Aircraft Spotting System for Laser Guide Star Safety

W. Thomas Roberts[a], and Brian Smithgall[b]

[a] Jet Propulsion Laboratory, California Institute of Technology, MS 161-135, Pasadena, CA 91109

[b] Image labs International, 151 Evergreen Drive, Bozeman, MT 59715

Objective:To develop a laser safety system which can reliably detect aircraft near the laser beam and shutter the laser system in time to avoid accidental illumination of the aircraft.

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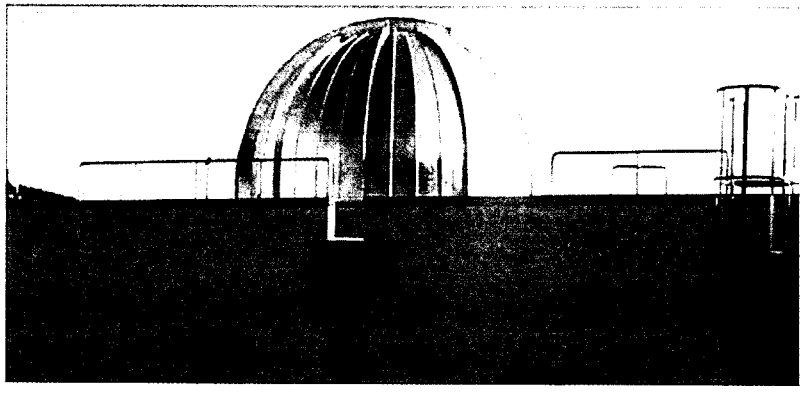
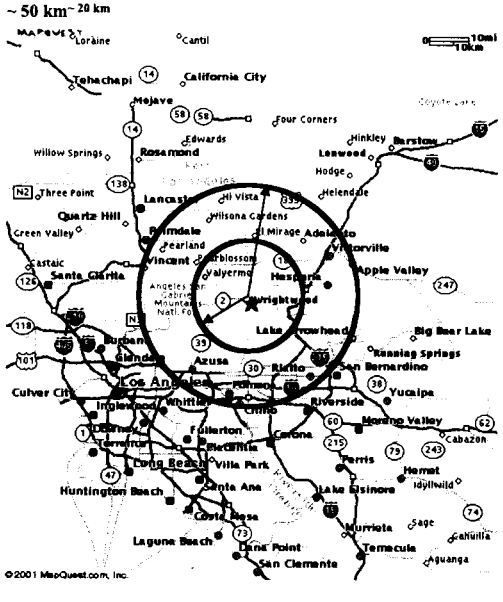
OCTL Facility

Optical Communications Research Laboratory





- At 7500 ft. outside Wrightwood, CA
  - 40 mi. from EAFB
  - Beneath V210 and V137 airways
- Planning for laser signals across wide spectrum
  - Q-switched 532 nm Nd:YAG
  - CW 589 nm Laser Guide Star
  - QCW 850 nm Comm Signal
  - Q-switched 1064 nm Nd:YAG
  - QCW 1550 nm Comm Signal

System Requirements

JPL

- Operational Conditions
  - Day and night operation
  - Full sky coverage
    - Excluding region within 30 degrees of sun
    - Excluding region within 20 degrees of horizon
  - Free of clouds within 15 degrees of beam
  - Bright stationary objects may be within FOV
  - Operate during telescope slewing up to 0.75 deg/sec
- Objects of concern
  - All aircraft within 300-3000 m range
- System Requirements
  - User modifiable threat identification and operational parameters
  - Real time logging of threat encounter events
  - Real time image recording of threat encounter events
  - Automatic reset and retransmit after threat is passed

