GENERAL STUDY OF CAMERA SYSTEMS FOR PHOTOGRAPHIC AERIAL RECONNAISSANCE

PURPOSE
INVESTIGATE TRADE-OFFS AMONG THE MANY PARAMETERS.
OPTIMIZE THE PHOTOGRAPHIC OUTPUT
DETERMINE THE REQUIRED CONDITIONS TO ATTAIN A SPECIFIED PERFORMANCE LEVEL.

PARAMETERS & CONDITIONS

CONTROLLED BY NATURAL LAWS
- SOLAR RADIATION
- ATMOSPHERIC TRANSMISSION & SCATTERING
- SCENE REFLECTANCE & CONTRAST
- DIFFRACTION OF LIGHT

SPECIFIED
- ALTITUDE
- GROUND RESOLUTION
- COVERAGE & MISSION LIFE
- VELOCITY
- WEIGHT LIMIT

VARIABLES (LIMITED BY STATE-OF-THE-ART)
- SPECTRAL REGION
- IMAGE SMOKE
- CAMERA SYSTEM
- VEHICLE ANGULAR MOTION & POSITION
- LENS
  - DIAMETER
  - FIELD
  - F/NO. AND FOCAL LENGTH
  - IMAGE QUALITY
- FILM
  - SENSITIVITY
  - IMAGE QUALITY
- CAMERA TYPE
ALTITUDE

1000 - VAN ALLEN RADIATION

LOW V/H

SATELLITE

100 - ATMOSPHERIC DRAG, HEATING, AND TURBULENCE

HIGH V/H

INSUFFICIENT LIFT

10 - AIRCRAFT

1 - BETTER GROUND RESOLUTION
## Optimum Spectral Region for Aerial Photography

**Choice Based On**
- Solar Irradiance
- Atmospheric Transmission
- Scene Reflectance
- Scene Contrast

**Optimum Contrast (Visible)**

<table>
<thead>
<tr>
<th>Wavelength (microns)</th>
<th>Optimum Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>Low Solar Energy</td>
</tr>
<tr>
<td>0.4</td>
<td>No Atmospheric Transmission</td>
</tr>
<tr>
<td>0.6</td>
<td>Low Solar Energy</td>
</tr>
<tr>
<td>0.8</td>
<td>No Atmospheric Transmission</td>
</tr>
<tr>
<td>1.0</td>
<td>Low Solar Energy</td>
</tr>
</tbody>
</table>

**Optimum Sensitivity**
- Infrared for special uses
- Low Solar Energy

**Maximum Available Energy At Good Contrast**
- Low Solar Energy
RESOLUTION vs FIELD ANGLE

SO-132 FILM
2:1 CONTRAST

RESOLUTION AT EDGE OF FIELD
RESOLUTION AT CENTER
Δ RESOLUTION IF DIFFRACTION LIMITED
☐ PANORAMIC SYSTEMS

ANGULAR RESOLUTION AT 2:1 CONTRAST—ARC SEC

GROUND RESOLUTION FROM 100 M—FEET

LENS—FILM

BIOTRON 35 MM 1/4

SCH. XEN. 60MM 1/4

PO 5" 1/2 8

PANORAMIC SYSTEMS

WIDTH OF COVERAGE FROM 100 M ALTITUDE — M

1° 2° 3° 5° 10° 20° 30° 50° 100°

FULL FIELD ANGLE OF LENS & PAN ANGLE
# Ideal Correction of Image Smear

<table>
<thead>
<tr>
<th>Effect</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrain Altitude</td>
<td>1000 ft</td>
</tr>
<tr>
<td>Attitude</td>
<td>0.2°</td>
</tr>
<tr>
<td>Rate, Each Axis</td>
<td>2 \times 10^{-4} rad/sec</td>
</tr>
<tr>
<td>Camera Vibration</td>
<td>0.5%</td>
</tr>
<tr>
<td>Vertical Sensor and Camera Drive</td>
<td>0.2°</td>
</tr>
<tr>
<td>Inexact TMC Oblique Strip Convergent Pan</td>
<td>0.1%</td>
</tr>
<tr>
<td>Lens Distortion and Focal Length Error</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

