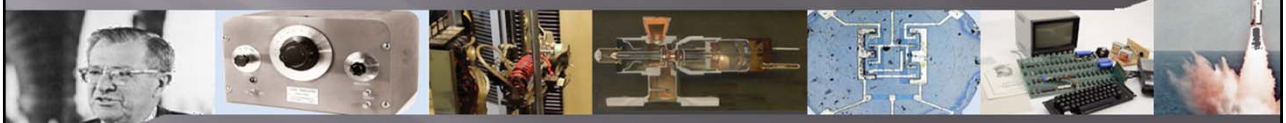
SILICON VALLEY TECHNOLOGY HISTORY COMMITTEE'S WEBINAR ON

LOCKHEED

RECONNAISSANCE SATELLITES



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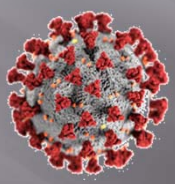
IEEE WEBINAR ON LOCKHEED'S RECONNAISSANCE SATELLITES

CORONA IS MORE THAN



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IEEE WEBINAR ON LOCKHEED'S RECONNAISSANCE SATELLITES

Link To NRO Video

NRO Video
Approved for release
April 2010
Case S10-0115
https://www.youtube.com/watch?v=x1kg-bBozQI

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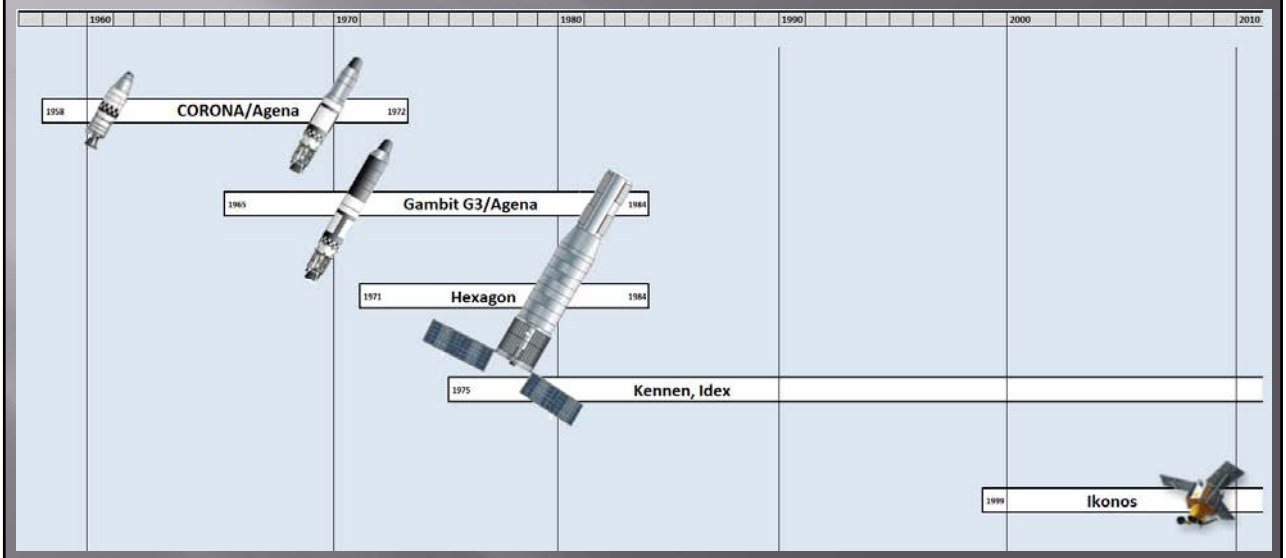
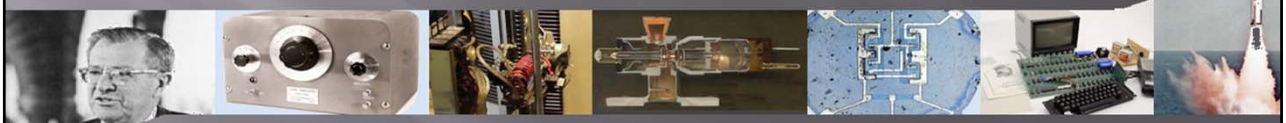
Lockheed's Reconnaissance Satellites



LOCKHEED'S RECONNAISSANCE SATELLITES - AGENDA

Session	Subject	Speaker	Time
1	Overview	Sam Araki	10
2	CORONA Program	Bill Monroe	25
3	Systems Engineering	Miles Johnson	15
4	Guidance and Control	Jim Carlock	20
5	Horizon Sensing	Terry Zaccone	10
6	Thermodynamics	Hugh Satterlee	10
7	CORONA'S Legacy	Sam Araki	15
	Q&A	All	



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LOCKHEED'S RECONNAISSANCE SATELLITES

- Overview

Sam Araki

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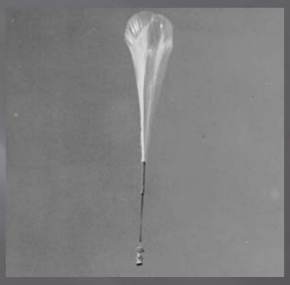
Background - 1955

Soviet Nuclear
Bomber and ICBM Threat

U2
Airborne Reconnaissance
13.3 mile altitude



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

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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**

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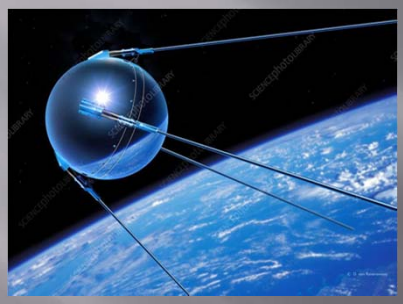
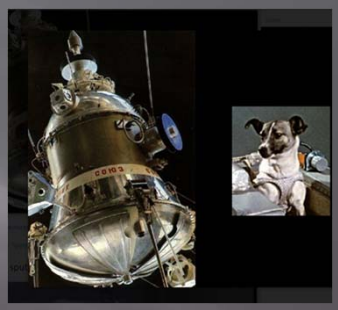
1957 – Sputnik launches



Sputnik 1
Four week life



Sputnik 2
Laika died in space

Shocked the world! Nuclear weapon in space next?

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CORONA Challenge

U2 Airplane

RAND Report
WS117L Satellite Program

To be Launched in Nine Months

10

1958 – Pres. Eisenhower Sets The Stage

Space Race

CORONA

- Adopt U2 Bissel 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

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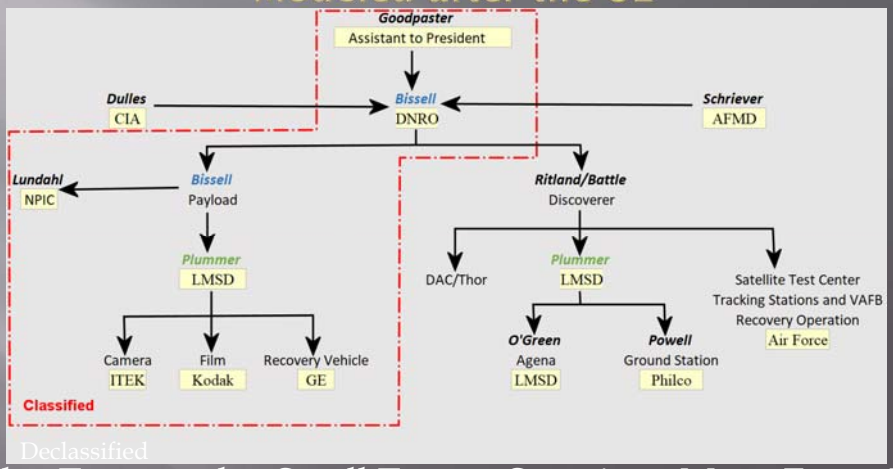
The CORONA Team

Modeled after the U2



Funded 1995 Teamwork—Small Team—Security—Move Fast—Innovate
Nine months to launch

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CORONA Program
LMSD —System Integrator

CORONA/Agena
LMSD

Thor Booster
Douglas

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

Recovery – Air Force

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

Photographic Interpretation
CIA
Defense Mapping Agency
US Army

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CORONA PROGRAM — Innovation Hotbed

	59-60	60-61	61-62	62-63	63-69	69-72
Camera	KH-1 Mono	KH-2 Mono	KH-3 Mono	KH-4 Stereo KH-5 Mapping KH-6 Hi Res	KH-4A Stereo KH-5 Mapping	KH-4B Stereo
Reentry Vehicle	←– – – – – – – 1 (50 lbs Film) – – – – – – – – – – →				←– – – 2 (100 lbs Film) – – – – – →	
Agena	Agena A	Agena B	←– – – – – – – – – – – Agena D – – – – – – – – – – →			
Booster	←– – – – – – – THOR – – – – – – →			TAT	THORAD	
Life (Days)	1	2-3	1-4	6-7	4-15	19
Flights	10	10	6	26	52	17
Success Rate	1/10	2/10	4/6	←– – – – – – – – – – 70% – – – – – – – – – →		

DMSP first launch August 1962

Successful transition - Hexagon first launch 1971 vs. CORONA last launch 1972

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LOCKHEED'S RECONNAISSANCE SATELLITES - OVERVIEW SUMMARY

KH-1

KH-4B

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CORONA PROGRAM OVERVIEW

- America's First Satellite Program
  - Piercing the Curtain

Bill Monroe
October 8, 2020

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Last CORONA Launch at Vandenberg

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Orbital Paths
Low Earth Orbiting Satellite

90 Minute Orbital Period
~80-250 N-Mile Altitude
~17,000 MPH to stay in orbit

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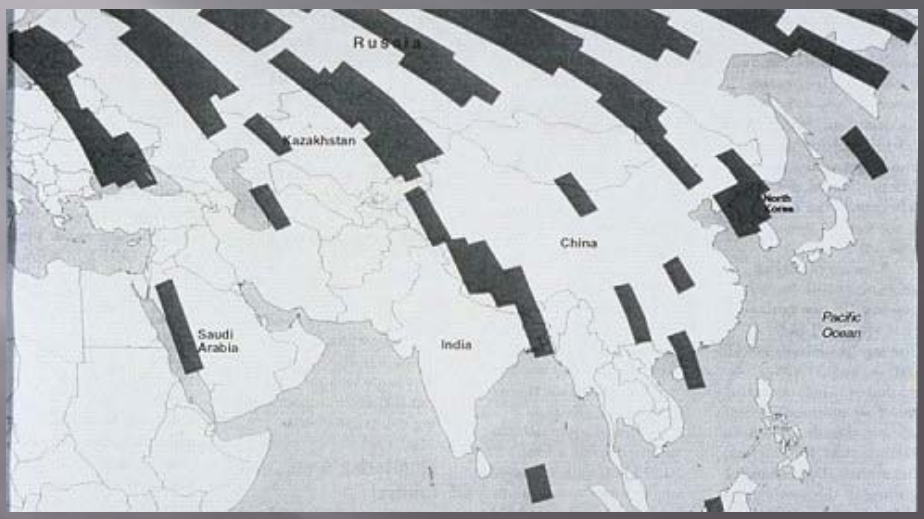
Eurasian Photographic Coverage Areas