Expected Aircraft Parameters

Type	Size	Speed	Altitude
Civil	Small (1-10 m^2)	Slow (50 m/sec)	1000-10,000 ft AGL
Commercial	Large (100 m^2)	Fast (100-200 m/sec)	> 3000 ft AGL
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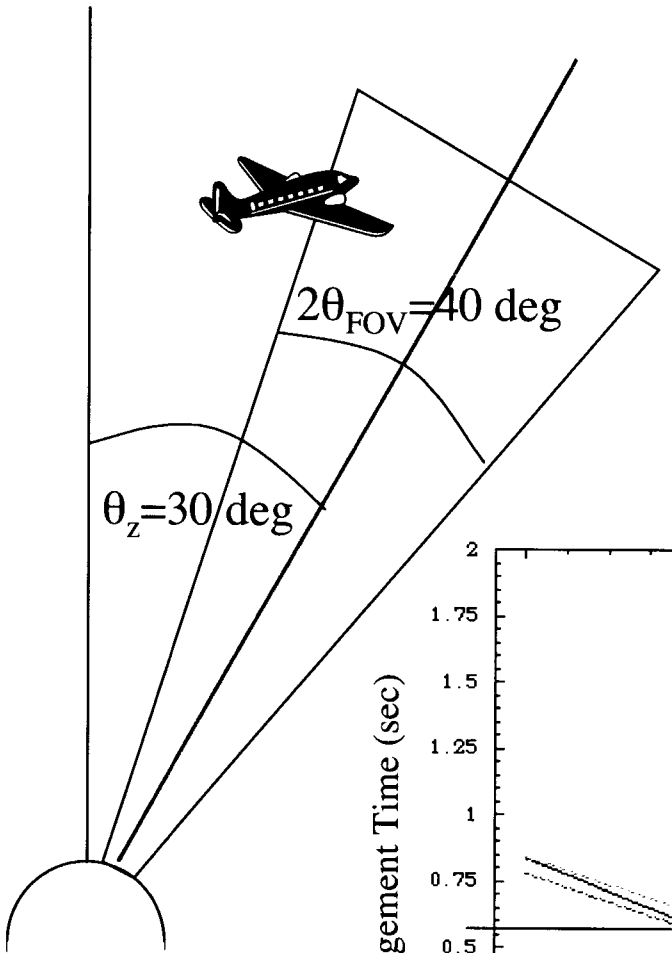
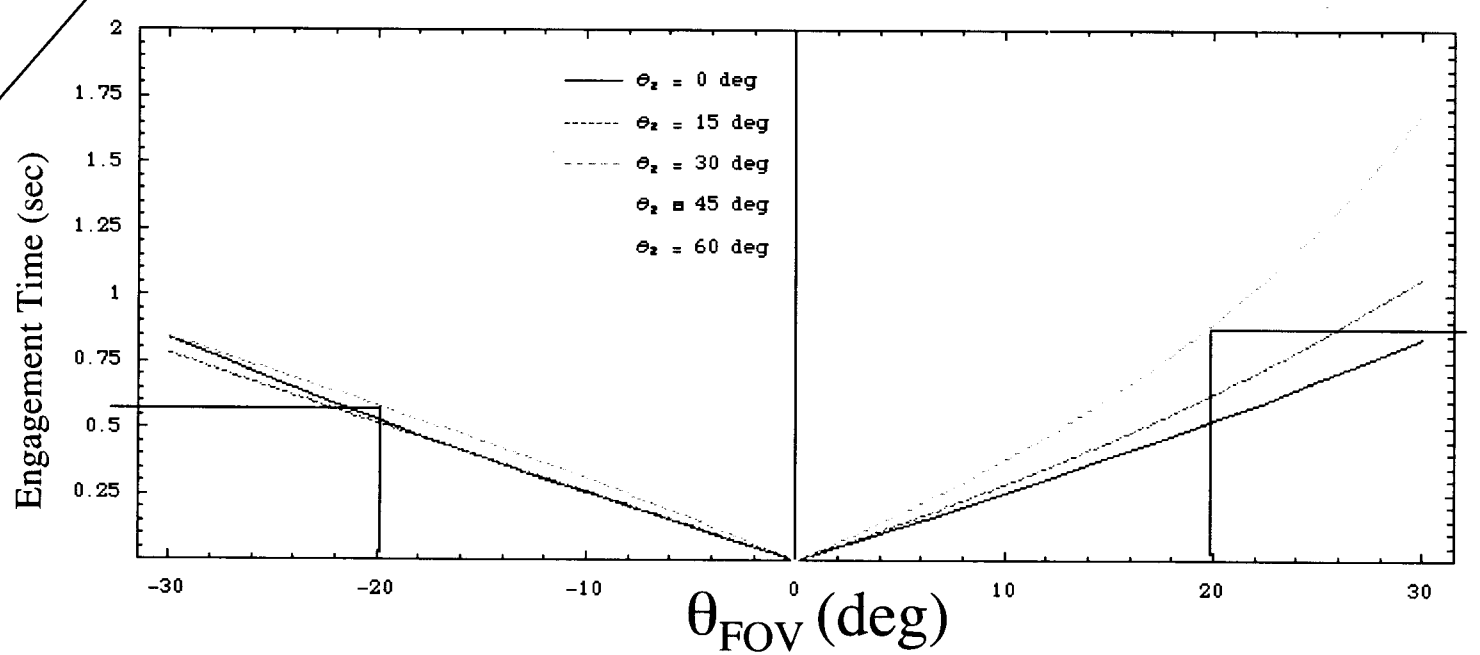
Camera FOV vs. Engagement Time

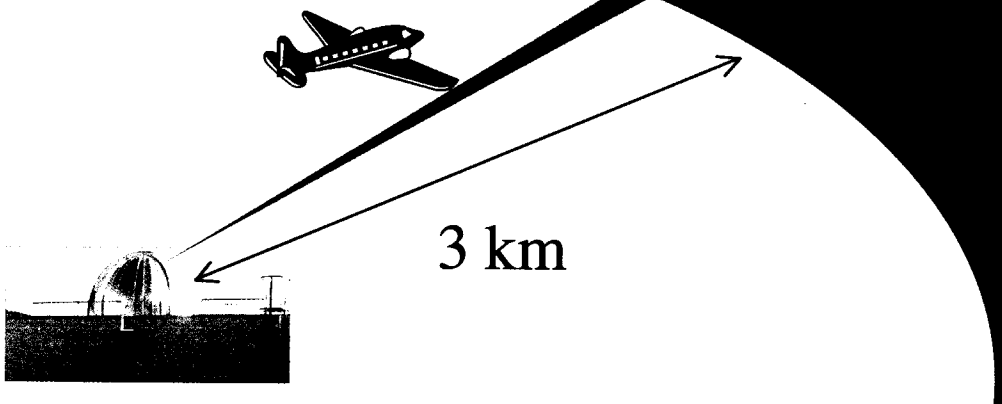


- Reaction time from aircraft entering FOV to encountering laser changes with zenith angle θ_z
- For aircraft flying at speeds of 400 knots and altitudes of 300 m (1000 ft.) most stressing engagements have reaction times of just over 0.5 seconds
- At the same altitude and speed, an aircraft flying into the beam from the right has nearly 1 second



Multi-Tiered Approach

- Laser safety is apportioned according to an approach which breaks the threat up into four overlapping regions
  - Tier 0 - internal OCTL personnel safety
  - Tier 1 - short-range aerial safety
  - Tier 2 - long-range aerial safety
  - Tier 3 - space asset protection



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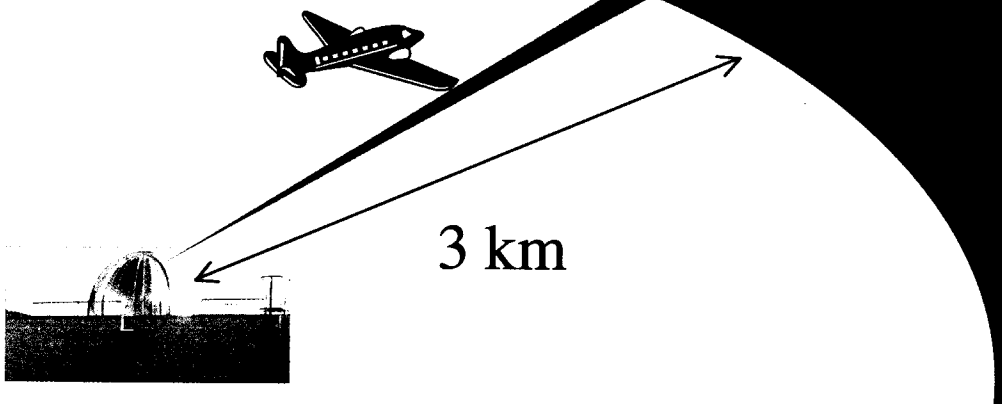

