LOCKHEED'S RECONNAISSANCE SATELLITES

- AGENDA

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<th>Session</th>
<th>Subject</th>
<th>Speaker</th>
<th>Time</th>
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<td>Overview</td>
<td>Sam Araki</td>
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<td>CORONA Program</td>
<td>Bill Monroe</td>
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<td>Systems Engineering</td>
<td>Miles Johnson</td>
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<td>CORONA'S Legacy</td>
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<tr>
<td></td>
<td>Q&amp;A</td>
<td>All</td>
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</table>

• Overview

Sam Araki
**Background - 1955**

Soviet Nuclear Bomber and ICBM Threat

- **U2**
  Airborne Reconnaissance
  13.3 mile altitude

- **Genetrix WS-119L**
  Balloon Reconnaissance
  10-19 mile altitude

**1956 - RAND Report**

- **Air Force WS 117L Competition** – Lockheed, Martin, RCA, Bell Labs
- **Lockheed wins:**
  - **MIDAS:** Atlas/Agena – Aerojet payload
  - **SAMOS:** Atlas/Agena – Eastman Kodak payload
    - Onboard Film Processor, Scan, Video Downlink
  - **Discoverer:** Thor/Agena – GE Capsule
- **Col. Fritz Oder** – AF WS 117L Program Manager
1957 – Sputnik launches

Sputnik 1
Four week life

Sputnik 2
Laika died in space

Shocked the world! Nuclear weapon in space next?

CORONA Challenge

Space the new frontier

Vacuum
Zero Gravity
Extreme Temperature
Radiation

U2 Airplane
RAND Report
WS117L Satellite Program

To be Launched in Nine Months
1958 – Pres. Eisenhower Sets The Stage

Space Race
CORONA
- Adopt U2 Bissell Model
  - CIA/AF teamwork
  - Government/Contractor teamwork
  - Propensity for action
  - Manage for innovation
  - Customer focus
  - Benchmark for success
  - Cost and time factor
- CORONA 9 months to launch

Technology Race
MIT & Stanford
- MIT
  - Route 128
  - Camera
  - Computers
- Stanford
  - From prunes to silicon
  - Moore’s Law
  - Astronautics

The CORONA Team
Modeled after the U2

Nine months to launch
**CORONA Program**

LMSD — System Integrator

- **CORONA Satellite**
  - Reentry Vehicle — GE
  - Camera — Itek
  - Film — Kodak
  - Payload & Agena — LMSD

- **Mission Control**
  - Launch — VAFB
  - On-Orbit Control — Multiple
  - Recovery - Hawaii

- **Recovery** — Air Force

- **Photographic Interpretation**
  - CIA
  - Defense Mapping Agency
  - US Army

**CORONA PROGRAM — Innovation Hotbed**

<table>
<thead>
<tr>
<th>Camera</th>
<th>59-60</th>
<th>60-61</th>
<th>61-62</th>
<th>62-63</th>
<th>63-69</th>
<th>69-72</th>
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<tbody>
<tr>
<td>KH-1 Mono</td>
<td>KH-2 Mono</td>
<td>KH-3 Mono</td>
<td>KH-4 Stereo</td>
<td>KH-4A Stereo</td>
<td>KH-5 Mapping</td>
<td>KH-4B Stereo</td>
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<tr>
<td>Reentry Vehicle</td>
<td>1 (50 lbs Film)</td>
<td>2 (100 lbs Film)</td>
<td>6-7</td>
<td>4-15</td>
<td>19</td>
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<tr>
<td>Agena A</td>
<td>Agena B</td>
<td>Agena D</td>
<td>TAT</td>
<td>THORAD</td>
<td></td>
<td></td>
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<tr>
<td>Booster</td>
<td>THOR</td>
<td>THORAD</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Life (Days)</td>
<td>1</td>
<td>2-3</td>
<td>1-4</td>
<td>6</td>
<td>52</td>
<td>17</td>
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<td>Flights</td>
<td>10</td>
<td>10</td>
<td>6</td>
<td>26</td>
<td>52</td>
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<tr>
<td>Success Rate</td>
<td>1/10</td>
<td>2/10</td>
<td>4/6</td>
<td>70%</td>
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</table>

Successful transition - Hexagon first launch 1971 vs. CORONA last launch 1972
LOCKEED'S RECONNAISSANCE SATELLITES
- OVERVIEW SUMMARY

