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INFRARED THERMAL IMAGING OF ATMOSPHERIC TUBULENCE

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ABSTRACT

A technique for analyzing infrared atmoshperic images to obtain cross-wind measurements is presented. The technique is based on Taylor's forzen turbulence hypothesis and uses cross-correlation of successive images to obtain a measure of the cross-wind velocity in a localized focal region. The technique is appealing because it can possibly be combined with other IR forward look capabilities and may provide information about turbulence intensity. The paper describes the current research effort, its theoretical basis, and its applicability to wind shear detection.

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Image Cross-Corelation for Atmospheric Wind Measurement: Review of Work in Progress

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GOALS

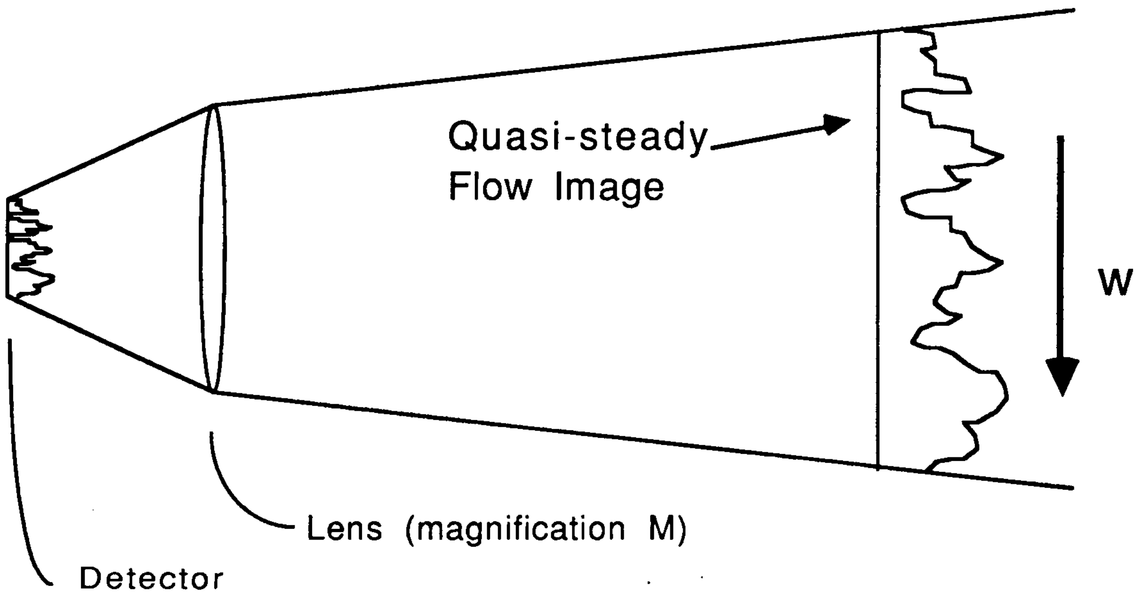
- Primary goal is to develop a predictive on-board windshear detection device

The desired specifications of a future detection system include

1. Capable of detecting 1-2 kilometers ahead of plane
2. Capable of obtaining some measure of the NASA/FAA hazard index.
3. Monitor crosswind by image anaylsis.