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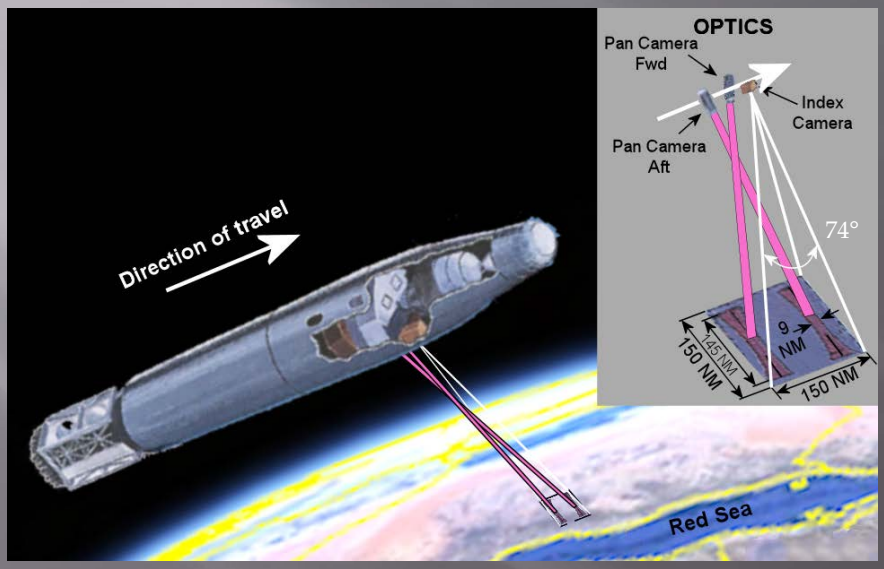
CORONA KH-4B On-Orbit



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

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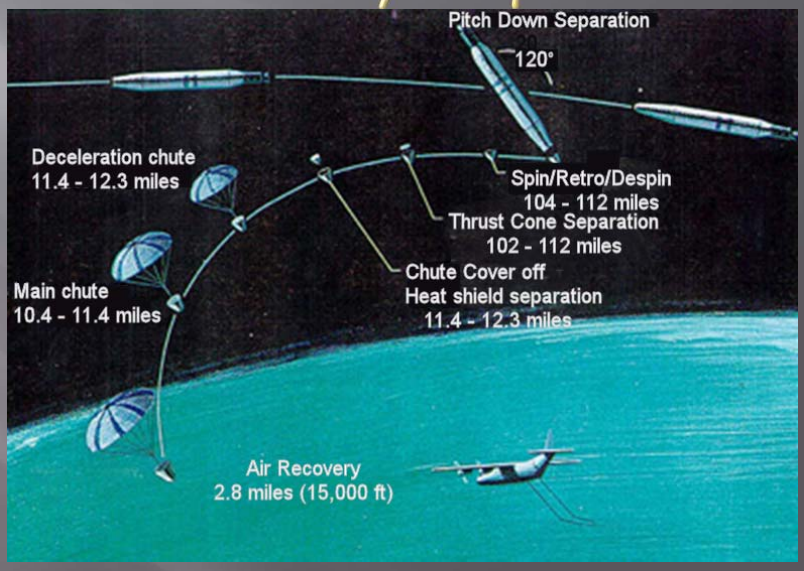
CORONA Recovery Sequence

Recovery vehicles parachuted to Earth

Caught by Air Force C-119 aircraft



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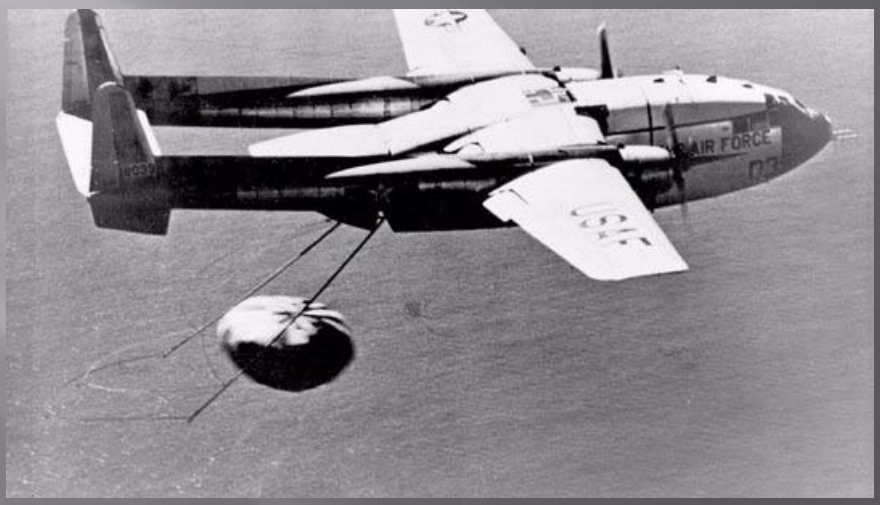
Midair Recovery, C-119, August 1960



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Midair Recovery Painting– Amazing Task In Context

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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

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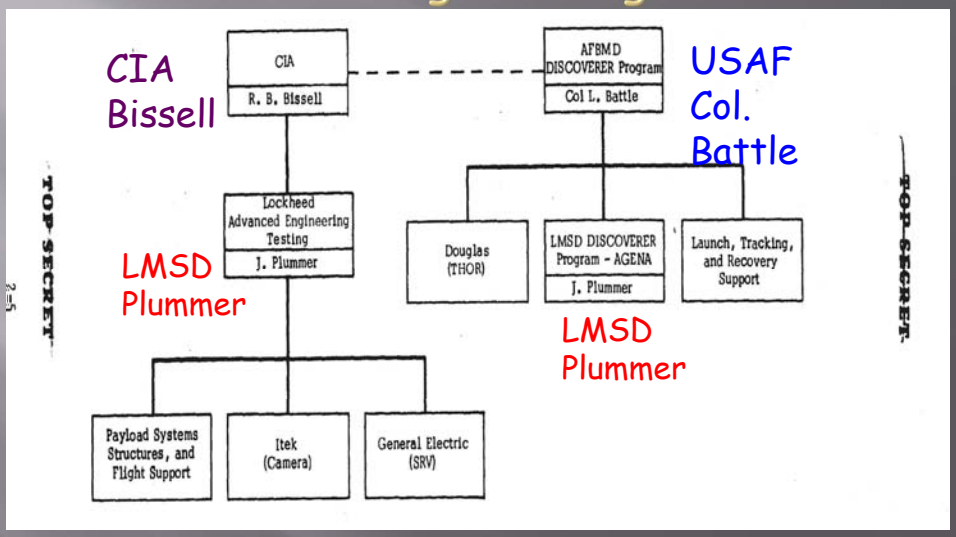
CORONA Program Organization



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Affirmations from the Customer Side

- "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

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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

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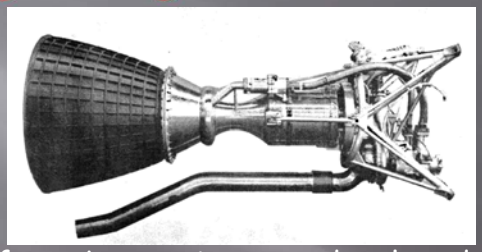
Main Agena Engine – Bell Model 8096



- 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.

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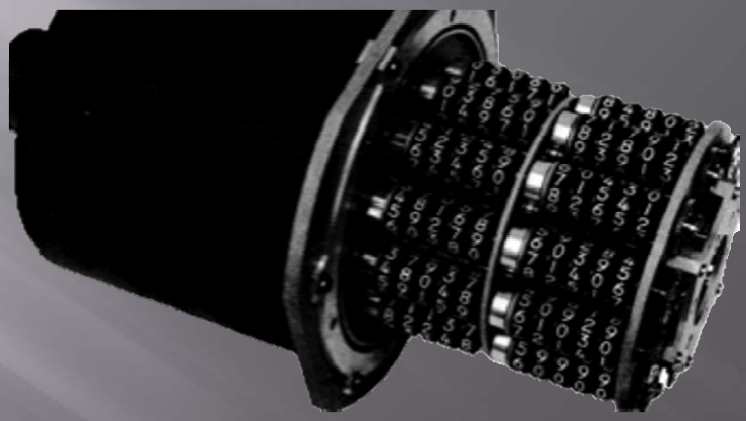
D-timer or 'Sequence Computer'



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Agena D Integration

30

"Advanced Engineering" Tasks Occurred on Willow Road

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

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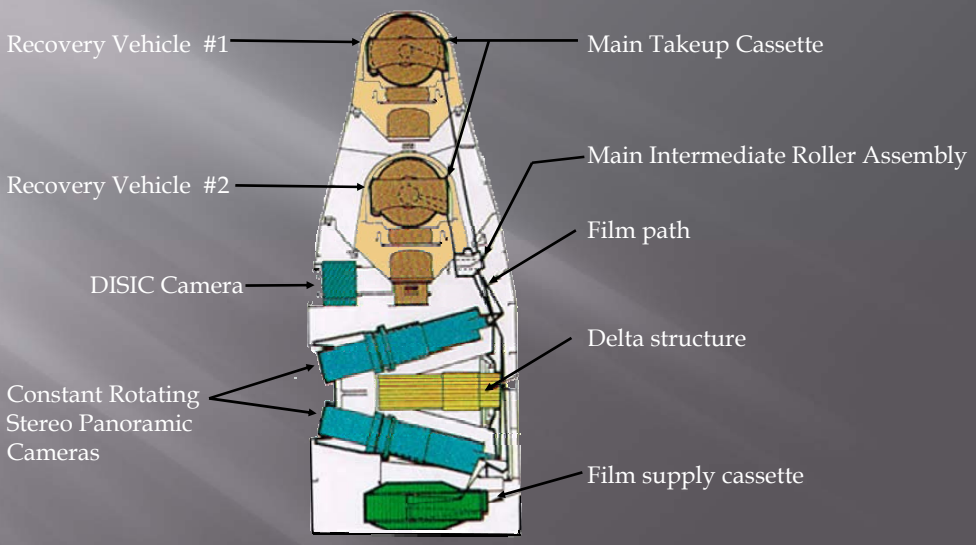
CORONA KH-4B



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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

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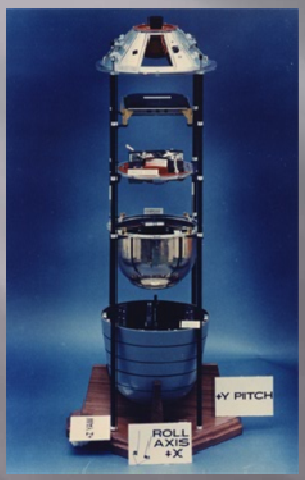
GE's Golden Bucket with Film Spools



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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.