KH-1

KH-4B

CORONA PROGRAM OVERVIEW

- America's First Satellite Program
- Piercing the Curtain

Bill Monroe
October 8, 2020
Last CORONA Launch at Vandenberg

Agena

Thorad Booster

CORONA Payload

Orbital Paths
Low Earth Orbiting Satellite

90 Minute Orbital Period
~80-250 N-Mile Altitude
~17,000 MPH to stay in orbit
Objectives: Search, Mapping, Charting, Geodesy

Two convergent Panoramic cameras - Each scan ~150x150 NM

Film - 31,500 feet x 70 mm
40 lb. early - 160 lb. later

Coverage - ~7 million sq. mi./mission

Total program coverage - 557 million sq. mi.

Program total film length 2.1 million feet, ~400 Miles
Recovery vehicles parachuted to Earth

Caught by Air Force C-119 aircraft

CORONA Recovery Sequence

Midair Recovery, C-119, August 1960
Midair Recovery Painting - Amazing Task In Context

CORONA Paths

- Launch-Photograph-Recovery sequence
  Not the beginning nor the end of this story.
- I’m going to talk about several paths
  - CORONA Program organization & the colonels
  - Lockheed’s story, & LMSD’s people & expertise
  - GE’s story, Itek’s story, EK’s
  - The film paths
  - The ground stations paths
  - The accomplishments and legacy
Almost all of the people on the government side were more interested in getting the job done than in claiming credit or gaining control.

- Richard Bissell, CIA

The program was its own reward. It was damn exciting. It was the highlight of my life.

- Col. Lee Battle, Program Director

The real work was done by the shop people, the technicians, and the design engineers. It's obvious no single individual created this system. Industry worked with government. It was clearly a team effort.

- Jim Plummer, LMSC
LMSD - Sunnyvale in Early 1960's

- Program Offices, including Discoverer
- Systems Engineering
- SS/A - Airframe
- SS/B - Propulsion - Santa Cruz Test Base
- SS/C - Electrical
- SS/D - Guidance/Controls/Dynamics
- SS/H - Tracking, Telemetry and Command
- R&D Support
  - Structural Strength & Structural Dynamics Analyses
  - Ascent and Orbital Thermodynamics
  - Reliability & others
- Integration & Test
- VAFB Launch Base

Main Agena Engine - Bell Model 8096

- Bell Aircraft rocket engine was developed for B-58 Hustler bomber program, then rescued for Agena.
- Rocket fuels were Unsymmetrical Di-Methyl Hydrazine (UDMH) & Inhibited Red Fuming Nitric Acid (IRFNA)
- Test fired in Agenas at Santa Cruz Test Base.
D-timer or 'Sequence Computer'

Agena D Integration
"Advanced Engineering" Tasks Occurred on Willow Road

- Managers and engineers from Lockheed
- Customers from Agency & Air Force
- Structures and electronics from Lockheed
- Cameras from Itek
- Film from Eastman Kodak
- Reentry systems from General Electric
- Technicians from Hiller Helicopter
- Integration & Test
- Transported in Hertz truck to Vandenberg for launch

CORONA KH-4B

- Recovery Vehicle #1
- Main Takeup Cassette
- Recovery Vehicle #2
- Main Intermediate Roller Assembly
- DISIC Camera
- Film path
- Constant Rotating Stereo Panoramic Cameras
- Delta structure
- Film supply cassette
General Electric Re-Entry Body

- GE, Chestnut St., Philadelphia, based on missile ablative heat shield work.

- Subsystems include:
  - Film take up spools in interior gold bucket
  - Cold gas spin-up system
  - Solid propellant retro rocket
  - Ablative heat shield
  - Drogue and main parachutes

GE's Golden Bucket with Film Spools
Camera - Itek Corporation

- Created by purchase of Boston University’s Physical Research Lab for $100k in late 1957.
- Panoramic camera proposed for the CORONA “search” mission necessitated 3-axis Agena design & beat out Fairchild.
  - Ref: Meetings at Flamingo Hotel in San Mateo, March 1958
- Itek’s gen 2 design featured a 24” focal length, f3.5 Petzval lens, about 7” in diameter.
- What we were doing: Equivalent to ~110 miles away in sort of terrestrial terms, say with our camera in Geyserville or just beyond King City, we would finally be photographing goings-on at Moffett field, with 4-5 foot resolution.
Film Paths

- Before/during Exposure
  - **Kodak** invented & coated polyester based 70mm film. (ASA 2)
  - Traveled from spools, through cameras, into buckets.