APPROACH

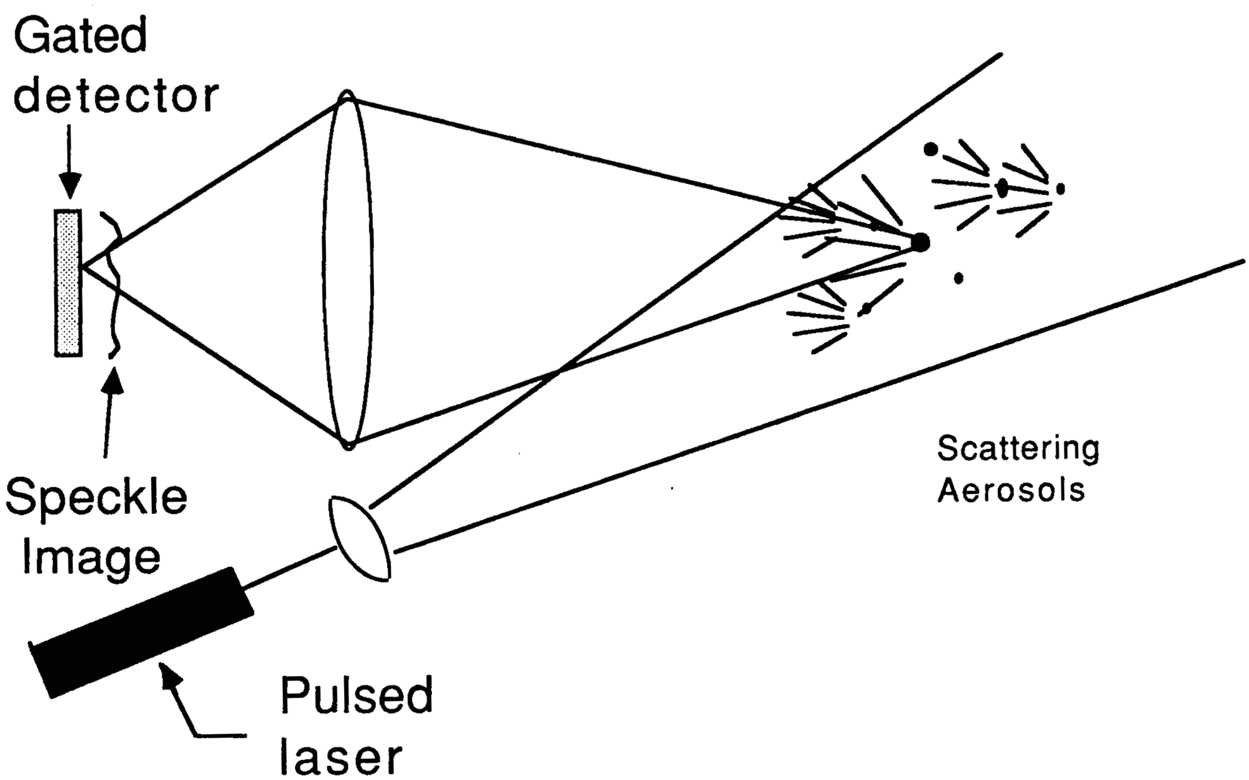
Image Cross-correlation Velocimetry



- Taylor's "Frozen Turbulence" Assumption:
  1) Flow image moves at dominant velocity scale.
  2) Fine scales change slowly, Flow image steady
- Velocity determined comparing two successive images within short time interval.
- Comparison mechanism is cross correlation function.
- Continuously monitor cross-wind velocity.
- Images generated by various optical phenomena.

Quasi-Steady Turbulence Generated Images

Laser Speckle



* Speckle is coherence artifact

* Steady Scattering and Refractive Index Field

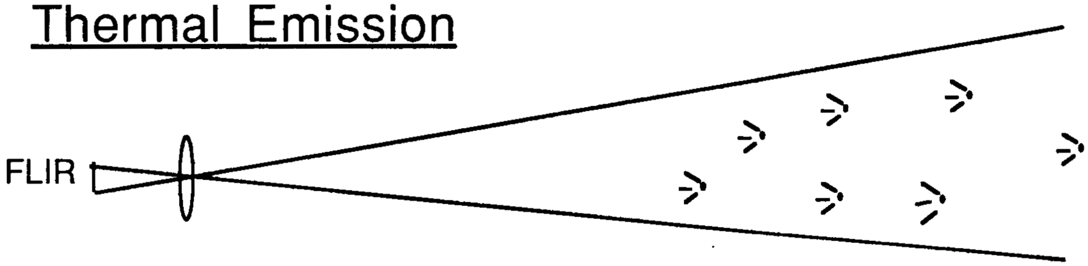
* Requires laser & gated detector for ranging