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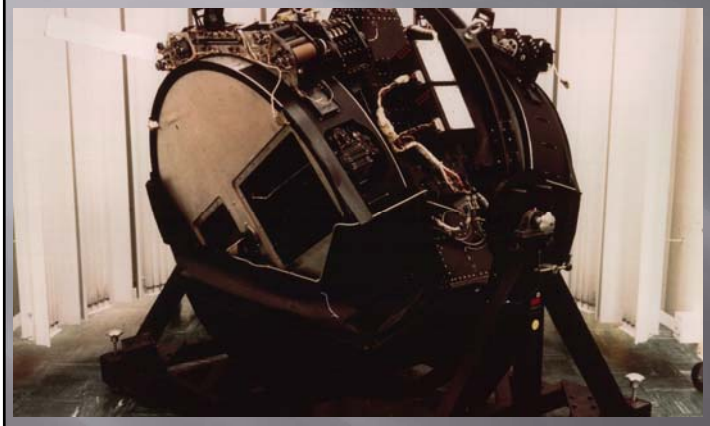
Itek's Constant Rotating Camera Assy. & Petzval Lens



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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)

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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.

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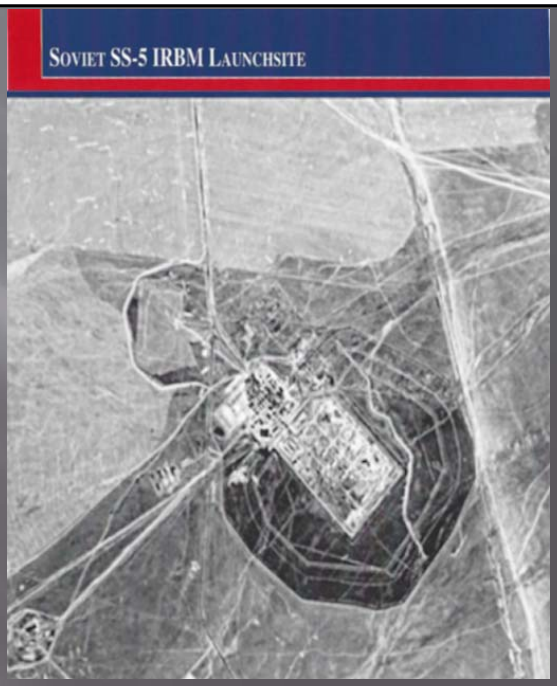
Results:

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



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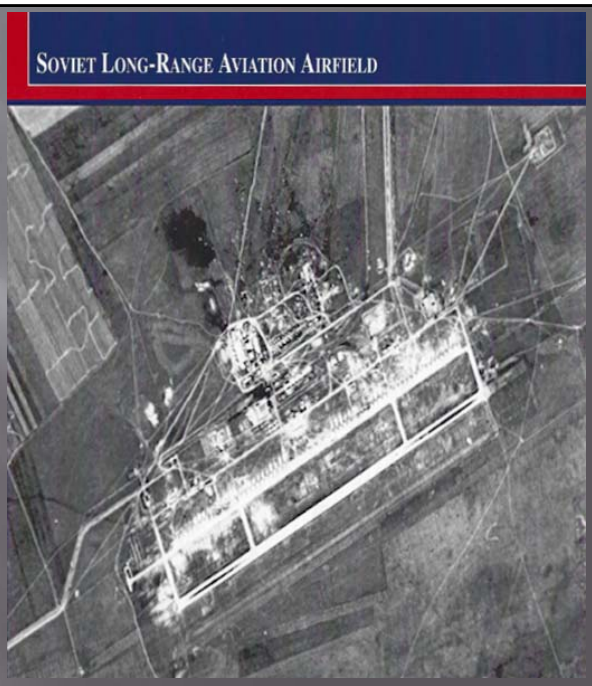
Results:

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

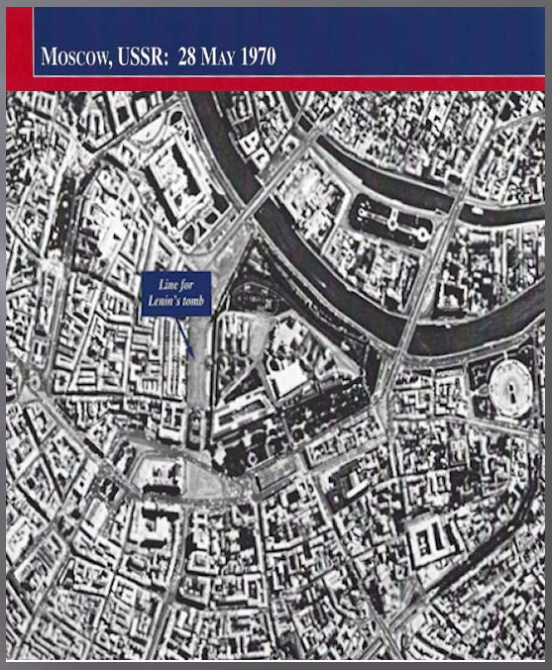


40

Results:

Moscow in May 1970

PI's identified a line of visitors to Lenin's Tomb



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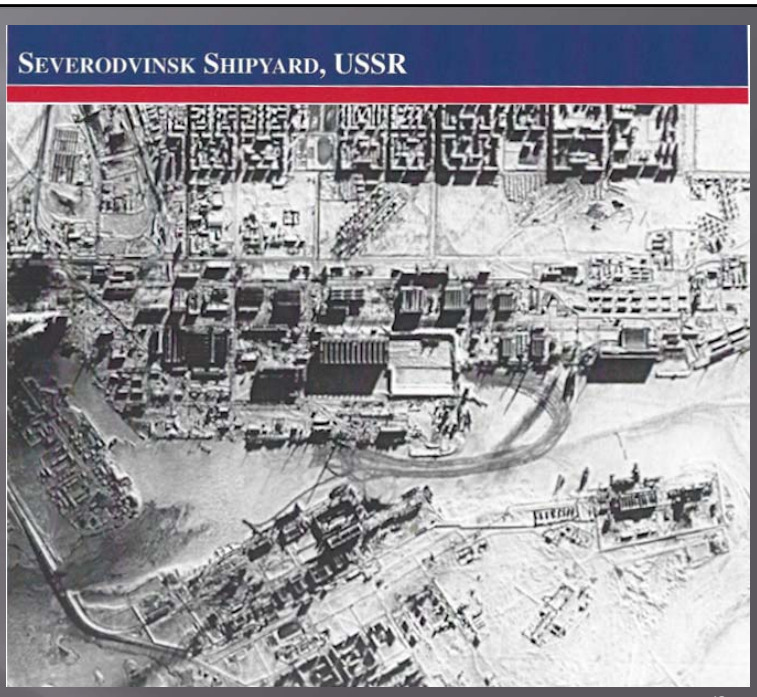
Results:

KH-4 Imagery followed construction of both nuclear and Diesel-powered submarines at Severodvinsk Shipyard



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New York City Central Park

Results:

Corona image of Central Park in 1968

Example of later image exploitation

From USGS via Gado Images

43

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

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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.

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CORONA Program Intelligence Accomplishments (2)

- 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.

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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
  - Itek Optical Systems PM – Frank Madden
  - Kodak Lead Engineer – Don Schoessler
  - GE Recovery Vehicle Lead – Edward Miller

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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.)

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CORONA PROGRAM OVERVIEW

- America's First Satellite Program

SUMMARY

- As summed up by Dr. Jack Rodden, Lockheed Guidance & Controls Manager:

"It worked real good."

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LOCKHEED'S RECONNAISSANCE SATELLITES

- Systems Engineering

Miles Johnson

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CORONA Program
LMSD —System Integrator

CORONA/Agena
LMSD

Thor Booster
Douglas

VAFB

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

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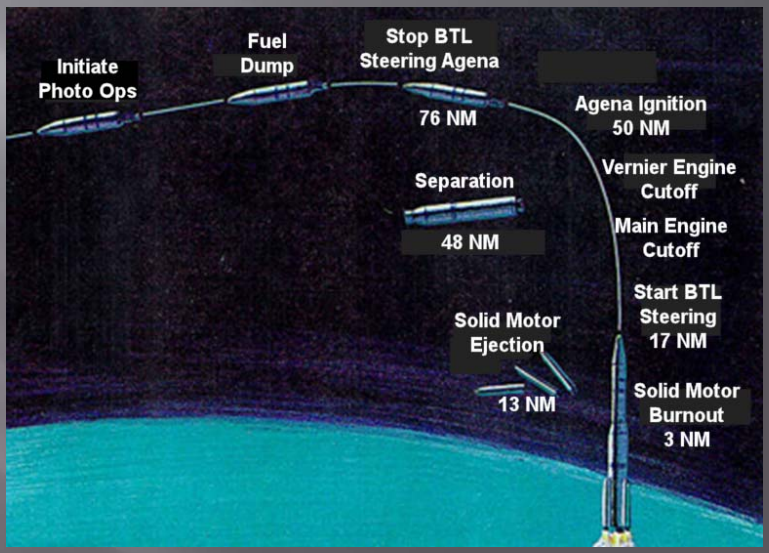
Corona Satellite Launch Sequence

THOR booster

AGENA half acted upper stage.



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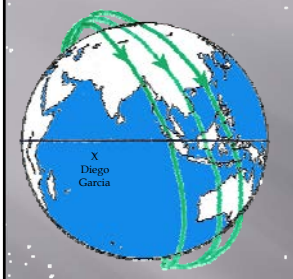
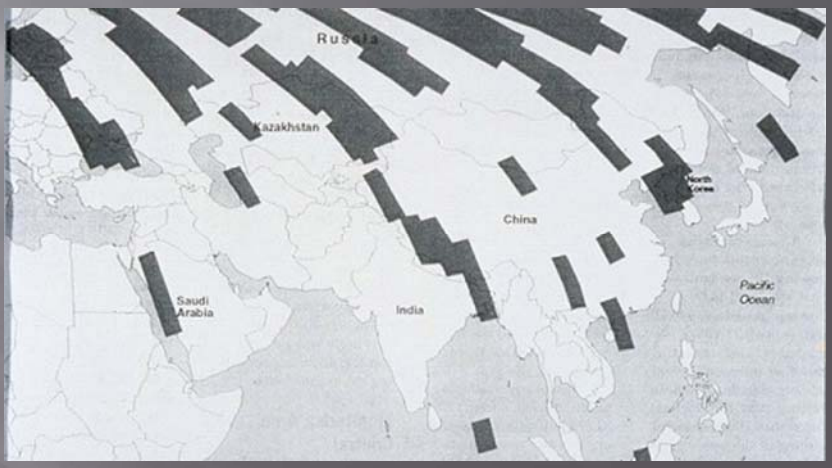
CORONA Program Mission