- After Exposure & Re-entry
  - Air catch, then to Hickam to Moffett to LMSC to Moffett
  - Then to Westover AFB, near Springfield, MA, for developing & duplicating.
  - Next, to National Photographic Interpretation Center (NPIC) at Washington, DC, Navy Yard, & to Defense Mapping Agency, St. Louis, for exploitation.

- After Program Declassification in 1995
  - to EROS in Sioux Falls, SD, for ongoing environmental and archeological studies (20,000 canisters of 70mm film)

Ground Stations Path

- LMSD built and outfitted the Satellite Test Center, the Blue Cube predecessor.
- Philco Corporation formed their Western Development Laboratory, “WDL”, moved west and built the 6 initial tracking stations.
  - **Cook**, Kodi, Hula, Boss, Tule, & Indi
- Philco later morphed into Philco-Ford, Ford Aerospace, Loral Space & Comm, now Maxar.
- Loral’s Space & Range, & Satcom Terminals, Divisions became part of Lockheed Martin in the 1990s.
Results:

This missile site footprint led to discovery of missile site construction in Cuba.

Follow-up U2 photos were shown to the public.

Note: Slides from handouts at 1995 Declassification Ceremonies.

Results:

Long range airfield photo shows two regiments of Tupelov Bear bombers on a 13,200 foot runway.
Results:

Moscow in May 1970
PI's identified a line of visitors to Lenin's Tomb

Results:
KH-4 Imagery followed construction of both nuclear and Diesel-powered submarines at Severodvinsk Shipyard
New York City Central Park

Results:

Corona image of Central Park in 1968
Example of later image exploitation
From USGS via Gado Images

3-Bar Photo Targets in Arizona Desert

Results:

Standard USAF 3-bar targets used for calibration camera performance in lines/mm
Created speculation for pilots & hikers
**CORONA Program Intelligence Accomplishments**

- Imaged all Soviet medium-range, intermediate-range, and ICBM complexes.
- Imaged each Soviet submarine class from deployment to operational bases.
- Provided inventories of Soviet bombers and fighters.
- Revealed the presence of Soviet missiles in Egypt protecting the Suez Canal.
- Identified Soviet nuclear assistance to the People’s Republic of China.
- Provided the initial indication of Soviet MRBM site preparation in Cuba.
- Monitored the SALT-1 Treaty.
- Uncovered the Soviet ABM program and sites (GALOSH, HEN HOUSE, etc.)
- Identified Soviet atomic weapon storage installations.
- Identified PRC missile launching sites.
- Determined precise locations of Soviet air defense missile batteries.
- Observed construction and deployment of Soviet ocean surface fleet.
- Identified Soviet command and control installations and networks.
- Provided mapping for Strategic Air Command targeting and bomber routes.
- Identified Plesetck Missile Test Range, north of Moscow.
Charles Stark Draper Prize for CORONA

- Awarded by National Academy of Science, Engineering, and Medicine in 2005. $500k
- For “the design, development, and operation of CORONA, the first space-based earth observation system.”
- Five Individuals Honored
  - Lockheed Program Manager – Jim Plummer
  - Lockheed Lead Engineer – Sam Araki
  - Itrek Optical Systems PM – Frank Madden
  - Kodak Lead Engineer – Don Schoessler
  - GE Recovery Vehicle Lead – Edward Miller

Finally, Some Historical Context

When President Kennedy announced the man on the moon program in 1961, necessary basic technologies had been demonstrated by CORONA and were known to him: rockets, spacecraft, trajectories, re-entry, and recovery. Man-rating was the biggest challenge left for NASA.

GPS satellite contracts were yet to awarded.

NASA’s Landsat-1 was launched in 1972. Our sparse knowledge of aerial observed planet environment back to 1960 comes mainly from CORONA film delivered to EROS.

The HP-35 Scientific calculator was introduced in 1972, the year of the last CORONA launch.
  - (We certainly needed it earlier.)
CORONA PROGRAM OVERVIEW

• America's First Satellite Program

SUMMARY

• As summed up by Dr. Jack Rodden, Lockheed Guidance & Controls Manager:
  “It worked real good.”

