Airborne High-resolution, Panoramic Camera Systems
Floating Debris Detection

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Marine Debris Mapping System - Guidelines

• High-resolution, large-area coverage

• Maximize pixel resolution: 6 to 12 inches (15-30cm)
  ➢ Detection of a floating seat cushion / suitcase / buoys
  ➢ Detection of Malaysia Airlines Flight 370 “Flaperon”

• Natural-color imagery
  ➢ Colored objects on water are much more distinguishable

• Maximize area coverage per hour of flight
  ➢ Wide angle total field of view: ~90 degrees
    • ~10 mile (16km) swath from 25,000 foot flight altitude
  ➢ Long-range jet aircraft capable of 400 mph (~500 km/hr)
  ➢ Mapped area: ~4,000 sqmi/hr (~10,000 sqkm/hr)
Airborne Reconnaissance (film)

- Cold War with Soviet Union (1947 – 1991)
  - Requirement to know what was behind the “Iron Curtain”

- USAF and CIA were tasked to supply answers
  - 1955: Lockheed begins building a fleet of U-2 aircraft
    - Flight altitude: 70,000 feet
    - Airspeed: ~500 miles per hour
    - However, U-2 could be tracked by Soviet radar
      - 1960: Francis Gary Powers shot down over Soviet Union
      - 1962: Maj. Rudolph Anderson shot down over Cuba
  - 1962: Lockheed begins building a fleet of SR-71 aircraft
    - Flight altitude: 85,000 feet
    - Airspeed: ~2,400 miles per hour (Mach 3.2)
U-2 and SR-71
Concurrent with aircraft development: **Sensor development**

The nation’s best talent and adequate funding were brought to radar and camera development.

**ASARS:** Advanced Synthetic Aperture Radar System  
**OBC:** Optical Bar Camera
SR-71 Reconnaissance Systems

NOTE:
Areas of coverage indicated are approximate.
Areas of coverage for ASARS-1 spot modes are shown in larger scale because of their relatively small size.
Optical Bar Camera
ITEK Panoramic “Optical Bar” Camera

- ITEK Corporation built U-2 / SR-71 / Apollo Lunar cameras
- Termed “Optical Bar”, the camera utilized rotating lens and “painted” image through a slit onto a long strip of film
- Film spools held 10,000 feet of 5” wide B&W or Color film
Along the Way:

- OBC was flown on Apollo-17 to map lunar surface
Optical Bar Camera “Pixel Equivalency”

- Each OBC frame (digital equivalent):
  - ~20,000 along-track pixels
  - ~200,000 cross-track pixels!!
  - Each frame: ~4 Gpixels / image!

- Latest medium format digital camera:
  - PhaseOne XF 100MP (100 Mpxixels / image)
  - 8,700 along-track pixels
  - 11,600 cross-track pixels

- OBC image: ~40x larger than single digital camera image!

- However, cross-track pixels are most important in mapping
  - OBC image is 17x wider than single digital camera image
  - A panoramic array of 17 PhaseOne cameras would match OBC!
Monterey Bay and Monterey Peninsula from 65,000 ft altitude
(Left half of OBC CIR image)

~10x magnification of Monterey Harbor
Mooring Buoy Array
(18-inch diameter)
2000 to 2010: Film has a big problem
— Sudden transfer to digital imaging

• Paul Simon: “Mama Don’t Take My Kodachrome Away”
  – Lyrics written in 1973 and in 2010 Kodak did just this!
  – In 2012 Kodak declared bankruptcy
  – Aerial film severely affected
  – NASA retired its Optical Bar Camera
  – USAF OBC continues with B&W film on a limited basis

• 2010 - Film has ceased to be available for aerial mapping
Digital Panoramic Camera Approach

Single Camera System

Multi-Camera System
4-CAMERA M-MOS SYSTEM

22,000 CROSS-TRACK PIXELS
Marine-Mammal Observation System
M-MOS

A quad-camera, high-resolution, marine mapping system for UAVs
M-MOS Composite Image