Advantages of LWIR Imager

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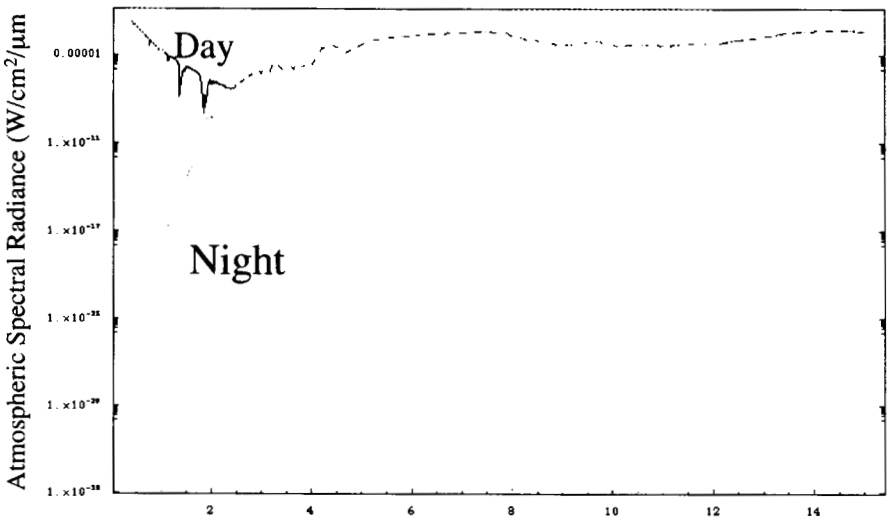
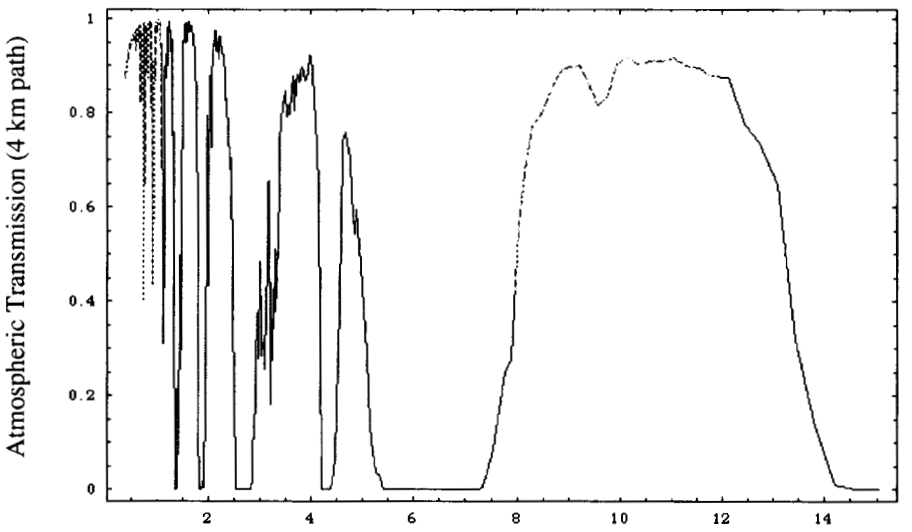
- Passive aircraft acquisition
  - No interference with flight operations or navigation systems
  - Does not require interrogation signal propagation time
- Consistent type of signal
  - Picks up thermal emissions from all objects
    - Aircraft lights not required
    - Aircraft transponder not required
  - Provides strong, consistent contrast with dark sky
    - Contrast unaffected by solar angle
    - Contrast unaffected by lighting conditions
  - Little scattered background from sky in LWIR
  - Good transmission of LWIR signals through haze
- Operates undamaged with sun in FOV

Atmospheric Spectral Properties



- In visible and near-IR bands daylight scattering is very strong
- No significant difference between day and night in LWIR
- Less scatter of light in daytime, from haze

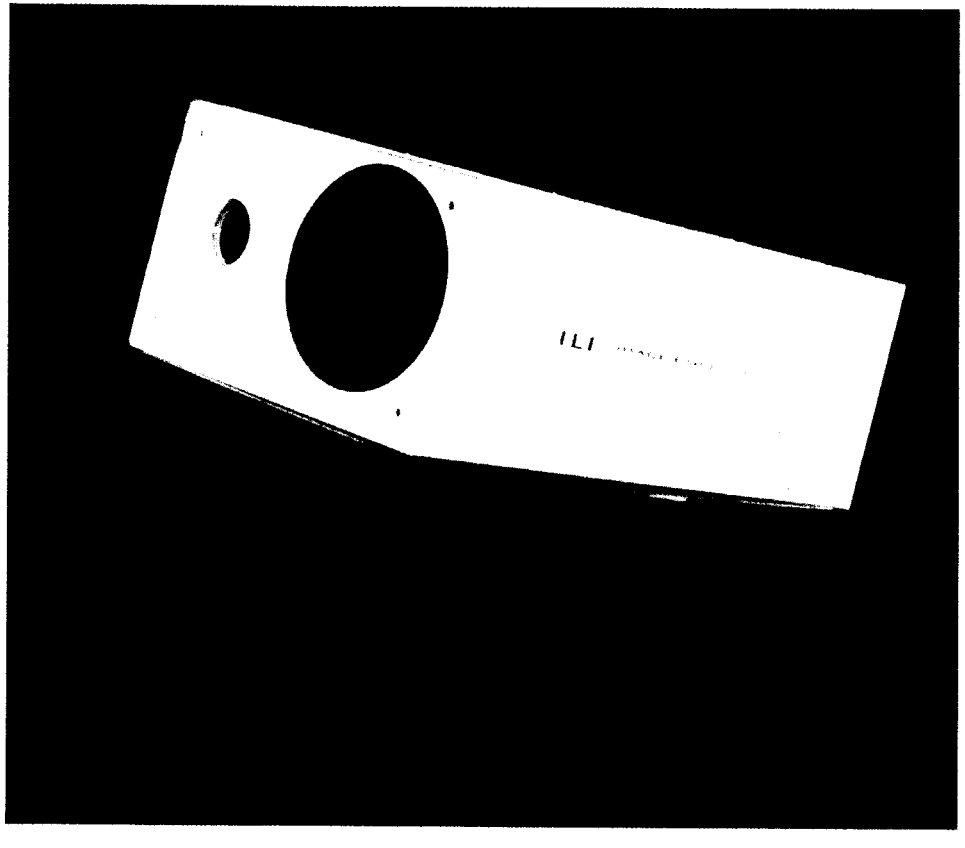
- Excellent atmospheric transmission in LWIR window