* Ranging by time of flight during gating interval

* Could be integrated with lidar

Quasi-Steady Turbulence Generated Images (cont'd)

Thermal Emission



-Passive Detection

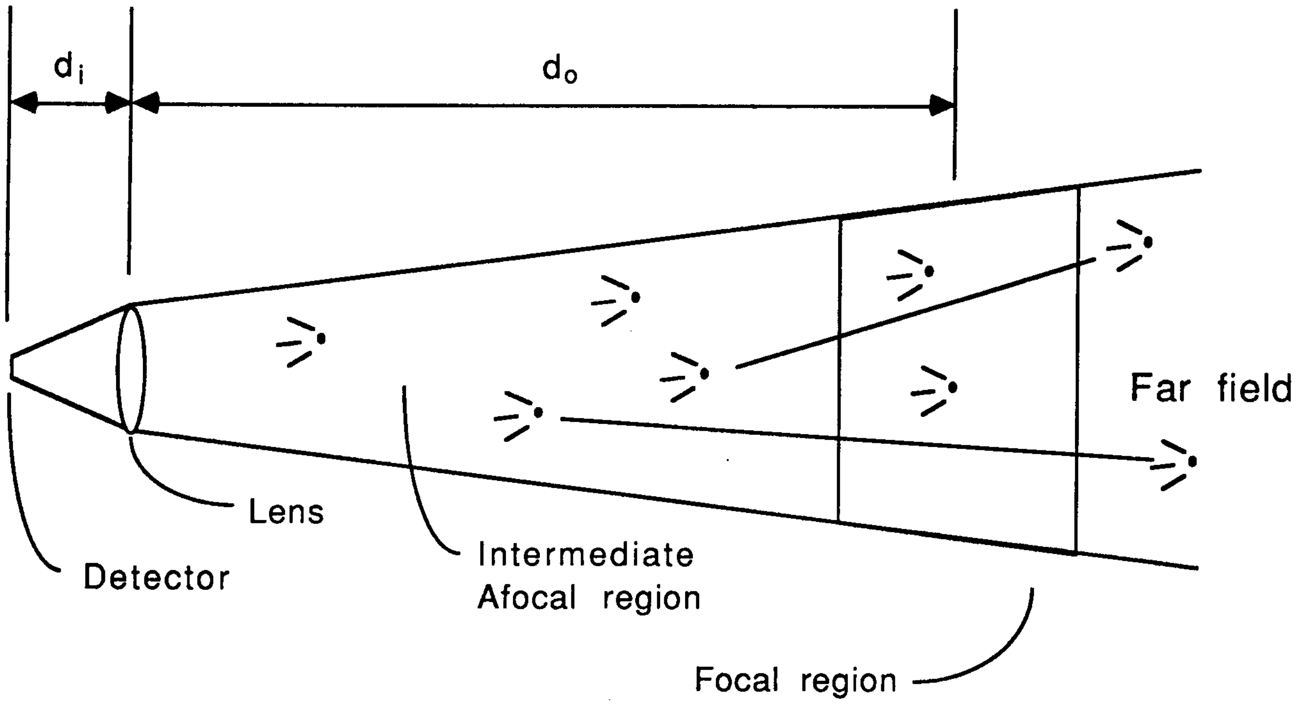
-IR intensity variation driven
by temperature fluctuations

-Images may provide other relevant information:
Turbulence Intensity
Temperature gradient

-Compatible with other aircraft
forward-look needs

-Signal strength to be evaluated in detection region

Passive IR Imaging In Absorbing-Emitting Media



Need to Isolate Focal Region

Far-field signal attenuated by atmospheric absorbtion

Signal from intermediate range is defocused.