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

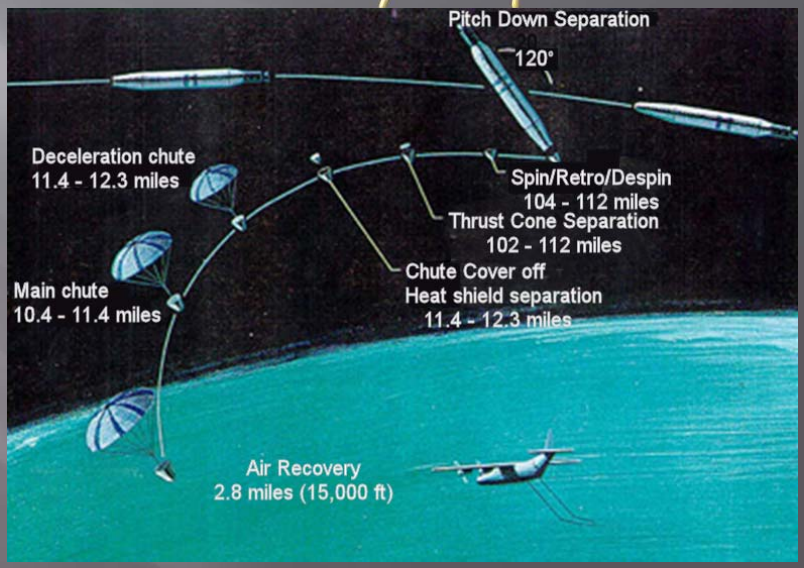


Typical photographic swaths
Preprogrammed with ground over ride

CORONA Recovery Sequence

Recovery vehicles parachuted to Earth

Caught by Air Force C-119 aircraft



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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

55

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

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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

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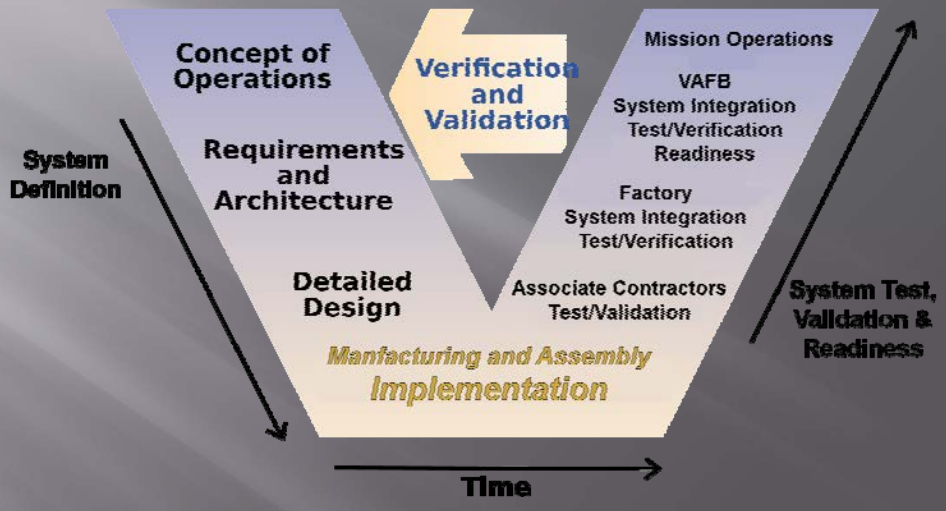
CORONA Program System Engineering Flow



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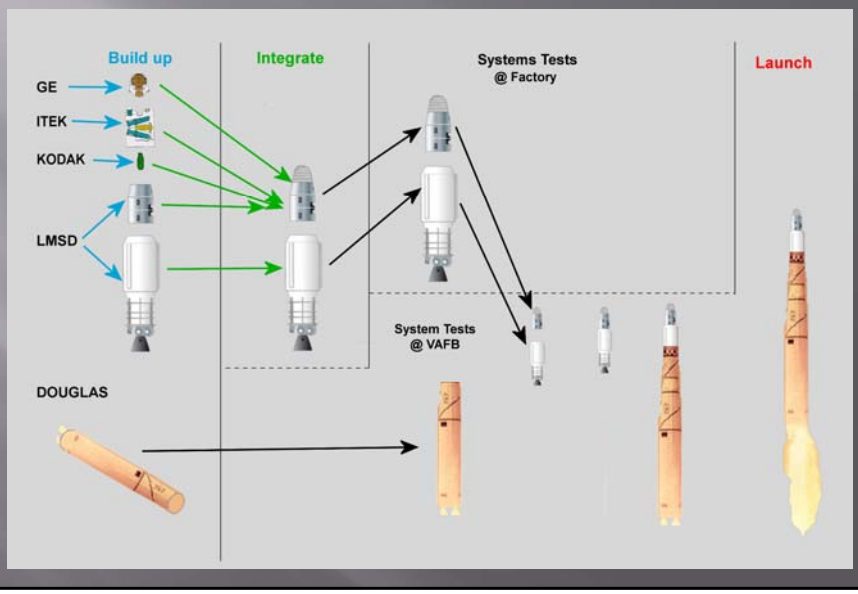
CORONA Program Factory to Pad Process



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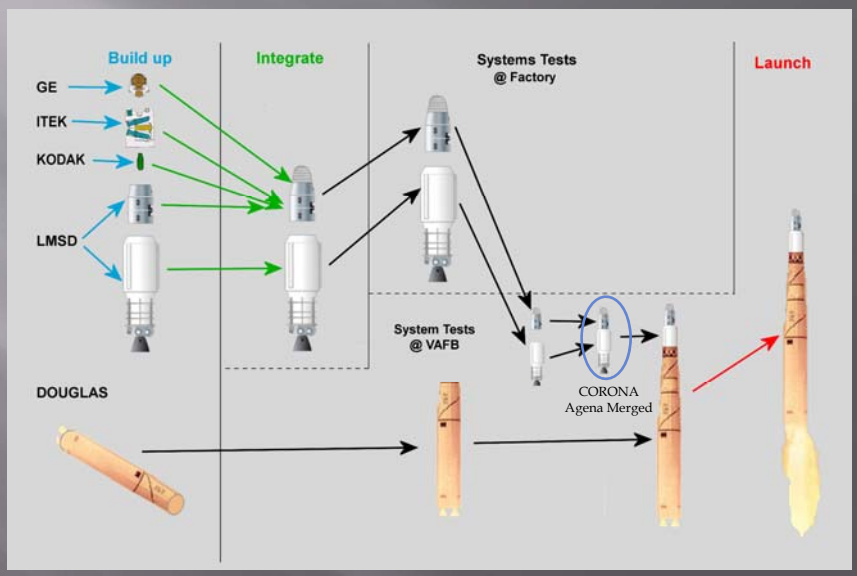
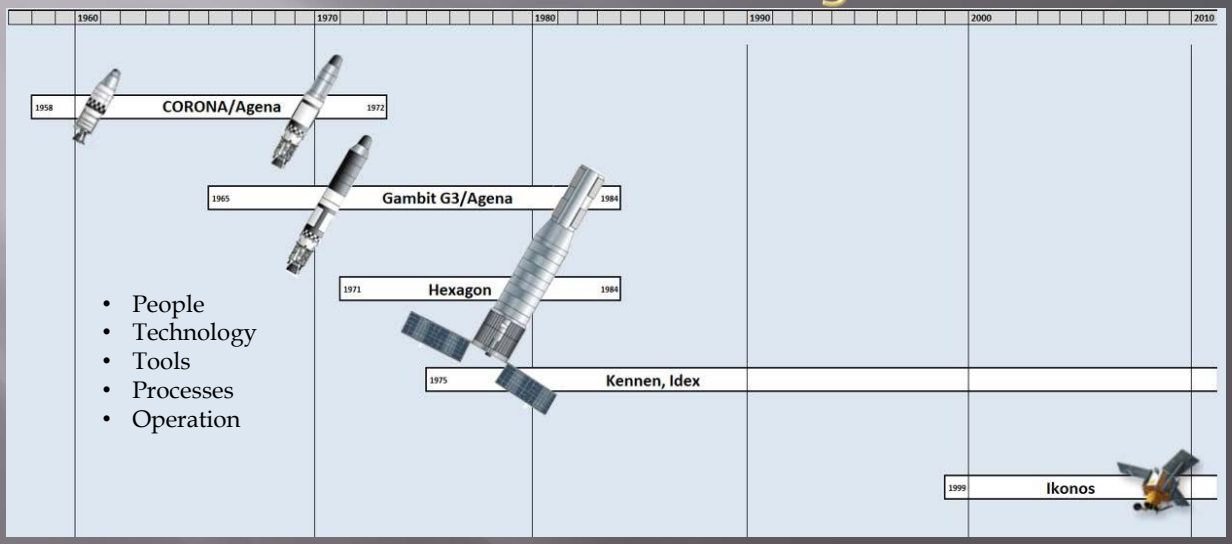
CORONA Program Factory to Pad Process



60

Evolution of Lockheed Space Photo Reconnaissance Programs



- People
- Technology
- Tools
- Processes
- Operation

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LOCKHEED'S RECONNAISSANCE SATELLITES

- Systems Engineering

Summary

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LOCKHEED'S RECONNAISSANCE SATELLITES

- Agena Control Systems

Jim Carlock

63

Agena Attitude Control

Develop Spacecraft Attitude Control systems

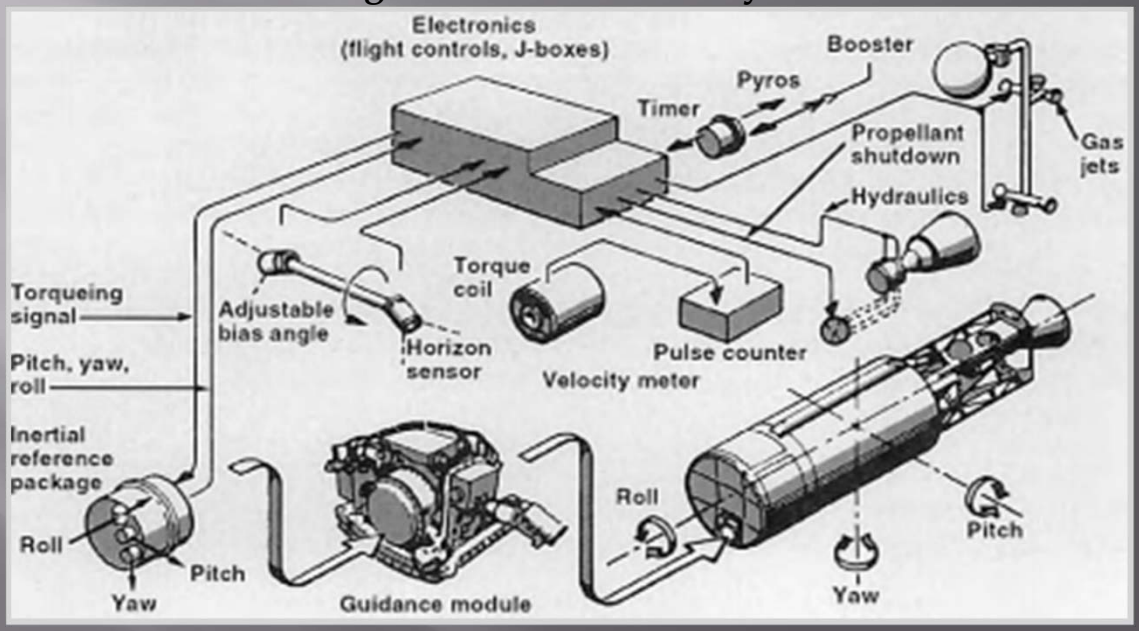
- All analog control, too early for digital
- Three-axis stabilization (as opposed to spinner)
  - keep z axis pointed to earth center
  - keep the x axis in the orbit plane
  - serves as a stable "tripod" for the payload
- Control during engine burn, and during coast phase