Candidate LWIR Arrays

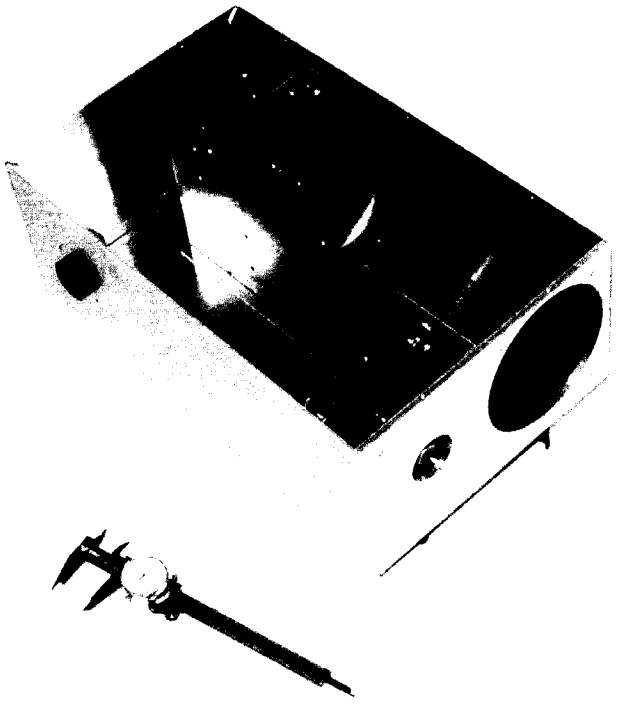
Type	Operation Principles	Array Sizes	Sensitivity	Spectral Range	Issues and Comments
QWIP (Quantum Well)	Epitaxially grown quantum wells allow for tuning of potential well depth for tailored bandgap	1000 x 1000	8-10 mK	8-9 μm	•Requires Stirling cooler – (reliability and lifetime) •Cost ($50-100 K)
HgCdTe	Admixture of two materials (HgTe and CdTe) with different bandgaps allows for tailoring of bandgap	640 x 480		8-12 μm	•Requires Stirling cooler •Uniformity issues •Cost
Micro-bolometer	MEMS technology allows production of bolometer array in which absorbed IR radiation heats elements leading to change in resistivity		70-200 mK	7-14 μm	•Fixed pattern noise •Periodic reset
BST	Resonant optical cavity	320 x 240	130 mK	7-14 μm	•High crosstalk lowers MTF •Halo effect

Optical Head



- WFOV Camera
  - F/1 18 mm Ge lens
  - 35x46 deg FOV
- NFOV Camera
  - F/1 75 mm Ge lens
  - Recessed for improved imaging in sunlight conditions
  - 9x12 deg FOV
- Single cable handles all power and signals to main processor
- Total weight 5 kg
- Total power < 15 W

LWIR Camera Head



Assembly Before Painting

- NFOV camera recessed for baffling
- WFOV camera flush-mounted for full field
- Both cameras rigidly mounted to structural plates
- Single cable supplies power, commands and returns data

Dual Algorithm Approach

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- To detect all objects of concern, the system uses two concurrent algorithms
  - Sensitive algorithm
    - Operates on NFOV camera
    - Identifies objects with weaker signatures
    - Establishes a track across multiple frames
    - Shutters laser when track intersects narrow exclusion zone
    - Generates shutdown signal within <430 msec of aircraft encountering edge of FOV
  - Quick algorithm
    - shutters laser whenever a large bright image appears too close to the laser beam
    - Operates on data from both cameras
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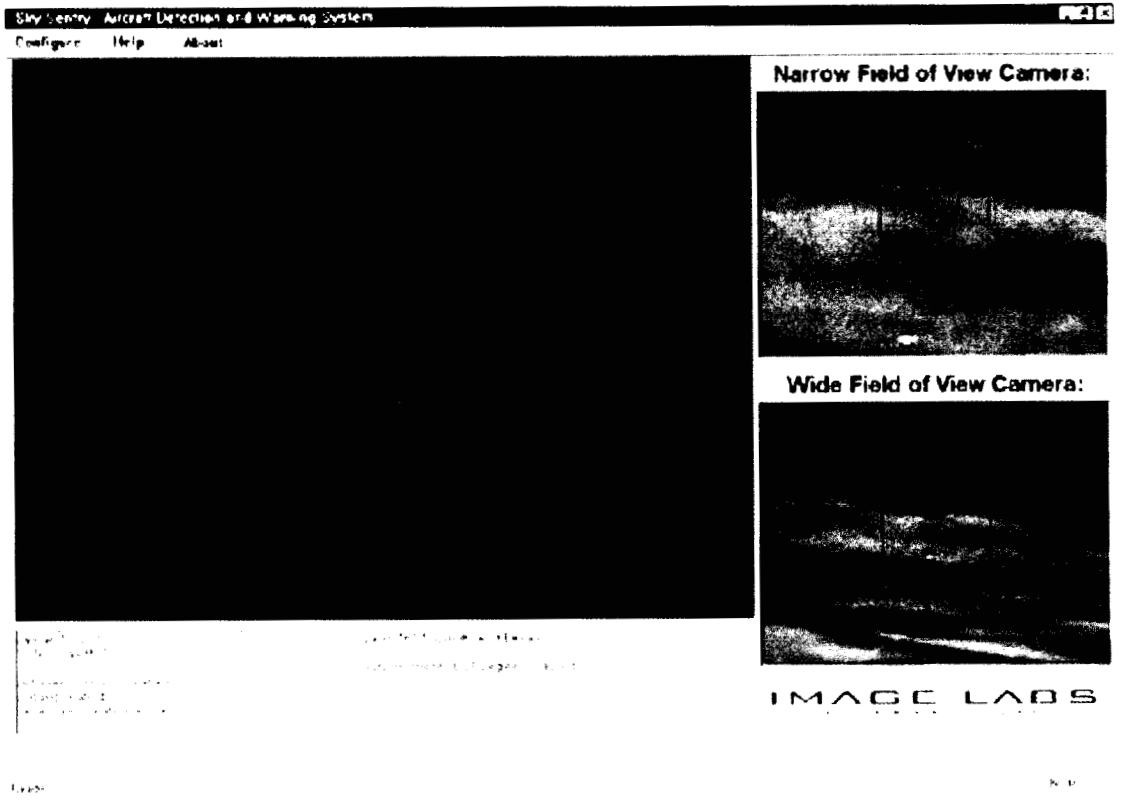
System Screen Display