Imaging Model

Radiative Transfer Equation

$$N = \int_{\nu}\int_{z}\int_{\omega} B(\omega, T)\ \phi(\nu)\ \frac{\partial\ \tau(\nu, z)}{\partial z}\ dz\ d\omega\ d\nu$$

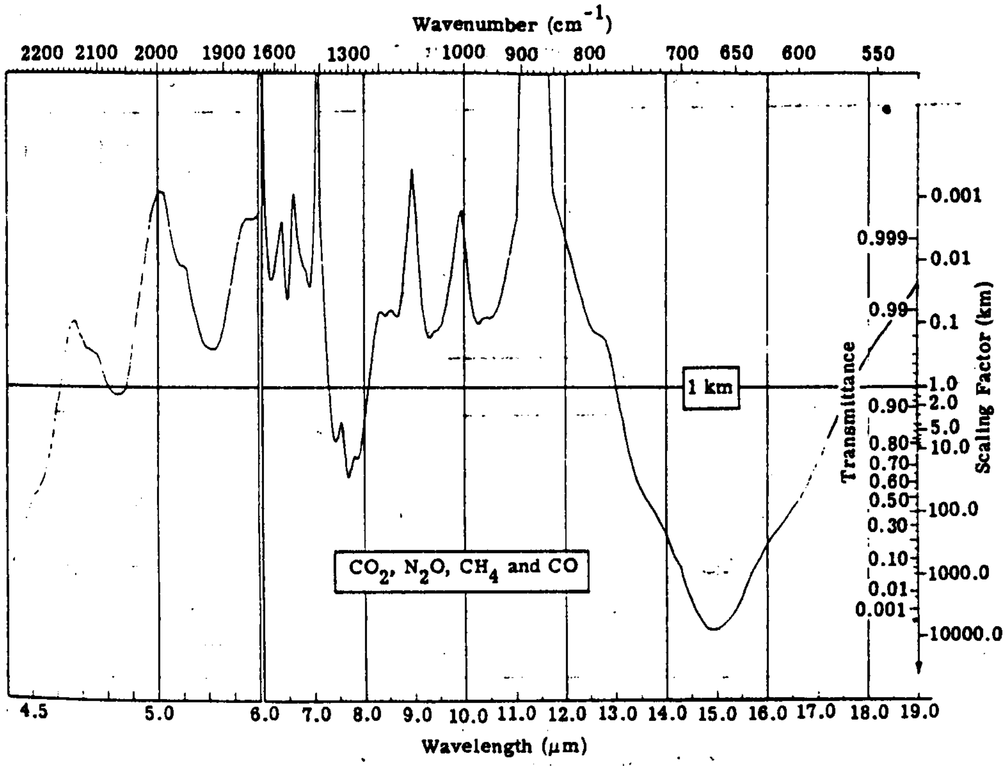
$B(\omega,T)$	=	Emitted and incident radiation
$\phi(\nu)$	=	Spectral transmittance of lens.
$\frac{\partial\ \tau(\nu,z)}{\partial z}$	=	Differential transmittance of atmosphere.
ω	=	Solid angle
N	=	Radiant flux onto detector pupil

Model Imaging Equation

$$i(x,y) = \iiint_{\omega(x,y,z)} h(x,y,z) * \underbrace{(\epsilon e_{b,\lambda}(x,y,z)\exp(-\alpha z))}_{\text{Model RTE}}\ dx\,dy\,dz$$

- h – point spread function
- ϵ – pointwise emissivity
- $e_{b,\lambda}$ – spectral emissive power
- $\omega(x,y)$–aperture solid angle
- $*$ –convolution

Emittance Calculation



(d) Transmittance of uniformly mixed gases (CO_2, N_2O, CO, CH_4, O_2) (4.5 to 19.0 μm).