Develop Tools and models for Verification

Develop understanding of Space environment

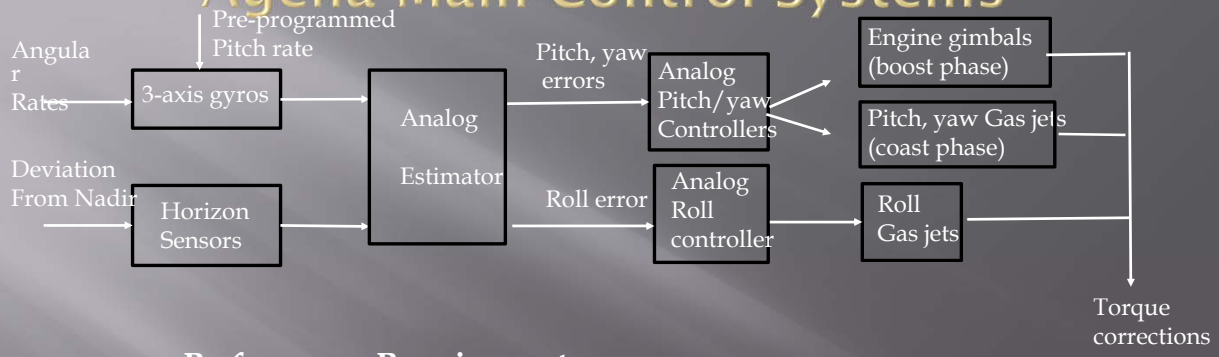
- Rotating coordinate system effects
- Disturbance torques, aerodynamic drag, gravity gradient, magnetic, etc.

Agena attitude control system



65

Agena Main Control Systems



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

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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.

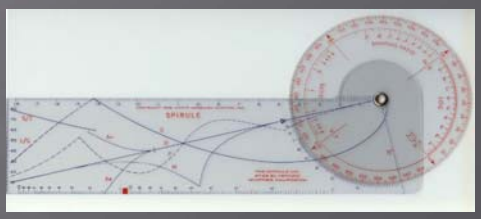
- Numerical integration simulation for non-linear controls
- General stability analysis program for linear system stability
- Time domain solution for linear differential equations

Initial Control System Tools

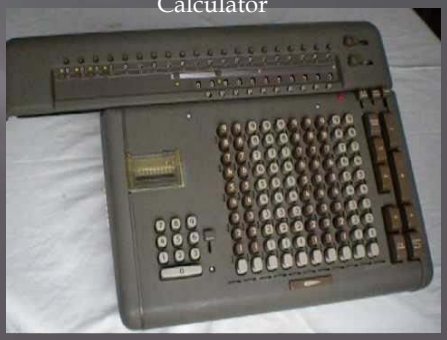
Sliderule, pencil & paper, graph paper +

Analog Computer

Spirule



Friden Calculator



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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 improvemen

- 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

71

Agena and separate optical payload (GAMBIT)

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

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LOCKHEED'S SPY SATELLITES

Agena Control Systems

SUMMARY

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LOCKHEED'S RECONNAISSANCE SATELLITES

- Horizon Sensors

Terry Zaccone

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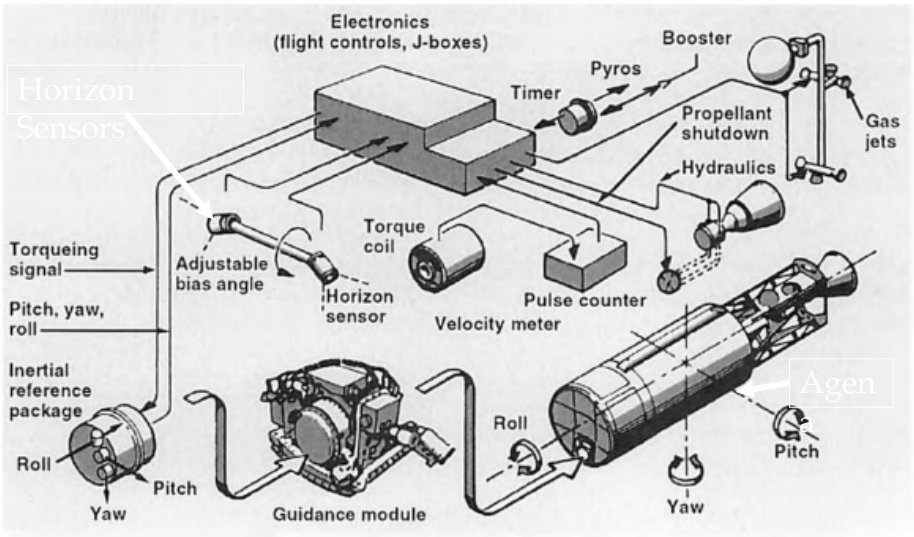
Infrared Horizon Sensors

- 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.

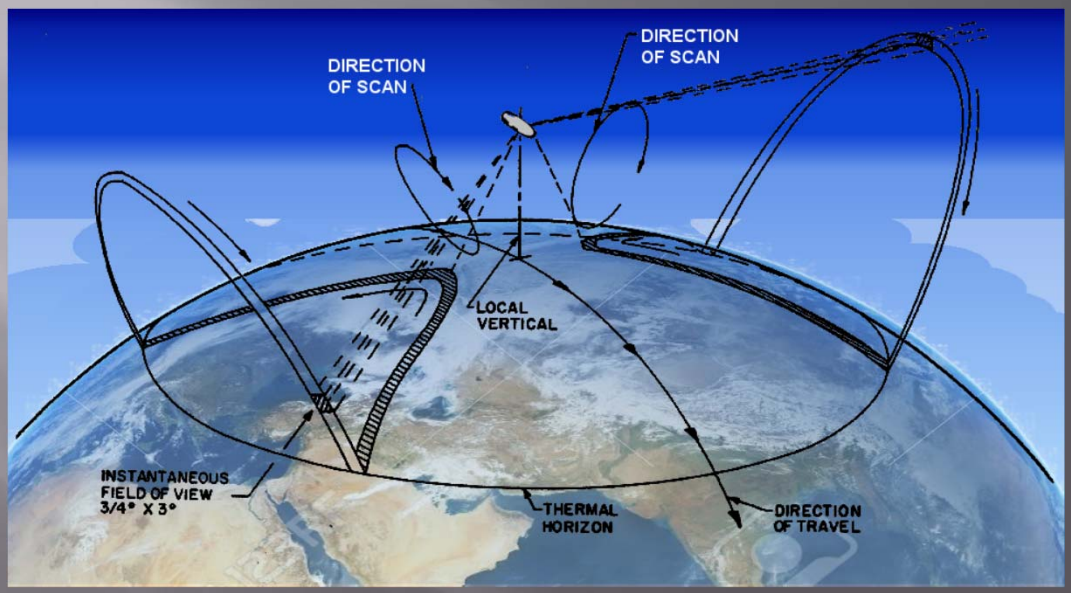
76



How The Horizon Sensors Fit Into The Agena Control System

77

Horizon Sensing From the Agena



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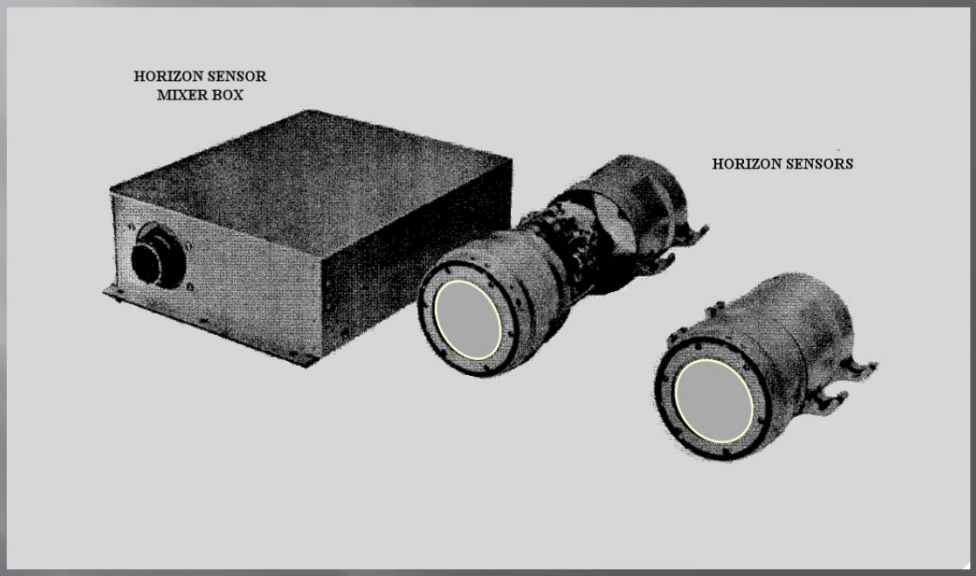
Horizon Sensor System



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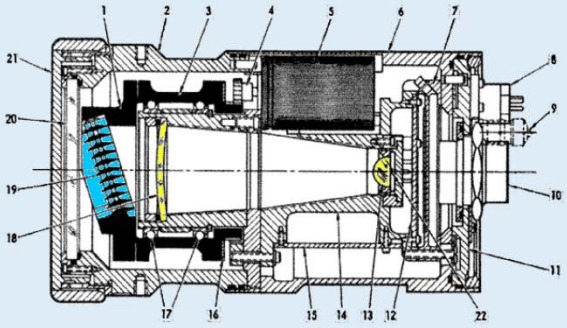
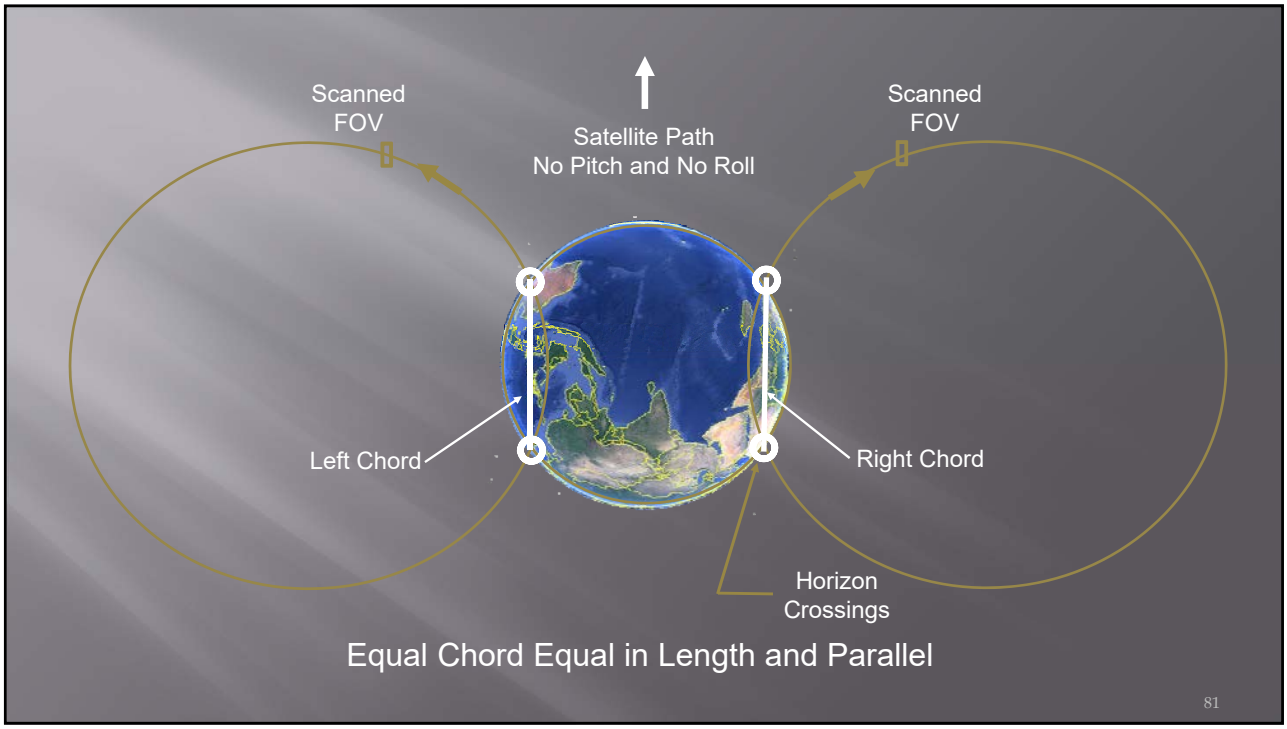
Horizon Sensor Head Detail