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- Bright targets appear white on screen
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- Main window shows identified objects of concern
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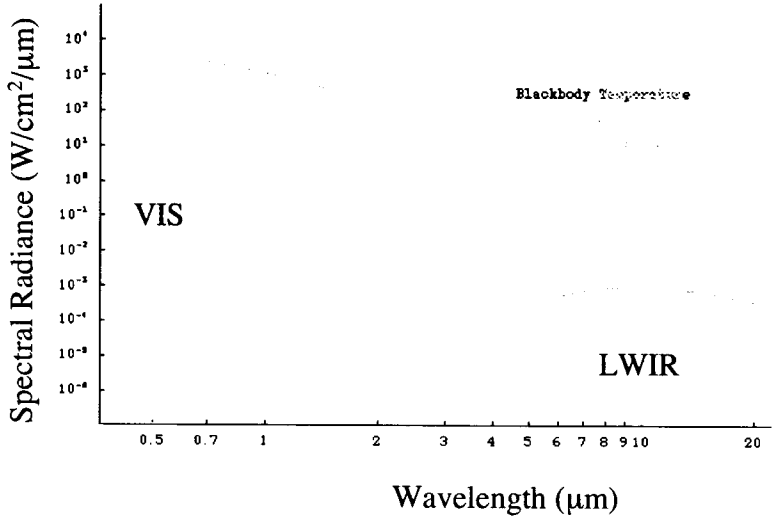
Helicopter Signature

- Small helicopter at 2 mile range
- F/1 lens on NFOV camera
- Stands out despite significant cloud cover
- Bright objects at edge of FOV do not reset gain in entire image

Operation with Sun in FOV



- Enormous differences between radiance of Sun and room-temperature objects in visible wavelengths is not so pronounced at LWIR wavelengths
- Image of sun on NFOV camera
  - Persistence trails remain for approx 30 sec
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Summary

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- The LWIR aircraft spotting system is designed to observe all aircraft within a 3-km range of the OCTL facility
- LWIR imagers were chosen primarily for the requirement to operate during day and night
- Two LWIR imaging cameras are used
  - NFOV to detect low-radiance aircraft at range
  - WFOV to detect fast, low-flying aircraft
- Two real-time detection algorithms assure detection of aircraft
  - Sensitive algorithm detects motion in static (or uniformly moving) scene
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- Operational test and evaluation has so far demonstrated successful acquisition, track and shutdown against all tested targets under anticipated operating conditions

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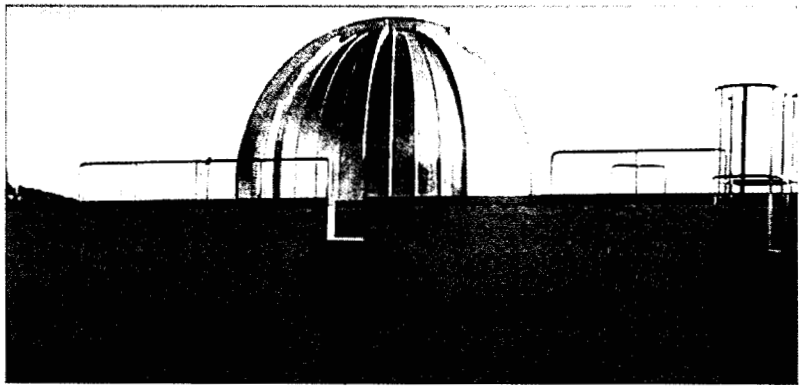

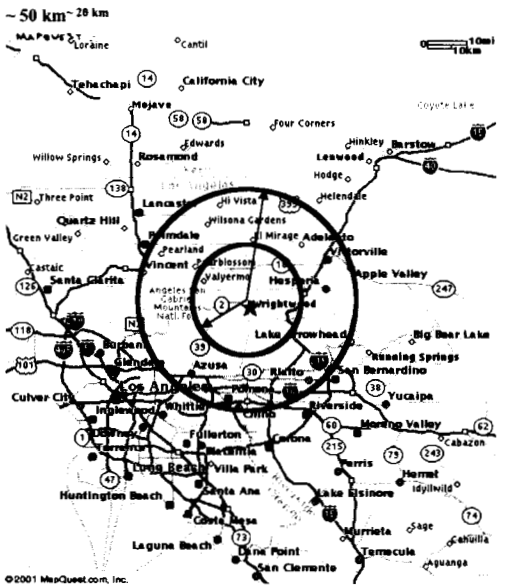

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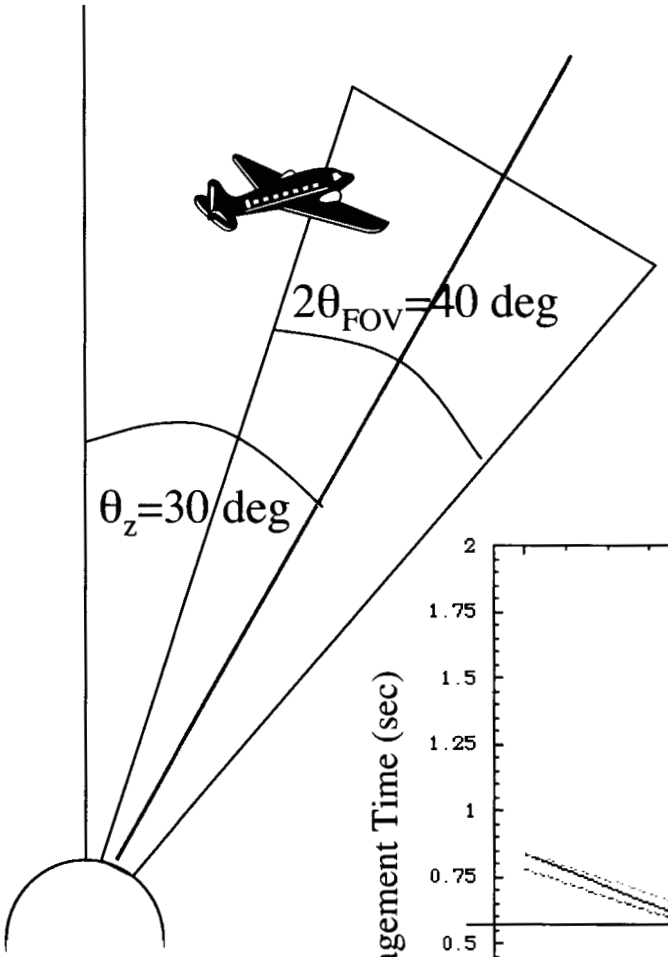