Moderate swath / High resolution

1000 meter (3280 feet) flight altitude

3.4cm (1.4in)  3.2cm (1.3in)  3.4cm (1.4in)

735 meter swath

Direction of flight

Aircraft nadir
M-MOS Image Footprint: Gagan Islet

Moderate swath / High resolution

1000 meter (3280 feet) flight altitude
10-CAMERA MOSAIC SYSTEM

40,000 CROSS-TRACK PIXELS
MOSAIC
High-Resolution, Large-Area Mapping System
Installation on Learjet Aircraft
Installation on Learjet Aircraft

View through window

Lower Door Hatch
### MOSAIC

**Swath Width & Area Coverage**

~40,000 x 4,000 pixels

<table>
<thead>
<tr>
<th>Altitude feet (AGL)</th>
<th>Swath Width miles</th>
<th>Pixel Resolution inches</th>
<th>Coverage sq.mi/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>20,000</td>
<td>4</td>
<td>6</td>
<td>1,000</td>
</tr>
<tr>
<td>40,000</td>
<td>8</td>
<td>12</td>
<td>2,800</td>
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</tbody>
</table>
6-inch MOSAIC Imagery – Reno Airport
20,000 ft above ground level

Direction of Flight

Left half of full MOSAIC frame
6-inch MOSAIC Imagery – Reno Airport
20,000 ft above ground level
Advantages of Multi-Camera System

- Advantages:
  - Scalable, using duplicate commercial components
  - Adaptable to future camera improvements
  - Reasonable cost compared to large sensor arrays
  - Parallel data recording
  - Computerized target recognition
  - Real-time detection possible
12-CAMERA ARGUS SYSTEM

65,000 CROSS-TRACK PIXELS
ARGUS Panoramic Camera System

12 cameras (Canon 1Ds Mark III) with 400mm lenses
ARGUS – Capabilities Review

High Resolution Configuration

60° FOV
11 mile swath
65,000 pixels

- **Twelve** high-resolution digital cameras aligned in a panorama
  - Single Argus image is 3744 x 65,000 pixels
  - 247 million pixels per image
  - 3.3 degree x 5.0 degree field-of-view for each camera
  - 3.3 degree x 60 degree total field-of-view for each full image
  - Approximately 4 percent side lap between cameras
  - Precision alignment, stability and timing
  - Precision GPS and Inertial Measurement Unit
NASA WB-57 Aircraft – Argus Camera Payload
One-quarter of an image frame

50,000 feet above Ellington Airfield - NASA Johnson Space Center
ARGUS Marine Examples from 50,000 feet

Jet Ski

Barge followed by tug
Oahu: Mapped within 1 flight hour

~12” (30cm) resolution
4,000 sqmi/hr
3 flight lines
~7 minutes each
Kauai and Niihau: Mapped within 1 flight hour

12” (30cm) resolution
4,000 sqmi/hr
4 flight lines
~6 minutes each
Maui, Molokai, Lanai and Kahoolawi: Mapped within 2 flight hours

12" (30cm) resolution
4,000 sqmi/hr
4 flight lines
~15 minutes each
Hawaii: Mapped within 3 flight hours

12” (30cm) resolution
4,000 sqmi/hr
8 flight lines
~15 minutes each
NASA WB-57
Approximate Marine Debris Locations
Summary

• The ARGUS panoramic camera is available at JSC
  – All “Areas of Interest” can be reached by the NASA WB-57

• Questions:
  – Can marine debris can be detected optically?
  – What resolution is required to detect “Areas of Interest”?
  – What temporal sampling is required?

• Future of digital camera technology:  Optimistic!
  – Sensor size and corresponding capability increasing rapidly
    ➢ 1996: 5Mpixel
    ➢ 2010: 25Mpixel
    ➢ 2016: 100Mpixel
    ➢ ~2018: 250Mpixel