**Total (RSS):**

<table>
<thead>
<tr>
<th>X (Flight Direction)</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Smear for this ideal case: 1% of $\gamma_H = 0.05$ rad/sec</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X (Flight Direction)</th>
<th>Y</th>
<th>Minimum % Error at 100 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Smear</td>
<td>1.24%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Mean Pan</td>
<td>1.10%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>
# Examples of Residual Smear Rate

**Rate Error - Milliradians/Second**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>E2</td>
<td>0.76</td>
</tr>
<tr>
<td>E6</td>
<td>2.64</td>
</tr>
<tr>
<td>G</td>
<td>0.57</td>
</tr>
<tr>
<td>SSS</td>
<td>0.96</td>
</tr>
<tr>
<td>AGENA</td>
<td>0.70</td>
</tr>
</tbody>
</table>

**Attitude & Altitude**

**Probable Limit**
ANGULAR AND GROUND RESOLUTION
FOR FIXED INPUT TO CAMERA LENS

**FIX**
- LENS DIAMETER
- LIGHT ENERGY
- DIFFRACTION (LENS WEIGHT)
- ANGULAR RATE OF SMEAR

**VARY**
- FOCAL LENGTH AND f/NO.
- FILM
- EXPOSURE (TO MATCH FILM AND f/NO.)

ANGULAR RESOLUTION
GROUND RESOLUTION
ANGULAR RESOLUTION vs. FOCAL LENGTH
FOR VARIOUS FILMS

FIXED INPUT
10 INCH LENS DIAMETER
2 MR/SEC. SHINE RATE

ANGULAR RESOLUTION
(ARC SEC)
2:1 CONTRAST

BETTER QUALITY

LOSS DUE TO ABERRATIONS
OF VERY FAST LENSES.
**COMPARISON OF SYSTEMS USING DIFFERENT FILMS**

**FIXED LENS DIAMETER & SMEAR RATE**

<table>
<thead>
<tr>
<th></th>
<th>SO-132</th>
<th>SO-206</th>
<th>SO-130</th>
</tr>
</thead>
<tbody>
<tr>
<td>RELATIVE GROUND AND ANGULAR RESOLUTION</td>
<td>1.0</td>
<td>1.07</td>
<td>0.92</td>
</tr>
<tr>
<td>IMAGE RESOLUTION</td>
<td>110</td>
<td>70</td>
<td>40</td>
</tr>
<tr>
<td>OPTIMUM FOCAL LENGTH</td>
<td>40</td>
<td>56</td>
<td>110</td>
</tr>
<tr>
<td>OPTIMUM f/NO.</td>
<td>4</td>
<td>5.6</td>
<td>11</td>
</tr>
<tr>
<td>RELATIVE FILM WEIGHT</td>
<td>1</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>RADIATION SUSCEPTIBILITY</td>
<td>~1</td>
<td>~2</td>
<td>~8</td>
</tr>
</tbody>
</table>
EFFECT OF IMAGE SMEAR

ANGULAR RESOLUTION vs. f/NO. AND FOCAL LENGTH

ANGULAR RESOLUTION (ARC SEC)
GROUND RESOLUTION VS. APERTURE
FOR A GIVEN SMEAR RATE

ANGULAR RESOLUTION (ARC SEC)

GRAND RESOLUTION
FROM 100 MPH - FEET

INDEPENDENT OF FILM

NGN RESOLUTION
FROM 1000 MPH - FEET

LENS DIAMETER - INCHES
REQUIRED CORRECTION OF IMAGE MOTION

ANGULAR RESOLUTION (ARC SEC)

