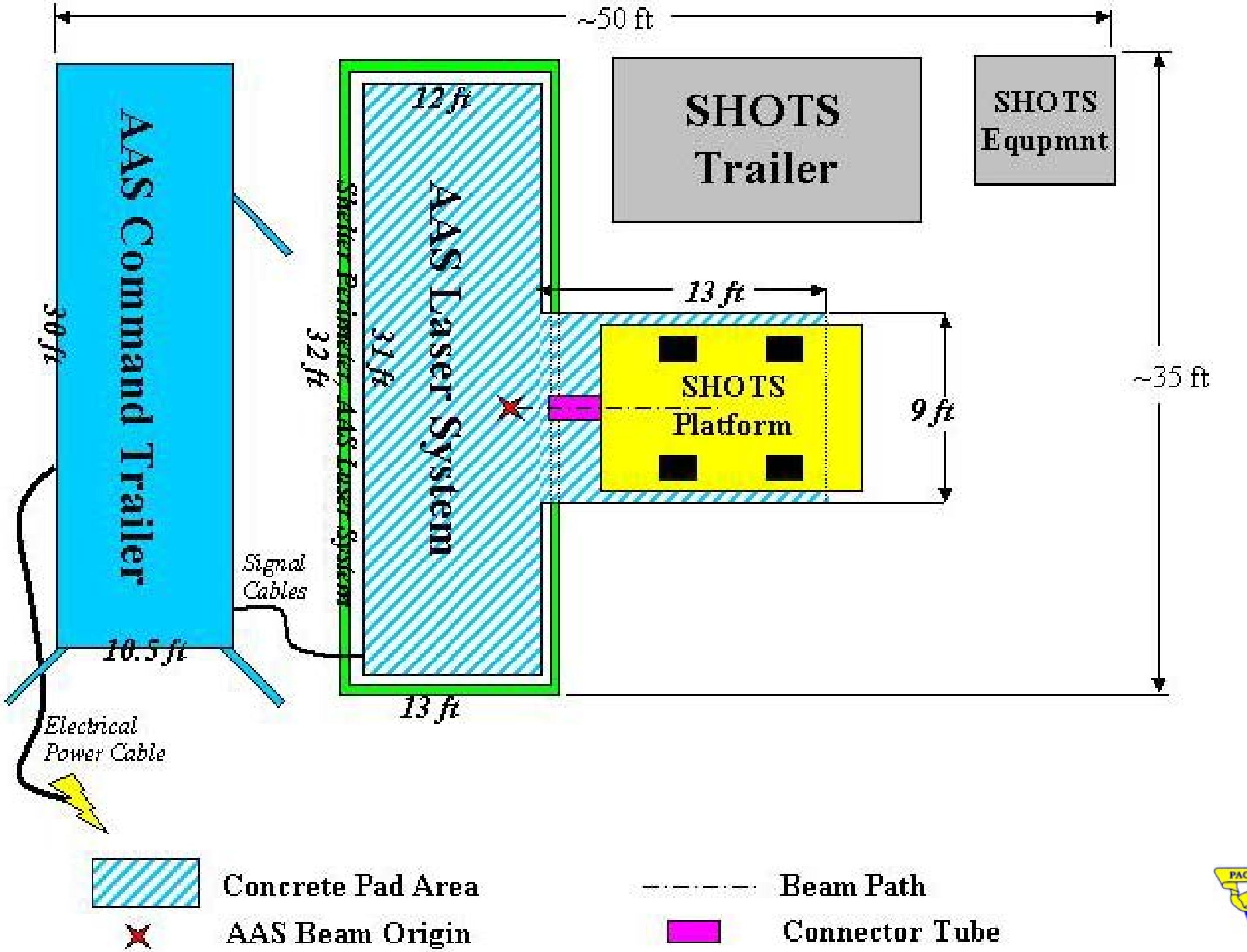
| RANGE TRACK ACCURACY | | |
|---|---|---|
| RANGE | 16 M | SATELLITE |
| RANGE RATE | 0.2 M/SEC | SATELLITE |

| DOPPLER IMAGING | DEMONSTRATED | TEST TARGET |
|---|---|---|
| RANGE RATE RESOLUTION | £.7 M/SEC | HELICOPTER ROTORS |
| RANGE RESOLUTION | 25 cm | RETRO REFLECTOR |