LOCKHEED'S RECONNAISSANCE SATELLITES

• Systems Engineering

Miles Johnson
CORONA Program
LMSD — System Integrator

CORONA/Agena Satellite
• Reentry Vehicle — GE
• Camera — Itek
• Film — Kodak
• Payload & Agena — LMSD

Mission Control
• Launch – VAFB
• On-Orbit Control – Multiple
• Recovery – Hawaii

Recovery
Air Force

Photographic Interpretation
NPIC

CORONA/Agena LMSD
Thor Booster
Douglas
VAFB

Corona Satellite Launch Sequence

THOR booster
AGENA half acted upper stage.
**CORONA Program Mission**

90 Minute Polar Orbit
100-250 N-Mile Altitude
Sun synchronous

Typical photographic swaths
Preprogrammed with ground over ride

---

**CORONA Recovery Sequence**

Recovery vehicles parachuted to Earth
Caught by Air Force C-119 aircraft
Challenges at CORONA Program Start-up

• CORONA Program Concept:
  ✓ Use Modified Standard Agena as Spacecraft Bus
  ✓ Add Camera Imaging, Recoverable Film Payload
  ✓ Launch Integrated Booster Corona/Agena from VAFB

• Lack of understanding of launch and on-orbit environments
• Absence of System Requirements and Verification Process
• Security and Classification Differences
• Siloed Engineering and Test Organizations

LMSD - Sunnyvale in Early 1960's

- Program Offices, including Discoverer
- Systems Engineering
- SS/A - Airframe
- SS/B - Propulsion - Santa Cruz Test Base
- SS/C - Electrical
- SS/D - Guidance/Controls/Dynamics
- SS/H - Tracking, Telemetry and Command
- R&D Support
  - Structural Strength & Structural Dynamics Analyses
  - Ascent and Orbital Thermodynamics
  - Reliability & others
- Integration & Test
- VAFB Launch Base
CORONA Lessons Learned

- Established Systems Engineer Office:
  - Cross all technical disciplines
  - Ensure program compatibility and function from “cradle to grave”
- Developed environmental analysis tools
- Flowed requirements down from mission to design, build, integration, test, launch, and operations
  - Environmental test of all components and integrated system
  - System level testing most effective for demonstrating readiness
- Avoid single point failures, but provide backup recovery capability
- Integrated factory to pad and launch process
CORONA Program Factory to Pad Process

CORONA Program Factory to Pad Process

CORONA Agena Merged
Evolution of Lockheed Space Photo Reconnaissance Programs

- People
- Technology
- Tools
- Processes
- Operation

Summary

LOCKHEED'S RECONNAISSANCE SATELLITES

- Systems Engineering

Summary
Agena Attitude Control

Develop Spacecraft Attitude Control systems
- All analog control, too early for digital
- Three-axis stabilization (as opposed to spinner)
  keep z axis pointed to earth center
  keep the x axis in the orbit plane
  serves as a stable "tripod" for the payload
- Control during engine burn, and during coast phase

Develop Tools and models for Verification

Develop understanding of Space environment
- Rotating coordinate system effects
- Disturbance torques, aerodynamic drag, gravity gradient, magnetic, etc.
Agena attitude control system

1. **Performance Requirements**
   - Must be stable, with margins
   - Specified Pointing Accuracy depending on the mission – down to tenths of a degree
   - Specified Pointing Stability – especially for the optical missions, to tens of microradian/sec
Agena Additional Control System
Functions

“D” Timer
• Electromechanical clock with Thumbwheel preset delay times
• Starts at sensed separation from the booster
• Control initial event sequence such as engine start and any pyro events

“H” Timer
• Controls on-orbit event timing, such as turning on/off communications and telemetry dump over tracking stations.
• Electromechanical operation

Backup control system (Optical Missions) “Lifeboat” or “BRAC”
• Totally independent control system to allow recovery of film buckets
• Functions in case of failure of primary attitude control
• Use magnetometer for pointing reference – Align Agena to magnetic field, then release film bucket on command

Controls analysis and simulation tools

Components and the entire system were tested. Component models developed based on component testing. Performance and stability predictions relied on analysis and simulation.
- Slide rule, pencil, paper, spirule for initial sizing
- Analog computer modelling for linear systems

Digital computer tools had to be developed in-house (Fortran) – none commercially available.
- Numerical integration simulation for non-linear controls
- General stability analysis program for linear system stability
- Time domain solution for linear differential equations
Initial Control System Tools