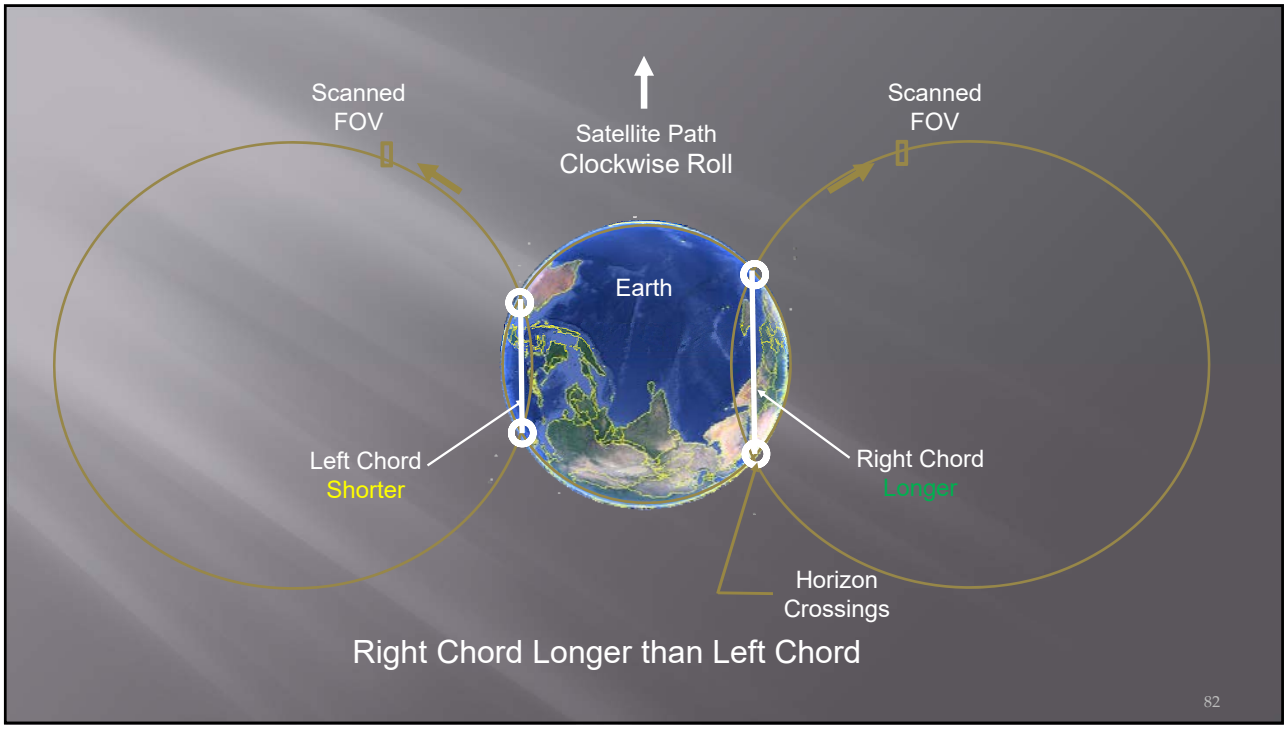


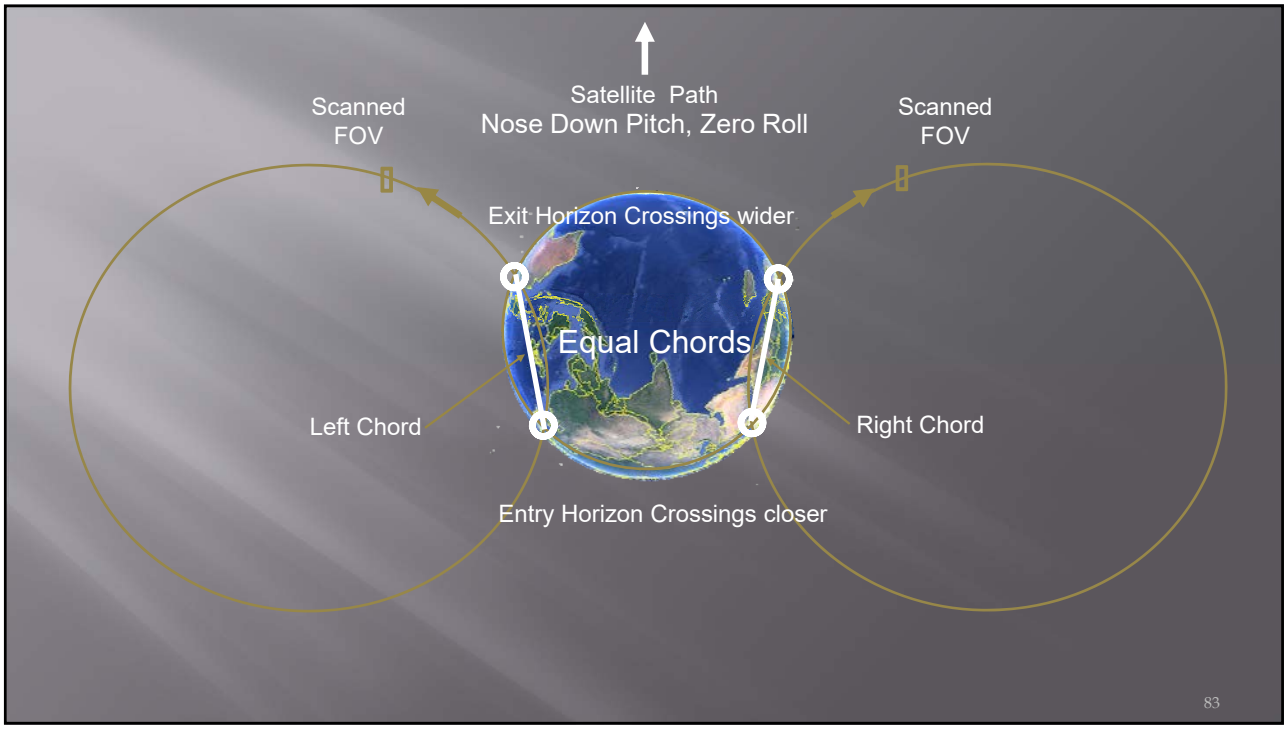
LEGEND

1. MIRROR HOUSING
2. EMI CASE
3. BEARING HOUSING
4. SPUR GEAR
5. MOTOR
6. MOUNTING CASE
7. SHIELD
8. PRESSURE TRANSDUCER
9. SCHRADER VALVE
10. BENDIX CONNECTOR
11. ENDCAP
12. PRINTED CIRCUIT BOARD PC 100
13. IMMERSION LENS
14. BOLOMETER MOUNT
15. PRINTED CIRCUIT BOARD PC 200
16. MAGNETIC VANE
17. BEARINGS
18. OBJECTIVE LENS
19. SCANNING MIRROR
20. WINDOW
21. DUST COVER
22. THERMISTOR FLAKE

80


Scanned
FOV
Satellite Path
No Pitch and No Roll
Scanned
FOV
Left Chord
Right Chord
Horizon
Crossings
Equal Chord Equal in Length and Parallel
81


Scanned
FOV
Satellite Path
Clockwise Roll
Scanned
FOV
Earth
Left Chord
Shorter
Right Chord
Longer
Horizon
Crossings
Right Chord Longer than Left Chord
82



Challenges

- Motor Lubrication
- Quality Control
  Extending sensor life from days to mission length
- Sensor Delivery

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LOCKHEED'S RECONNAISSANCE SATELLITES - HORIZON SENSORS

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.

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SATELLITE THERMODYNAMICS

A WHOLE NEW DISCIPLINE!

Hugh Satterlee

86

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:

Conventional – Earth Surface or Aircraft	In Space
Forced convection	Radiation
Conduction	Conduction
Natural convection	Convection during ascent and re-entry
Radiation	

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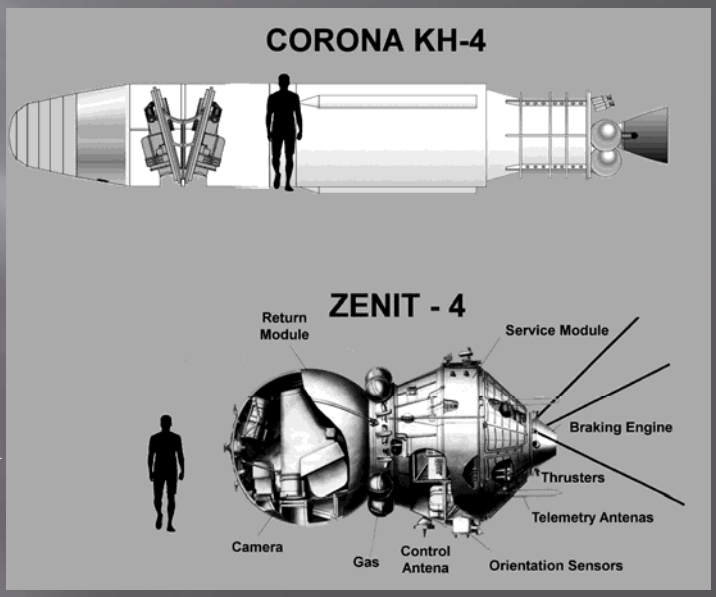
USA Approach vs. USSR Approach

Unpressurized

Pressurized



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Heat Transfer Phases

- 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.