# INTEGRATION OF SHOTS AND AAS LASER

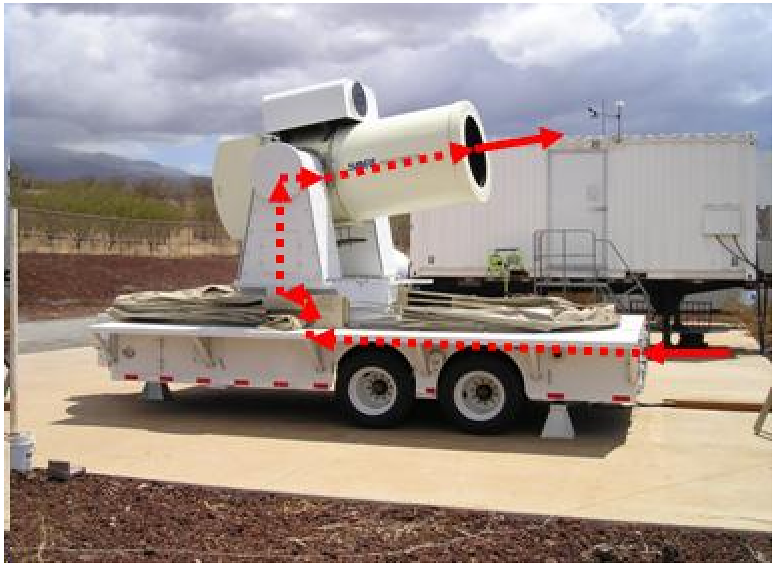


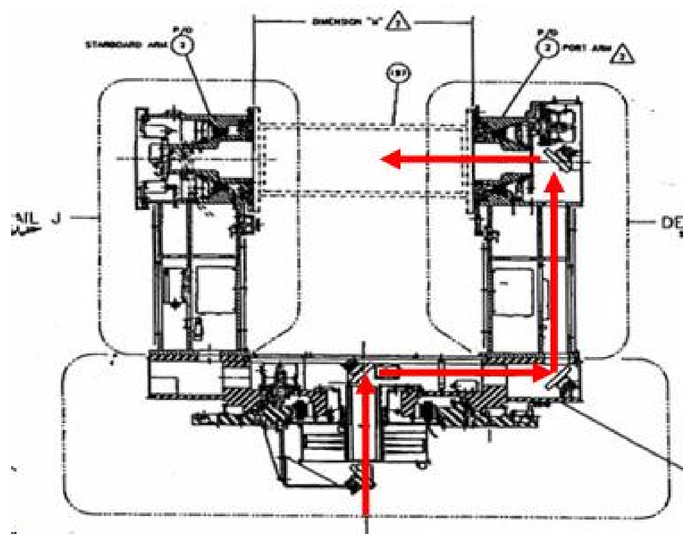
# AAS/SHOTS Conceptual Layout



AIM

# SHOTS Provides Coudé Path for AAS Integration





Existing Mirror Mount

# Ladar Integrates Major Components from AAS and SHOTS

- **SHOTS**
  - Large aperture (0.75 m) telescope for effective light collection; Coudé path for laser projection
  - Visible and MWIR sensors for acquisition, tracking and imaging
  - Mount control system
- **Advanced Airborne Sensor**
  - Dual waveform, coherent transmitter for precision ranging and imaging
  - Narrow and wideband, Doppler tracking, coherent receiver
  - Transmit-receive switch and “lead ahead/look back” hardware
  - Ladar data acquisition and control system
- **ONR contract provided Elements**
  - Beam transport optics
  - Mount control system modification for ladar “lead ahead/look back” capability

# AAS/SHOTS Operational Concept

- Preliminary concepts
- Track and lead-ahead with SHOTS
- Receiver Lag inside AAS
  - map SHOTS angles to detector
- Align AAS to SHOTS
  - internal AAS alignment
  - transfer align AAS visible tracker to SHOTS tracker
- Evaluate alignment stability

# SHOTS / AAS LADAR PERFORMANCE PREDICTIONS

AIM

# SHOTS / AAS LADAR CAPABILITIES

- AAS / SHOTS integration will
  - Produce a high-resolution, multi-spectral sensor with 3-D trajectory measurement capability
  - Provide high sensitivity, precision metric capability and maintain SHOTS optics capability
  - Provide a single sensor, high precision, 3-D target position / velocity estimate
  - Provide, with a wavelength agility upgrade, ability to detect high altitude chemical agent dispersal