Sliderule, pencil & paper, graph paper + Analog Computer

Spirule

Friden Calculator

Models to be developed and verified

- Engine hydraulic gimbal control
- Flexible body dynamics and coupling to control system
- Fuel slosh model, two tanks
- Gyro and Horizon Sensor models
- Etc
Agena attitude control system adaptation and continuous improvement

- Corona wide area search mission, 2 meter resolution, the original mission
- Other NASA, science, military missions - mostly minor modifications
- Gambit high resolution point targets, resolution better than 2 feet, ultimate Agena pointing
  - Required precision pitch, roll pointing to capture target
  - Required precision pitch, roll rate stability and yaw pointing
  - Precision knowledge of payload roll inertia, compensate with geared wheel
- Digital guidance and control mission, strapped down guidance system- 1969
- Advanced control digital control for more agile spacecraft and longer life, early 1970s
Attitude control legacy from Agena

• Advanced control system with improved accuracy, maneuverability, and lifetime (early 1970s development)

  Agena digital control experience
  Agena precision pointing control legacy
  Star sensors/trackers (photomultiplier) to replace horizon sensors for inertial reference
  Momentum devices for control, replaces expendable control gas jets and allows maneuvering

• Hubble Space Telescope, developed in 1980s, launched 1990
  Key control requirement of 0.006 arc-second pointing stability to target star

• Ikonos commercial imaging satellite, launched 2000, 1 meter resolution

• Other military applications
Infrared Horizon Sensors

- Part of the Agena Guidance System
- Scanned Earth CO2 horizon at 15.4 microns to provide local vertical information
- Optics, including the bolometer detector, were Germanium (Ge)
- Two sensors were used with the angle between the optical axes determined by orbit altitude.
How The Horizon Sensors Fit Into The Agena Control System

Horizon Sensing From the Agena
Satellite Path
No Pitch and No Roll

Equal Chord Equal in Length and Parallel

Satellite Path
Clockwise Roll

Right Chord Longer than Left Chord
Satellite Path
Nose Down Pitch, Zero Roll

Equal Chords

Exit Horizon Crossings wider
Entry Horizon Crossings closer

Motor Lubrication

Quality Control
Extending sensor life from days to mission length

Sensor Delivery
Summary

* Lockheed solved many new spacecraft challenges during the Agena Program.

* Horizon Sensor durability and accuracy were steadily improved over 397 missions from 1959 to 1984.
**THERMO for CORONA**

- Temperature control for satellites and all on-board equipment in unpressurized environment
- Product improvement for Agena:
  - Improved materials: high strength alloys
  - Durable surface materials
  - Development of means to control location of weightless liquid Agena propellants

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**MODES of HEAT TRANSFER**

In order of importance:

<table>
<thead>
<tr>
<th>Conventional – Earth Surface or Aircraft</th>
<th>In Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forced convection</td>
<td>Radiation</td>
</tr>
<tr>
<td>Conduction</td>
<td>Conduction</td>
</tr>
<tr>
<td>Natural convection</td>
<td>Convection during ascent and re-entry</td>
</tr>
<tr>
<td>Radiation</td>
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</tr>
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</table>
Ascent: Early Agenas utilized experience from other missile and space programs tailored to CORONA mission.

Orbital mission: Conduction and radiation only -- no convection.

Re-entry: Emerging experience from other programs were employed for GE's re-entry heat shield.
**Agena Exchanging Energy**

**ENERGY CURRENTS**

<table>
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<tr>
<th>Location</th>
<th>Spectrum</th>
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<tr>
<td>Solar</td>
<td>Top and one side, Solar 6000 K</td>
</tr>
<tr>
<td>Albedo</td>
<td>Lower, Solar 6000 K</td>
</tr>
<tr>
<td>Earthshine</td>
<td>Lower, Earth 300K</td>
</tr>
<tr>
<td>Deep Space</td>
<td>Top and sides, Earth 300K</td>
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</table>

**TARGET VEHICLE**

Two Band Radiation Model

---

**Space Hardened Coatings**

- Coatings vulnerable to damage by environment – esp. uv, radiation, ionizing radiation
- Extensive lab testing, development
  - example: white paint turns brown
  - Developed paint with ultra refined fillers, etc.
    Sherwin- Williams Co.
- New tape foils – bare aluminum, anodized titanium
Evolution to Future