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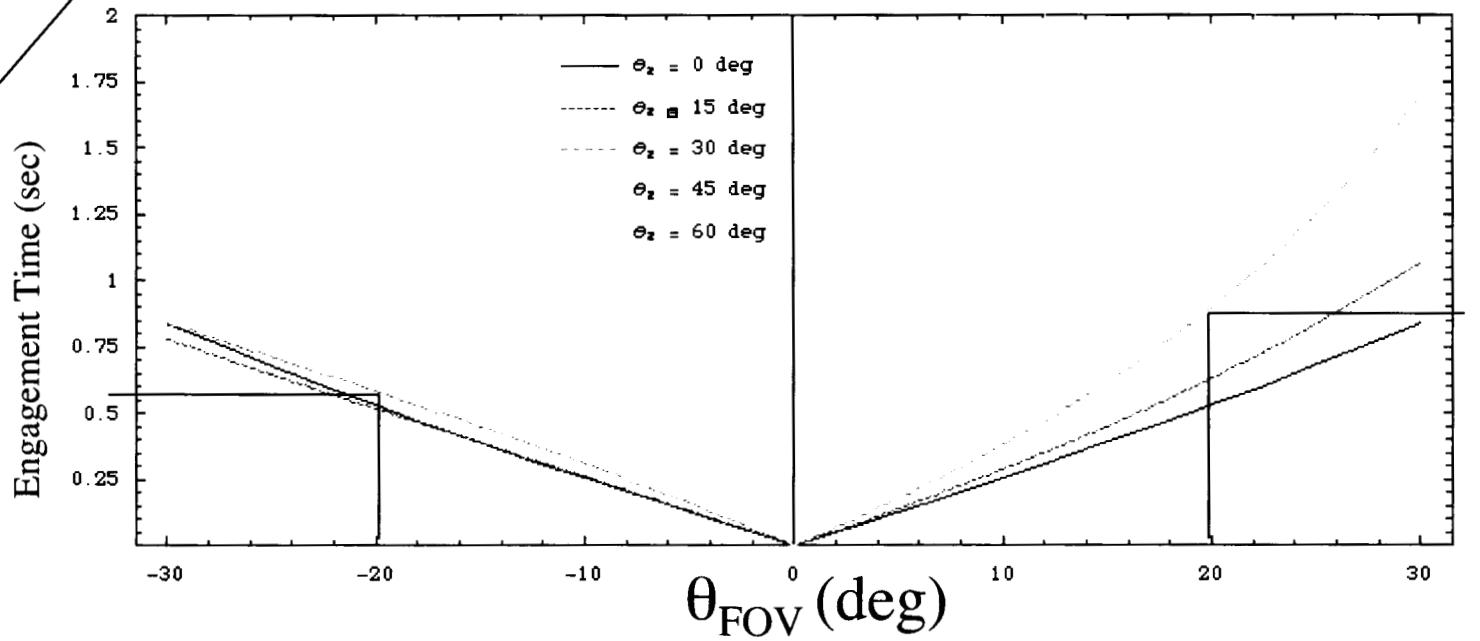

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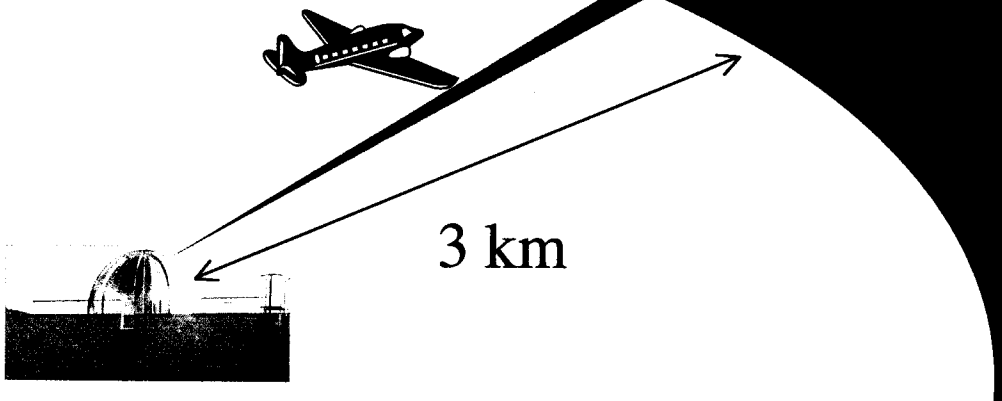

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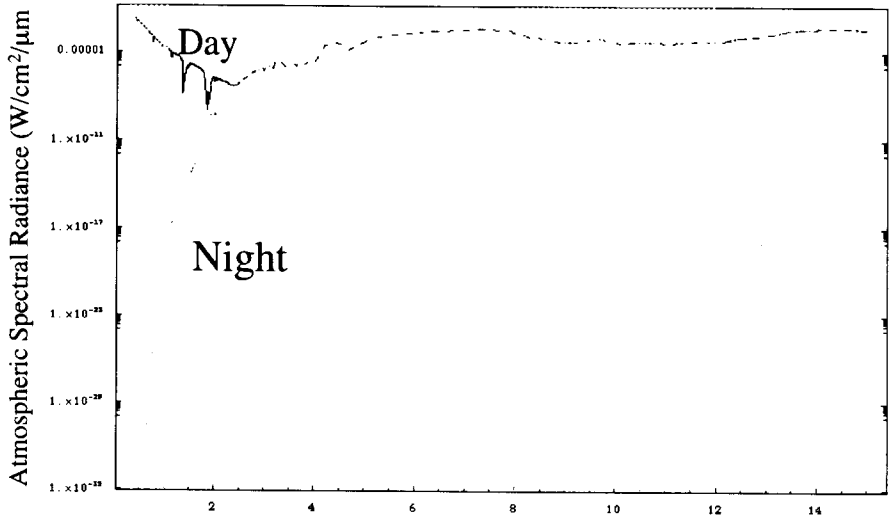