TEXTRON Systems

AIM

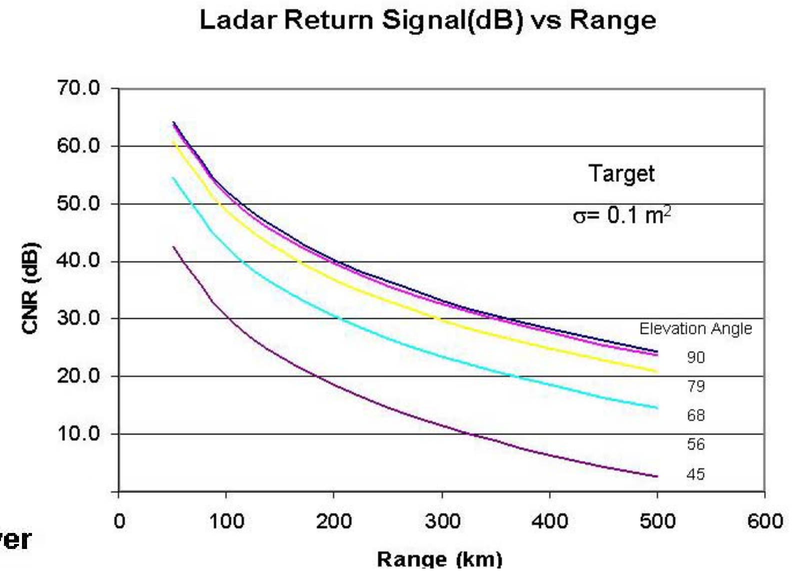
# AAS / SHOTS Provides High Sensitivity, Precision Metric Capability While Maintaining SHOTS Passive Sensor Suite

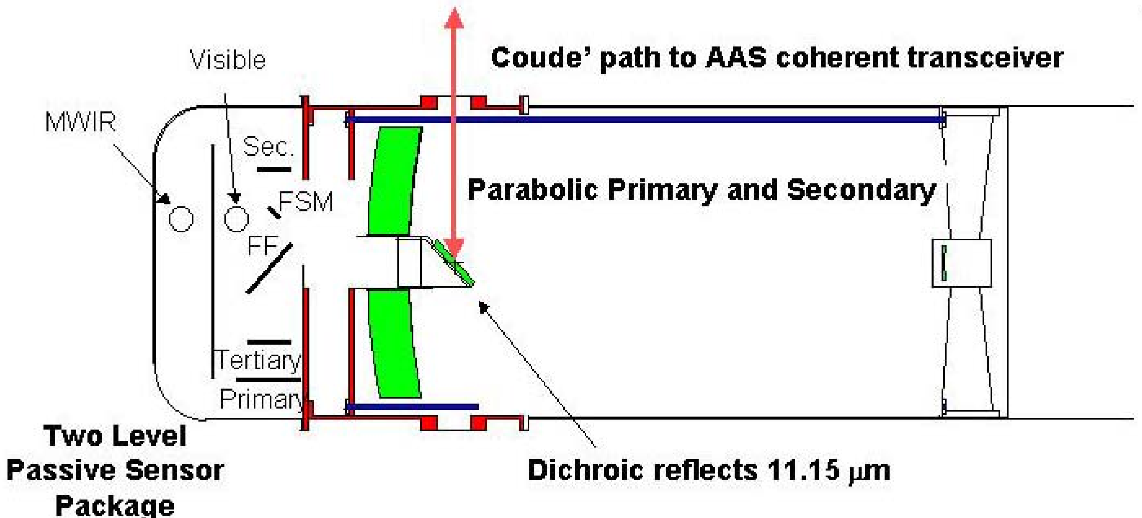
**Range accuracy**

- **Pulse-tone waveform - 16 m (current)**
  **~ 4 m (upgraded)**
- **Pulse-burst waveform – 0.2 m**