- Silicate paints – whiter than white paint, less vulnerable to environment
- Multilayer blankets
  - Thermal isolation
- Heat pipes
  - Large heat currents, e.g. battery cooling

Internal Heat Transfer

- Analog electrical network –
  - Divide skin/structure into elements with thermal capacity
  - Interconnected by thermal conduction resistors and radiation resistors
- Drive network circuit with
  - Internal heating from component and spacecraft duty cycles
  - External heating and cooling
**SPACECRAFT THERMODYNAMICS**

Lockheed successfully developed thermal designs for early and later Agena and other spacecraft. Development of needed surface coatings and other means of thermal control was carried out as needed.
Propellant Management for the Future

- Screen baffles used to segment liquid load to reduce sloshing extraneous forces
  - Maneuvering spacecraft

- Screen baffles for liquid to crawl on
  - Position liquid for firing station keeping thrusters
  - Station keeping for 24 hr satellites

Multiple Restart Capability

PURPOSES:
- Increase orbital apogee
- Replace array of multiple ullage rockets on aft rack
Restart Development

- Model drop tests
  - Determine mode of liquid flow front to back
    - Stanford ME Lab

- Full-scale tests
  - Verify collection of liquid and expulsion of gas
  - Santa Clara ME Lab
• Temperature Vacuum Stress Test
• Thermal Model Verification

LOCKHEED'S RECONNAISSANCE SATELLITES

• CORONA'S Legacy

Sam Araki
AGENA - THE SPACE PIONEER

- Three teams, many missions
  - Corona Agena - NRO, CIA, Air Force
    Eyes in the sky
  - Ranger/Mariner/Gemini Agena - NASA
    Race to the moon
  - SNAP-10A Agena - Air Force, AEC
    Nuclear power in orbit

1959 - 1987
362 launches in multiple configurations and missions

Lockheed’s Re却naissance Satellites
1956 — 1995

Space & Technology Race
Cold War Ends

“See it well”
G1 G2 G3 Gambit

“See it all”
Hexagon

“See it now”
Koren, IDEX

National Geospatial Intelligence
# Lockheed’s Reconnaissance Satellites

## 1956 – 1995

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Satellite/Program</th>
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<tr>
<td>1959</td>
<td>SpySatellites</td>
<td>CORONA</td>
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<td>1961-62</td>
<td>Space &amp; Technology Race</td>
<td>&quot;See it well!&quot;</td>
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<td>1963-65</td>
<td>&quot;See it all!&quot;</td>
<td>G1/G3 Gambit</td>
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<td>1965-69</td>
<td>&quot;See it now!&quot;</td>
<td>Hexagon</td>
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<td></td>
<td>Cold War Ends</td>
<td>National Geospatial Intelligence</td>
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<td>1973-76</td>
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<td>Kerren, IDEX</td>
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**Declassified**

1995

2010

## CORONA NRO Recognition

**Dr. Richard M. Bissell, Jr.**

1961 - 1962

**Dr. Joseph V. Charyk**

1961-1963

**Dr. Brockway McMillan**

1963-1965

**Dr. Alexander H. Flax**

1965-1969

**Dr. John L. McLucas**

1969-1973

**Mr. James W. Plummer**

1973 - 1976
CORONA Program Recognitions

Awardees at 1995 declassification

NRO 50th Anniversary (2012)
Gambit Declassification Ceremony

"See It Well"
GAMBIT-3 Satellite Configuration

Propellant Tanks
Roll Joint
Aft Rack
Forward Rack
Photographic Payload Section
Satellite Control Section
Reentry Vehicles