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Agena Exchanging Energy

ENERGY CURRENTS

	Location	Spectrum
Solar	Top and one side	Solar 6000 K
Albedo	Lower	Solar 6000 K
Earthshine	Lower	Earth 300K
Deep Space	Top and sides	Earth 300K

TARGET VEHICLE

Two Band Radiation Model

91

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

92

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

93

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

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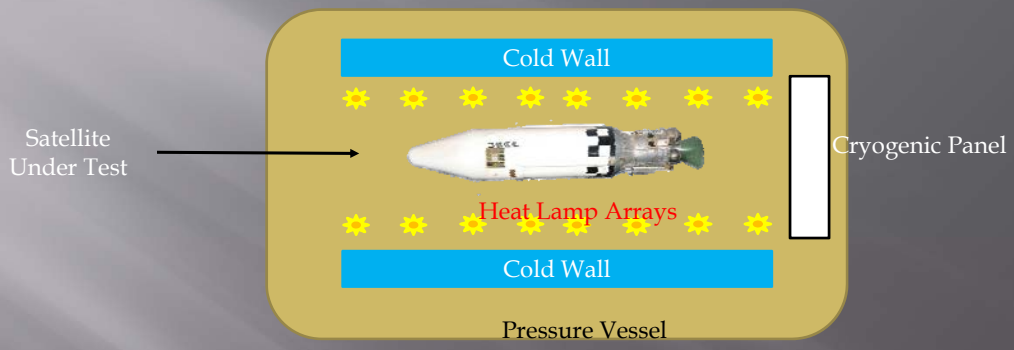
THERMAL-VACUUM VERIFICATON TEST



- Temperature Vacuum Stress Test
- Thermal Model Verification

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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.

96

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

97

Multiple Restart Capability

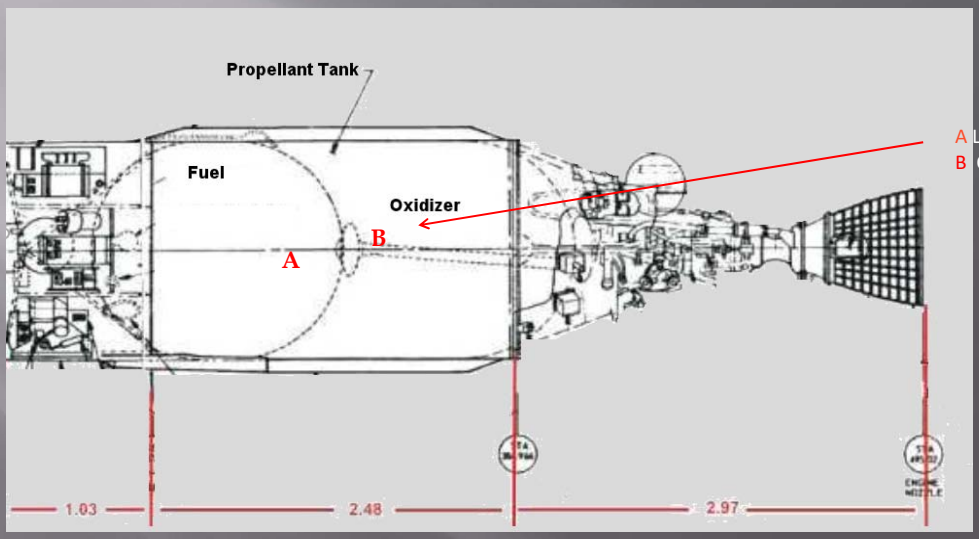
PURPOSES:

- Increase orbital apogee
- Replace array of multiple ullage rockets on aft rack

98

MULTIPLE RESTART CAPABILITY

PASSIVE – NO ACTIVE ELEMENTS



A LIQUID SUMP
B CONICAL SCREEN INLET

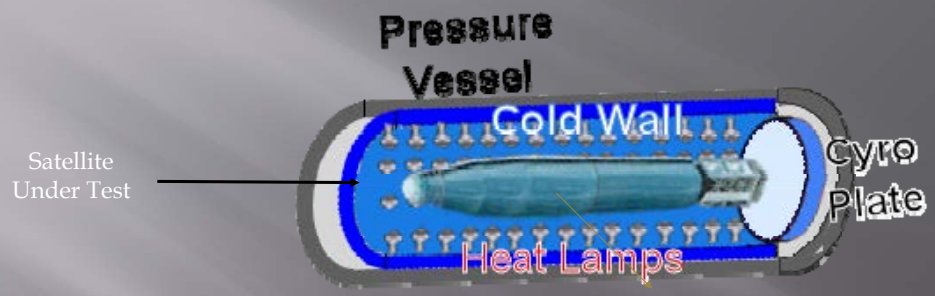
99

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

100

THERMAL-VACUUM VERIFICATON TEST



- Temperature Vacuum Stress Test
- Thermal Model Verification

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LOCKHEED'S RECONNAISSANCE SATELLITES

- CORONA'S Legacy

Sam Araki

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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

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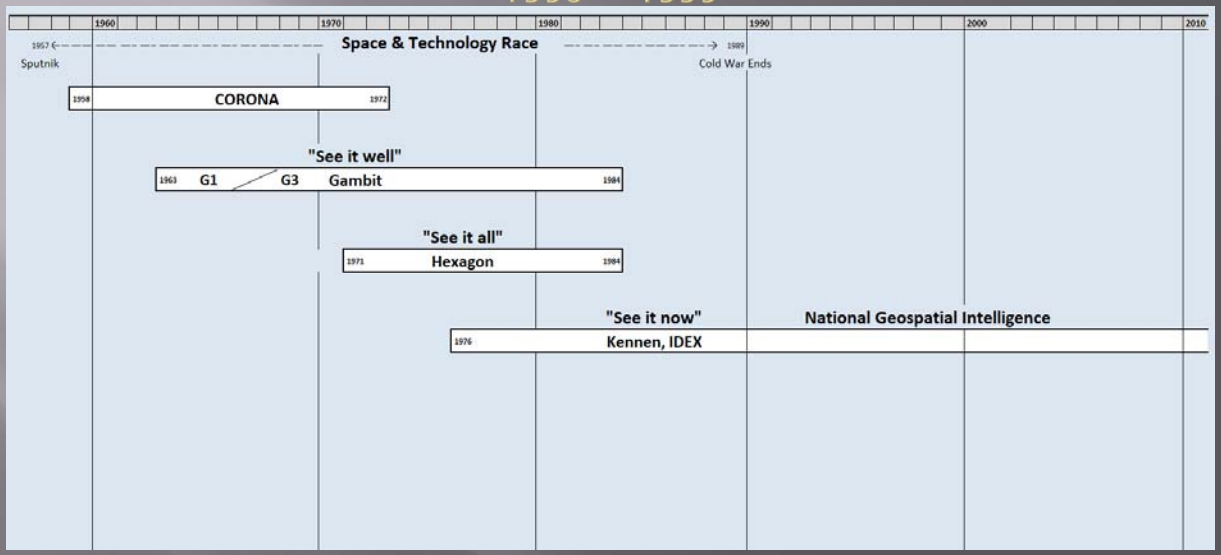
Lockheed's Reconnaissance Satellites
1956 — 1995



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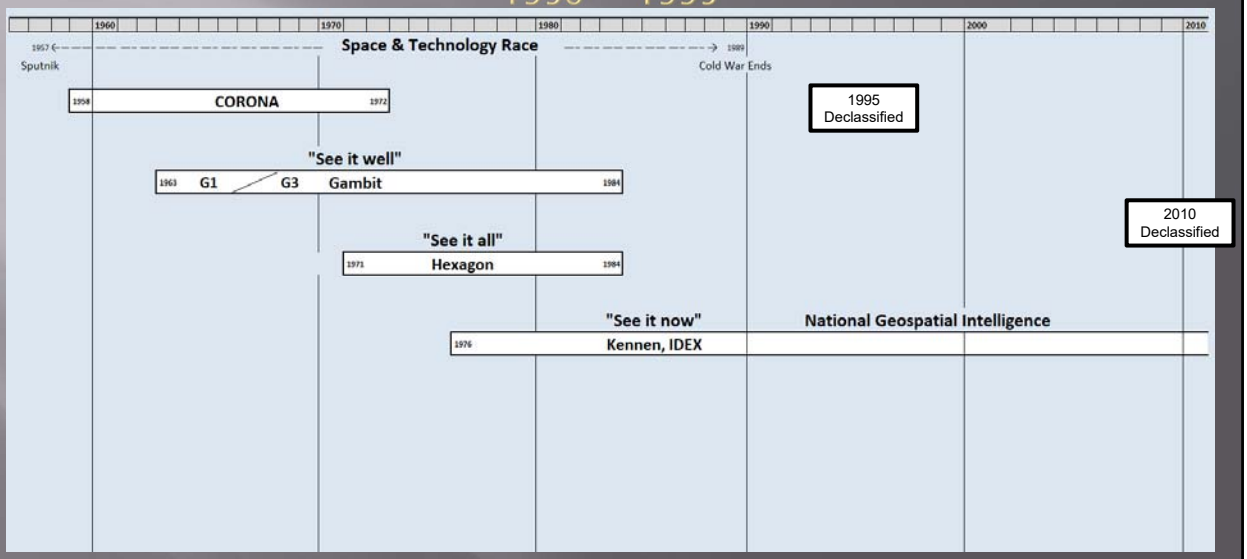
Lockheed's Reconnaissance Satellites
1956 — 1995



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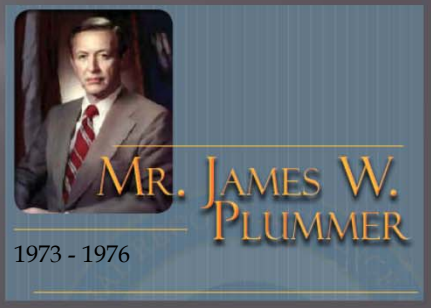
CORONA NRO Recognition

Dr. Joseph V. Charyk
1961-1963

Dr. Brockway McMillian
1963-1965

Dr. Alexander H. Flax
1965-1969

Dr. John L. McLucas
1969-1973



106

CORONA Program Recognitions

Awardees at 1995 declassification

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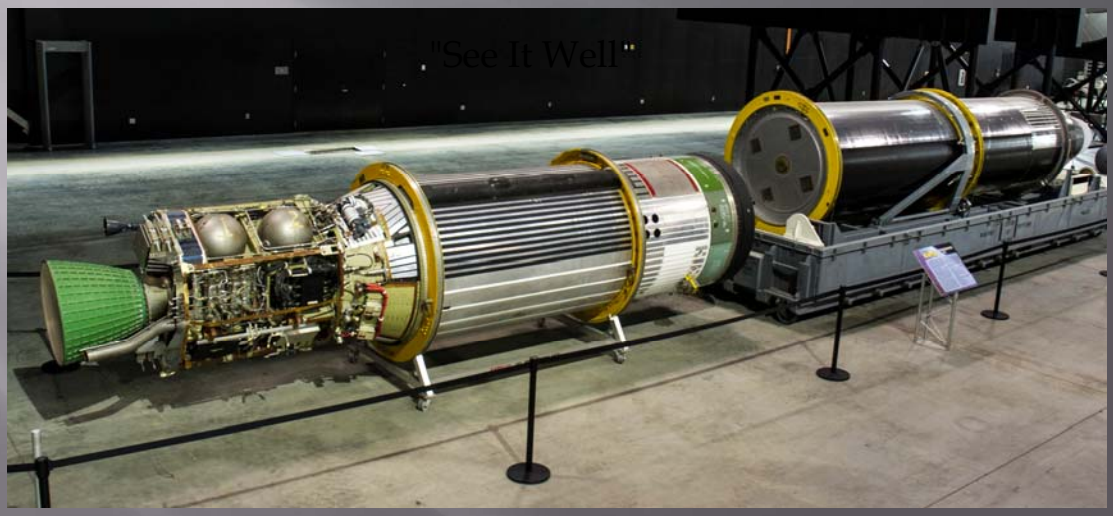
NRO 50th Anniversary (2012)
Gambit Declassification Ceremony