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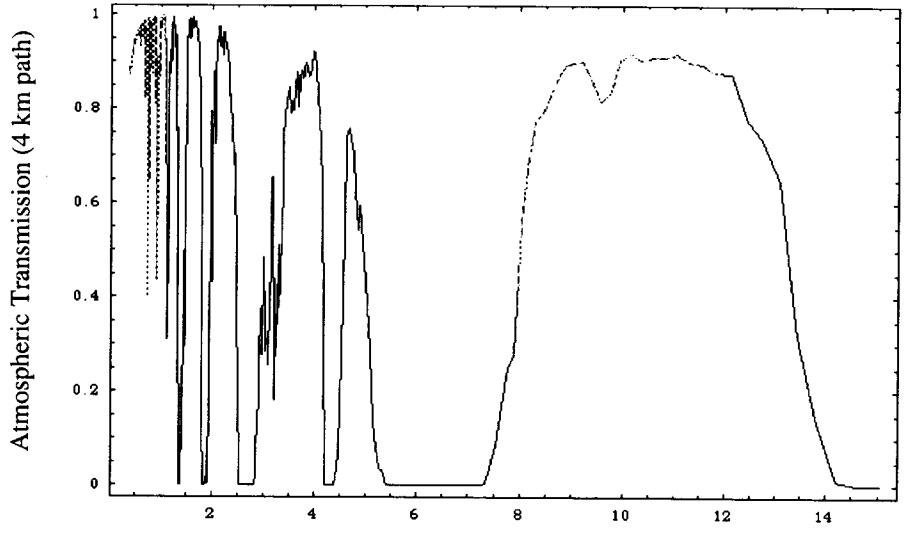

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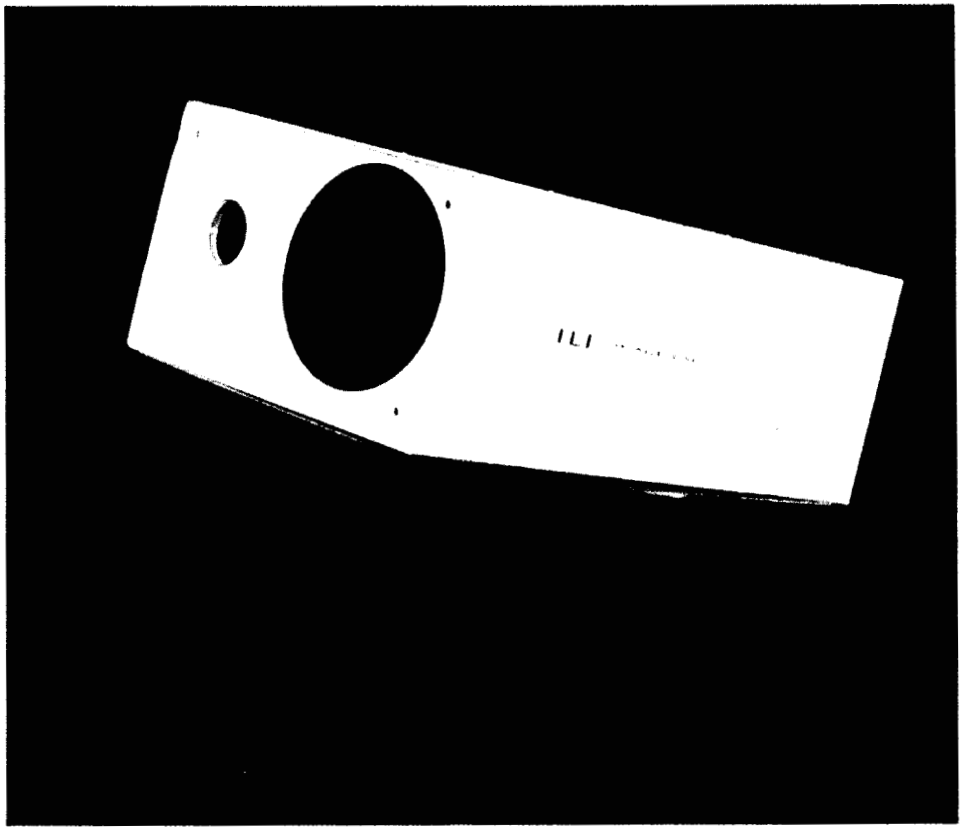

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- NFOV Camera
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  - Recessed for improved imaging in sunlight conditions
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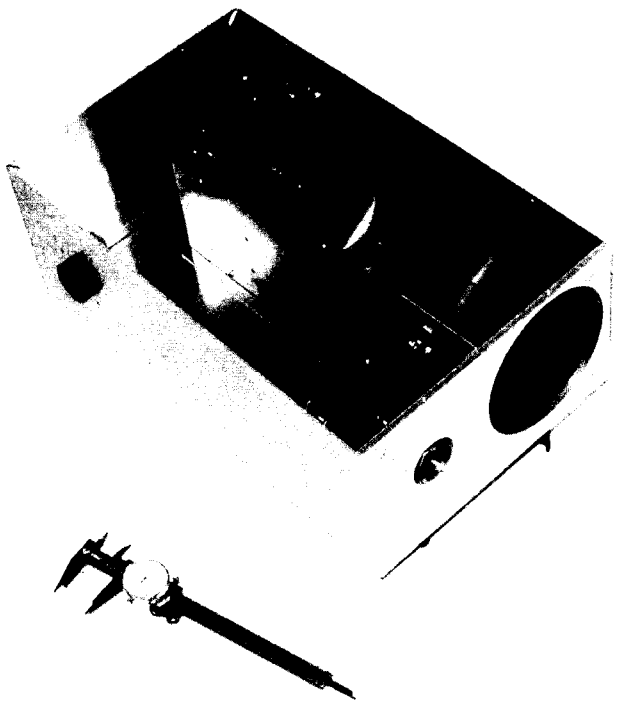