Transmittance-Beer's Law

$$\tau_\lambda (z) = \exp(-a_\lambda z)$$

Absorptance -emittance

$$\varepsilon_\lambda = \alpha_\lambda = (1 - \tau_\lambda)$$

Local Emissivity

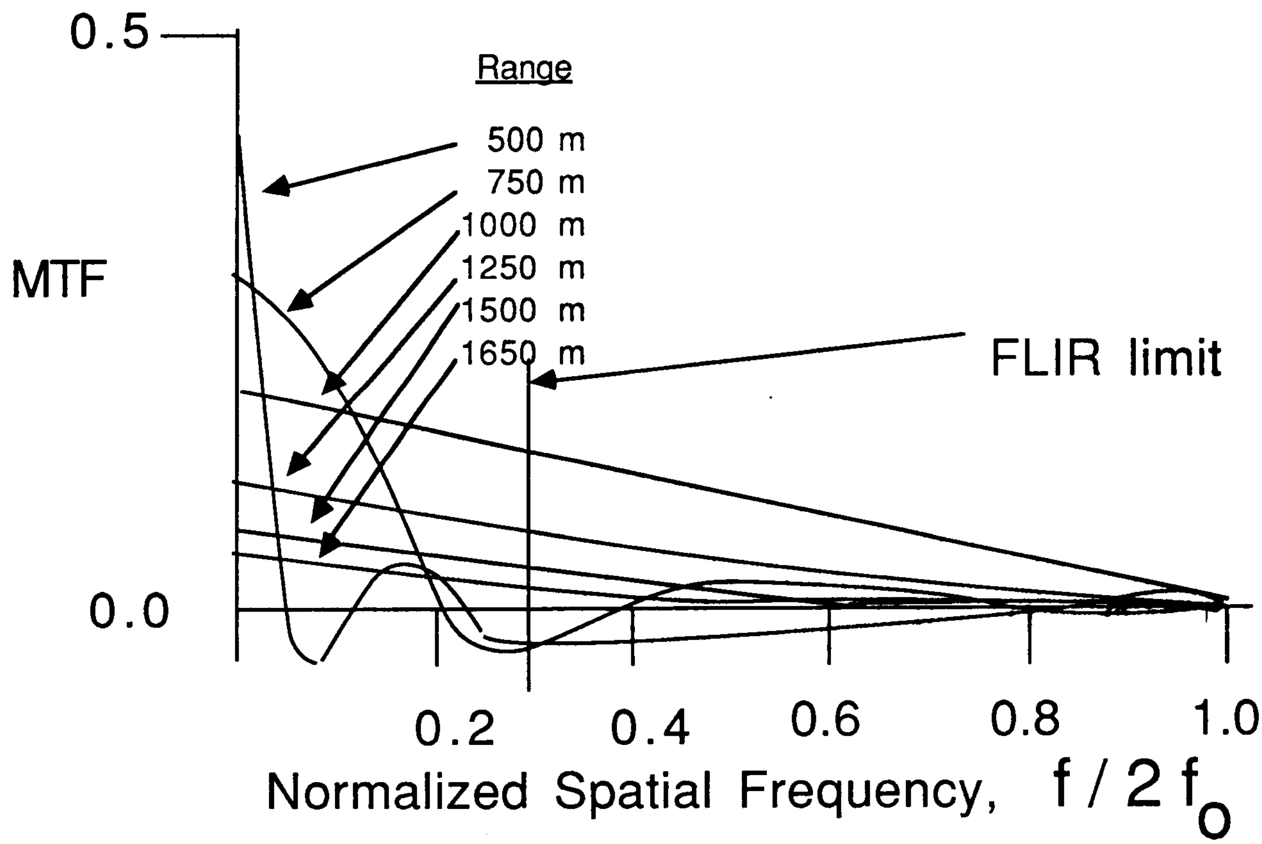
$$\varepsilon = 1 - \exp(-a\ \delta z)$$