**Accurate range rate determination**

- **Pulse-tone/pulse-burst – 0.25 m/s**




**Visible and MWIR capability retained while operating LWIR coherent ladar**

TEXTRON Systems

# AIM

## AAS/SHOTS Integrated System Provides Single Sensor, High Precision, 3-D Target Position/Velocity Estimate

**Range accuracy (ΔR)**

**16 m(today)/4 m upgraded (pulse-tone mode)**

**0.25 m (today - pulse-burst mode)**

**Azimuthal and elevation angle accuracy**

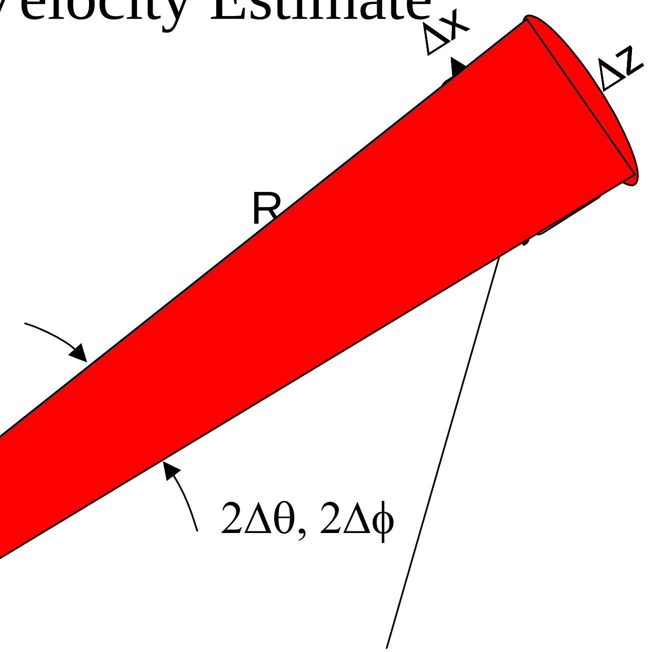
**$\Delta\theta$, $\Delta\phi \sim \lambda/D$ = 15 μrad**

**Range rate accuracy**

**0.25 m/s (pulse-tone and pulse-burst mode**

**Az/El angular rate accuracy**

**Current SHOTS capability**




**Uncertainty Volume Dimensions**

**$\Delta z = \Delta R$ = 17 m/0.25 m**

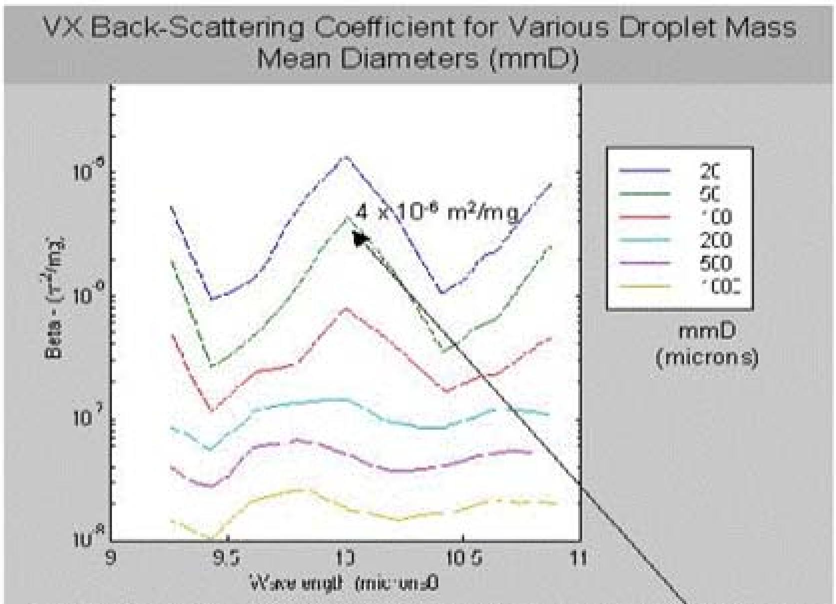
**$\Delta x = R\,\Delta\theta$ = 6.0 m @ 400 km**