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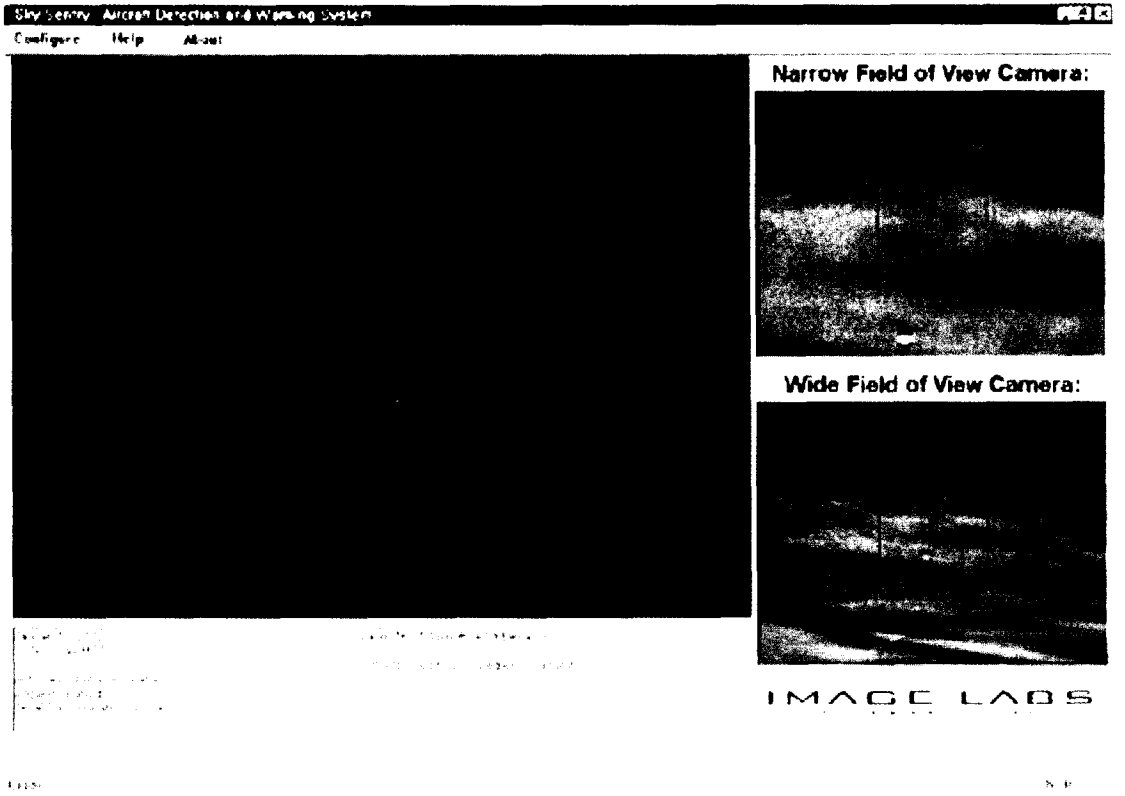

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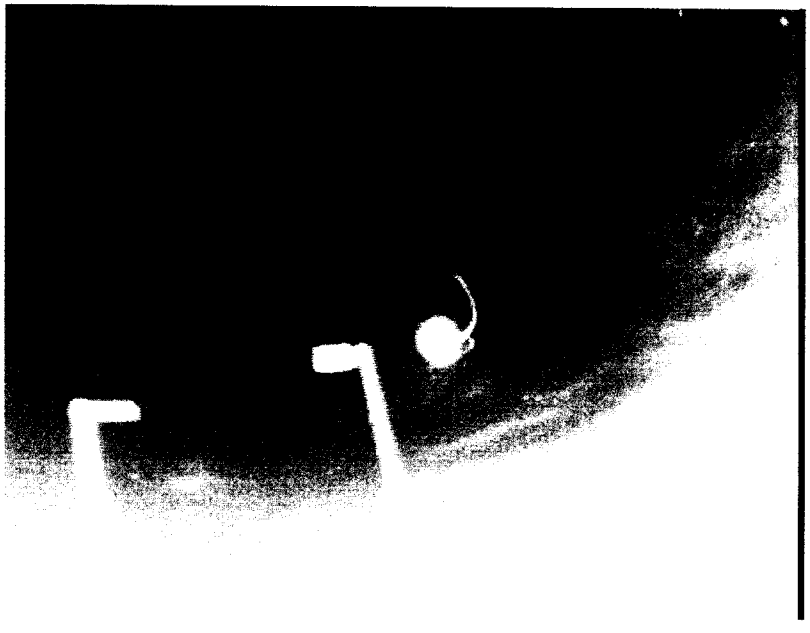

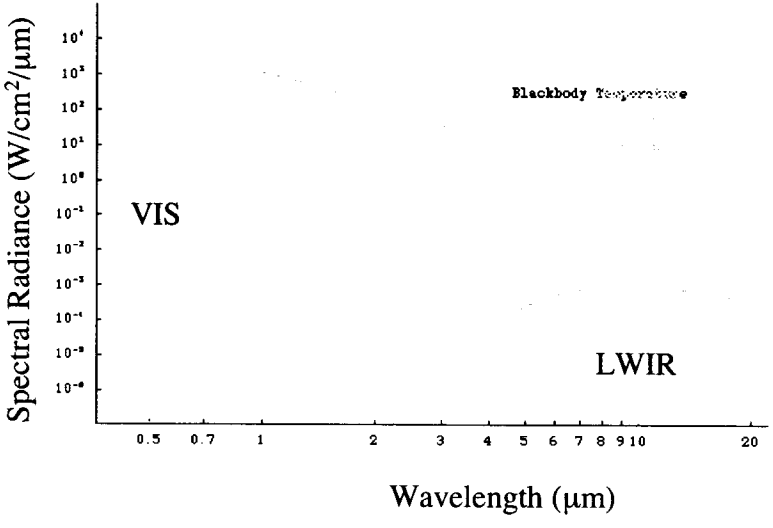

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