DESIGN GOALS OF VARIOUS SYSTEMS

LENS DIAMETER - INCHES
OPTIMUM DIAMETER, f/No., FOCAL LENGTH
FOR A GIVEN RESOLUTION AND SMEAR RATE  30-132 FILM
OPTIMUM DIAMETER AND f/NO.
FOR LENSES WITH EXPECTED ABERRATIONS  35-132 FILM

ANGULAR RESOLUTION  (ARC SEC)

LENS QUALITY DECREASES TO THE RIGHT OF THIS BOUNDARY
LIMITATION OF LENS QUALITY ON OPTIMUM DIAMETER

ANGULAR RESOLUTION (ARC SEC)

LENS QUALITY BOUNDARY FOR VARIOUS FILMS
- 90-132
- 90-206
- 30-130

GROUND RESOLUTION FROM 100 FT (F.F.)

LENS DIAMETER - INCHES
WIDTH OF GROUND COVERAGE VS. GROUND RESOLUTION

GROUND RESOLUTION FROM 100 NM - FEET

WIDTH OF COVERAGE FROM 100 NM ALTITUDE - NM

ANGLE OF COVERAGE

ABOUT 5X COVERAGE

STRIPE

PANORAMIC
WEIGHT OF OPTICS vs. LENS APERTURE
**Film Weight vs. Ground Resolution**

- **Film Weight (Pounds)**
  - 100%: 1
  - 10%: 0.1
  - 1%: 0.01

- **Ground Resolution (Feet)**
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
  - 7
  - 8
  - 9
  - 10

- **% Total Coverage**: 100% 10 1 0.1

- **Film Weight—Pounds**
  - (Stereo Coverage, % Redundancy & Wastage)
  - (Estar Thin Base Film)
PHOTOGRAPHIC PAYLOAD WEIGHT
VS. GROUND RESOLUTION

TWIN CONVERGENT PANORAMIC CAMERAS
100 NM ALTITUDE
1/2 ft/SEC. SMEAR RATE

GROUND RESOLUTION (FEET)
PHOTOGRAPHIC PAYLOAD WEIGHT

10
8
6
4
2
0

THOR AGENA
ATLAS AGENA
TITAN III

200 500 1000 2000 5000 10000 20000 50000 100000 200000
ITEMS CONSIDERED

FILM
  - Resolution
  - Speed
  - Mass
  - Type

LENS
  - Aperture
  - $/No.
  - T-Stop
  - Spectral Transmission
  - Focal Length
  - Angular Field
  - Mass, Configuration

EXPOSURE TIME
  - Smear Rate
  - Attitude
  - Altitude
  - Vibration
  - Imperfect IMC

CAMERA TYPE

SYSTEM
  - Mass, Size
  - Target Acquisition
  - Information Packing Density

REPRODUCTION
GENERAL CONCLUSIONS

1) SPECTRAL REGIONS
   VISIBLE, LIMITED BY LENS CORRECTION.
   IR FOR SPECIAL USES ONLY.

2) SMEAR RATE
   DIFFICULT TO IMPROVE UPON \( \frac{1}{2} \text{ mM/sec} \) ERROR.

3) FILM
   GROUND RESOLUTION INDEPENDENT OF CURRENT FILM FOR FIXED
   LENS DIAMETER AND SMEAR RATE.
   FINE GRAIN FOR MINIMUM WEIGHT AND RADIATION SUSCEPTIBILITY.

4) LENS DIAMETER
   DEPENDS ONLY ON SMEAR RATE AND ANGULAR RESOLUTION.

5) FOCAL LENGTH
   OPTIMUM EXISTS FOR A RANGE OF SMEAR RATE AND ILLUMINATION.

6) GROUND RESOLUTION OF 1 TO 2 FEET REQUIRES FASTER FILMS & MORE WEIGHT.

7) RESOLUTION LIMIT OF ABOUT 2 FEET WITH TITAN III.