**$\Delta y = R\,\Delta\phi$ = 6.0 m @ 400 km**

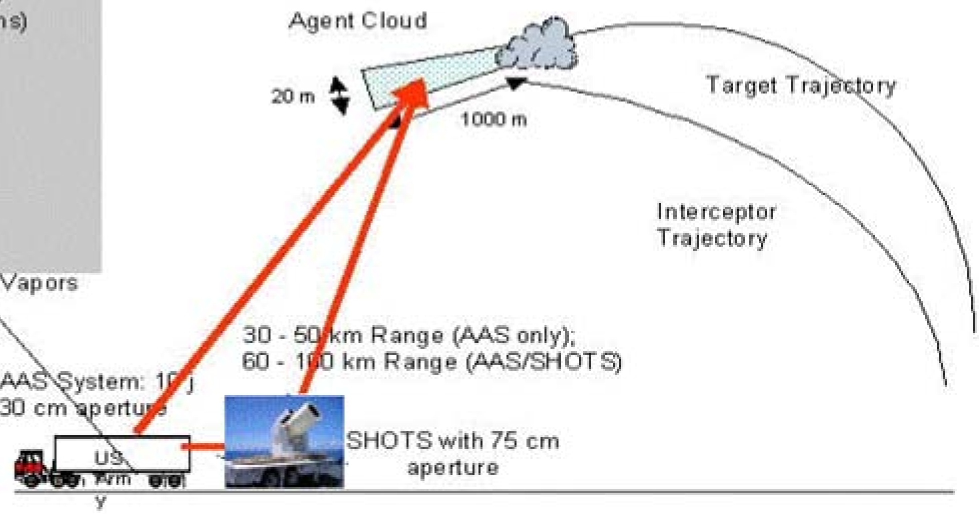
**TEXTRON Systems**

# AIM

## AAS/SHOTS With Wavelength Agility Upgrade Could Detect High Altitude Chemical Agent Dispersal




Dennis F. Flanigan, The Spectral Signatures of Chemical Agent Vapors and Aerosols, CRDC-TR-85002, April 1985




CNR ~35 dB for 150 kg VX dispersed within 20 m diameter x 1000 m long cloud (500 mg/m$^3$) having a 50µm mmD particle size distribution

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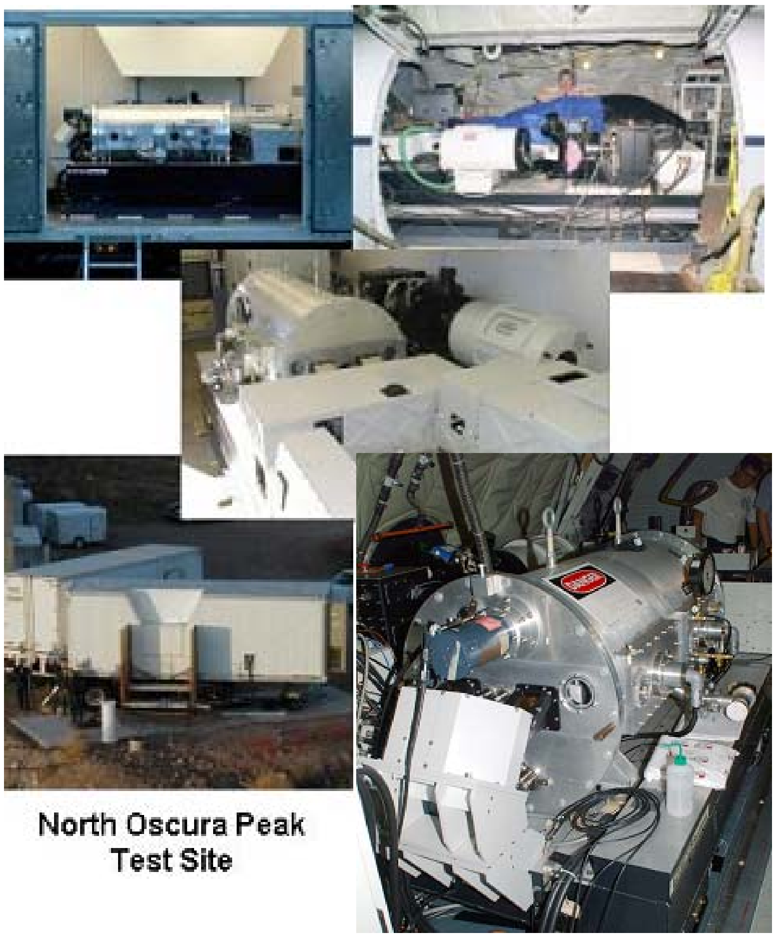
# AAS and SHOTS Hardware have been Demonstrated in the Field



North Oscura Peak Test Site

Obtained data on board MATSS in support of FM-6 , SRALT and FM-7, FM-8, JCTV-1

**SHOTS PMRF**

Obtained data at PMRF in support of FM-8, JCTV-1

# Integration Status

- Ship AAS laser from Massachusetts to Pacific Missile Range Facility, Kauai, Hawaii Spring 2006
- Fiberglass shelter for laser is complete
- Software modifications to upgrade tracking system in progress
- Full operation expected in late 2006 / early 2007

# SUMMARY

- SHOTS is a valuable stand alone optical asset to PMRF
- AAS laser will add the ability to acquire range, range rate, and Doppler imagery
- SHOTS optical imagery data acquisition will not be degraded