NRO 50th Anniversary (2012)
Hexagon Declassification Ceremony

"See It All"
### Spacecraft Feature Comparison

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<tr>
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<th>Hexagon</th>
<th>Corona</th>
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<tr>
<td><strong>Booster</strong></td>
<td>Titan IID</td>
<td>Thorad/Agena</td>
</tr>
<tr>
<td><strong>Satellite</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mission Life</td>
<td>120 days (40-270 days)</td>
<td>1-5 days (extended to 10 days)</td>
</tr>
<tr>
<td>Diameter</td>
<td>10 feet</td>
<td>5 feet</td>
</tr>
<tr>
<td>Length</td>
<td>67 feet</td>
<td>30 feet</td>
</tr>
<tr>
<td><strong>Camera</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S&amp;S camera</td>
<td>2 camera stereo</td>
<td>2 camera stereo</td>
</tr>
<tr>
<td>Film load</td>
<td>2000 lbs</td>
<td>80 lbs</td>
</tr>
<tr>
<td>Mc&amp;G camera</td>
<td>2000 ft stellar</td>
<td>3300 ft terrain</td>
</tr>
<tr>
<td><strong>Recovery Vehicle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S&amp;S film recovery</td>
<td>4 large recovery vehicle</td>
<td>2 MKV recovery vehicle</td>
</tr>
<tr>
<td>Mc&amp;G film recovery</td>
<td>1 MKV recovery vehicle</td>
<td></td>
</tr>
</tbody>
</table>

### Hexagon – Factory to Pad

[Diagram of spacecraft assembly process]
Kennen - "See it now"

- A high-agility, high-resolution satellite with near real-time (NRT) capability.
  - Sept 1971 – Pres. Nixon authorized program
    - Electro-optical based digital imaging system
    - "Quantum jump … unquestioned technical lead...“
      Dr. Edwin Land
    - Target date 1976
  - Jan 1977 - Operational

IDEX II
Image Data Exploitation II system
1991-2003

- Superior digital photo Interpretation
  - 100 deployed world wide
  - DoD & Intelligence Agencies
- At first used on high interest targets
  - Shade Removal
  - Contrast & Brightness Manipulation
- IDEX and commercial work stations replaced light tables
Lockheed’s Reconnaissance Satellites
1956 — 1995

- CORONA
- Gambit
- Hexagon

National Geospatial Intelligence

- Ikonos

Redesigned commercial geospatial information

Lockheed Martin Ikonos Satellite
Established commercial geospatial intelligence
1999 - 2014

- 681 km altitude
- Sun synchronous orbit
- 1.83 x 1.57 m 1800 lbs.
- Sensor bands:
  - Panchromatic @ nadir: 0.80 m
  - Multispectral, @ nadir: 3.2 m
- Average revisit rate ~3 days
- 240,000 km² collection/day
Lockheed’s Reconnaissance Satellites
1956 — 1995

SEVEN TENETS
1. Focus on threat-based need
2. Adhere to short timelines
3. Maintain resource stability in funding and staffing
4. Rely on small, streamlined, breakaway, collaborative team
5. Employ strong systems engineering & program management
6. Adapt and draw from the latest advances in technology and concepts of operation.
7. Establish a short chain of command & avoid bureaucracy

Corona Business Practices
Streamlined management
Empowered program manager
Adequate and stable funding
Flexible acquisition
Dedicated support
Internal competition
Acceptability of failure
Covertness
Government-Industry partnership
Top-quality personnel
Cradle-to-grave management
Objective specifications

Equal in accomplishment to Manhattan Project, Polaris, and F 117
Jeremiah Panel,
Defining the Future of the NRO for the 21st Century, August 26 1996
Panel Questions and Answers

Resources:

- Corona-Between the Sun & the Earth, R.A. McDonald Editor, American Society for Photogrammetry and Remote Sensing, © 1997
CORONA Lessons Learned

- Formation of Chief Systems Engineer
  End-to-End Technical Responsibilities
- Formation of Program Control - Cost Schedule Control
  Chief Program Expeditor
- Interface control documents between associate contractors
- Environmental testing of all components and system
- Factory-To-Pad launch process
- 1-2 page Statement and quote to start the program
Agena Subsystems

- SS/A - Airframe - With an aviation heritage, designers were confident using advanced materials including high strength aluminum, magnesium, mag-thorium, beryllium, titanium, etc.
- SS/B - Propulsion - The rocket engine was rescued from a cancelled aircraft program, often test fired at the Santa Cruz Test Base near Ben Lomand.
- SS/C - Electrical - Batteries were needed for up to 14 day operation, solar arrays were added later. Inverters were required for some units with aircraft heritage.
- SS/D - Guidance/Controls/Dynamics - A new field discussed later in this presentation
- Following are some hardware samples.....
NRO 50th Anniversary (2010) Ceremony

THE HEXAGON SYSTEM

PAYLOAD—mirrors, camera, film supply, command & control

DIMENSIONS
Length: 60 feet
Diameter: 10 feet
Weight: 95,000 pounds

CORONA Program Declassification

Executive Order 12951
February 22, 1995

Presidential Documents
Hubble