$\delta z^3 =$ volume of resolution cell

Image Localization by Defocussing

Incoherent Imaging MTF, with atmospheric absorbtion

Target Distance- 1000m, 50cm f.l., f/1.0

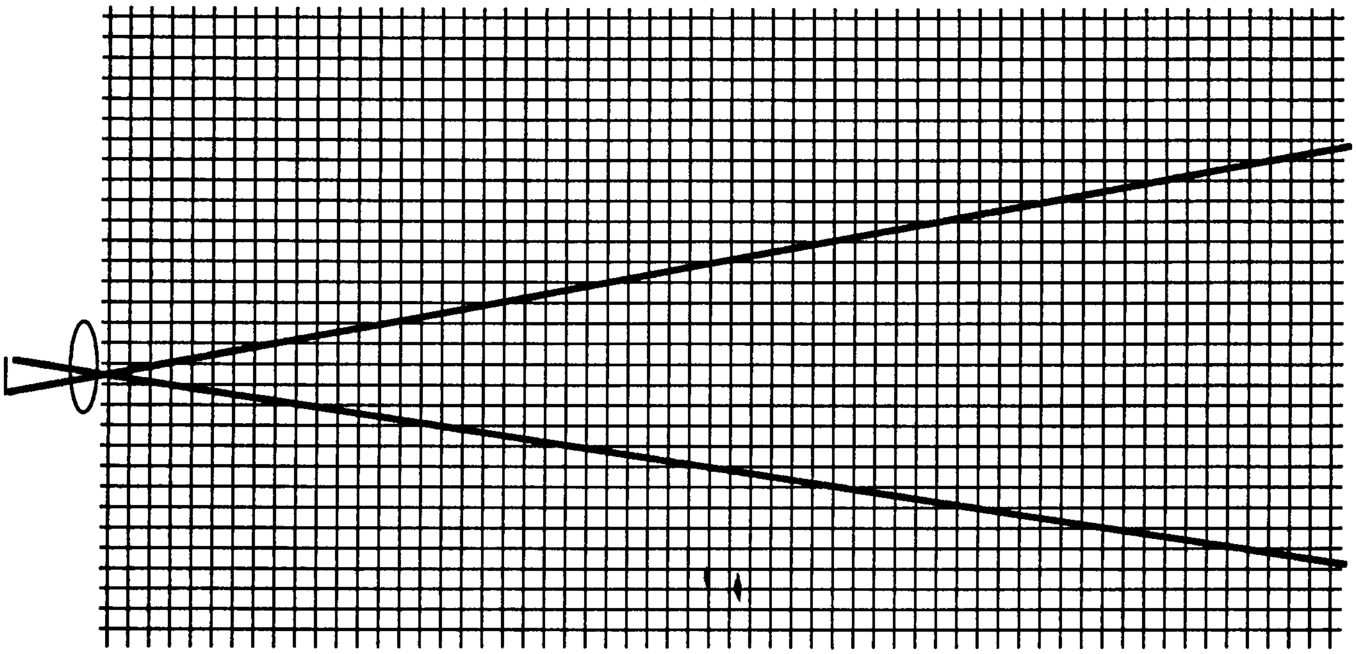


- At higher spatial frequencies, focal region contains most signal energy

- By high-pass spatial filtering signal can isolate focal region

- Upper limit imposed by sensitivity, spatial resolution of FLIR

Imaging Simulations



Model Features

--2-D Fractally Generated Temperature Field

--2 x 1 kilometers deep (1024 x 512 nodes)

--Uniform Emissivity and Absorptivity

--Intensity variation due to
temperature fluctuation only

--50 cm f.l., f /1.0 lens

-- $\lambda = 14\ \mu m$

-- Separate MTF calculated for each z location

-- Convection by rigid motion of all or part of

Preliminary Conclusions

- Convection does result in displacement of x-correlation peak
- Lens alone is not an adequate spatial filter to isolate target region, digital filtering is also necessary
- Image enhancement routines including trend removal and high pass spatial filtering needed to improve performance.
- Need Hg-Cd-Te FLIR detector to obtain adequate SNR

Future Work

- -- Assess the effects of refractive turbulence

- -- Adapt TASS Model for Imaging Simulation

  - --Develop Model of sub-grid temp. fluctuation

  - --Use standardized radiation model (HITRAN) to Account for precip. broad spectra.

  - --Several Flight Paths

- -- Obtain experimental FLIR images to assess suitability for this application.

- -- Simulate laser speckle imaging