"See It Well"

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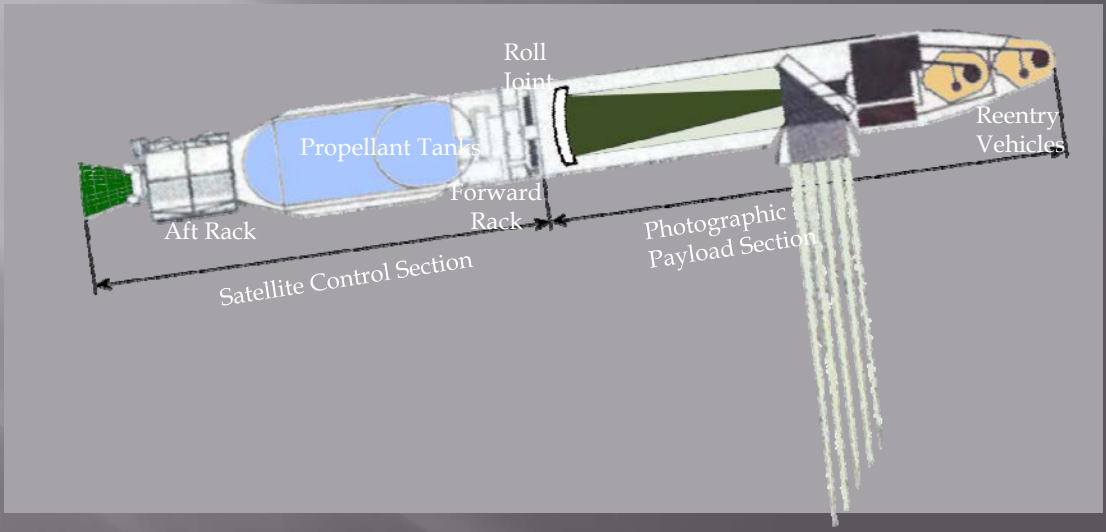
GAMBIT-3 Satellite Configuration



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NRO 50th Anniversary (2012)
Hexagon Declassification Ceremony

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Spacecraft Feature Comparison

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

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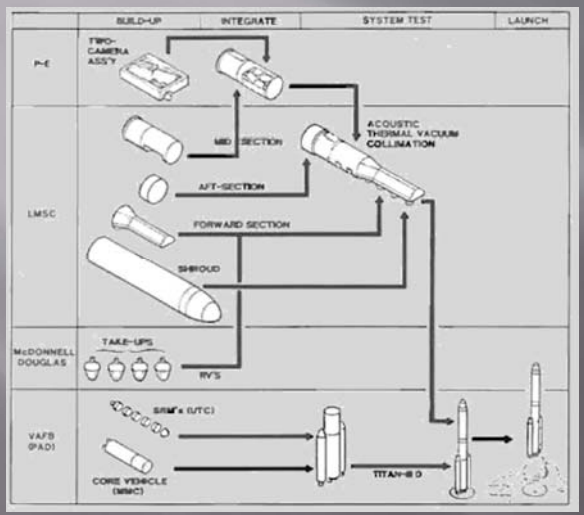
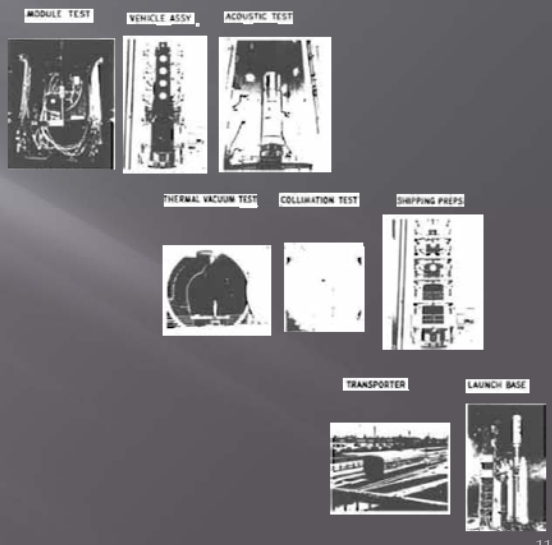
Hexagon – Factory to Pad





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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

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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

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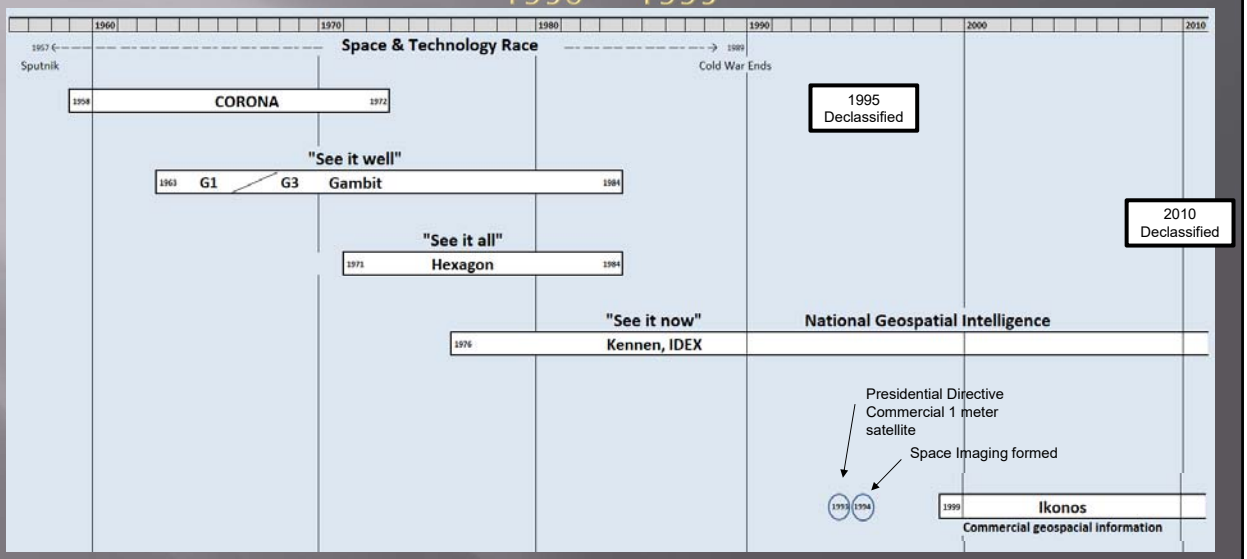
Lockheed's Reconnaissance Satellites
1956 — 1995



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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 km^2 collection / day

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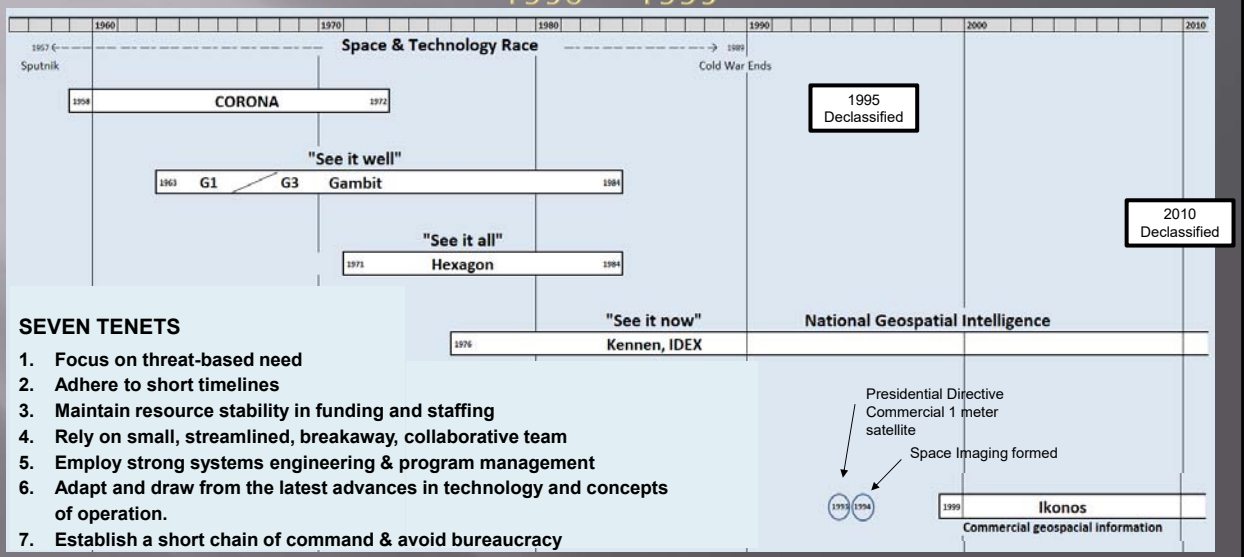
Lockheed's Reconnaissance Satellites
1956 — 1995



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**

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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

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LOCKHEED'S RECONNAISSANCE SATELLITES
- CORONA'S LEGACY

Panel
Questions and Answers

Resources:

- **Corona-Between the Sun & the Earth**, R.A. McDonald Editor, American Society for Photogrammetry and Remote Sensing, © 1997
- **CORONA**, NRO, https://www.nro.gov/History-and-Studies/Center-for-the-Study-of-National-Reconnaissance/The-CORONA-Program/
- **The Gambit and Hexagon Programs**, NRO, https://www.nro.gov/History-and-Studies/Center-for-the-Study-of-National-Reconnaissance/The-GAMBIT-and-HEXAGON-Programs/
- **National Reconnaissance Journal**, Spring 2012 https://www.nro.gov/Portals/65/documents/history/csnr/articles/docs/gh%20journal_web.pdf
- **Ikonos**, https://directory.eoportal.org/web/eoportal/satellite-missions/i/ikonos-2
- **The 4C1000 Seven Tenets for the 21st Century,** Araki et. al., NR Journal, June 2020 https://www.nro.gov/Portals/65/documents/history/csnr/articles/NRO_Journal_4C1000_Seven_Tenets_for_The_21st_Century_Pre-Print_7-2020.pdf?ver=2020-07-09-114911-710

Unused charts

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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

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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.....

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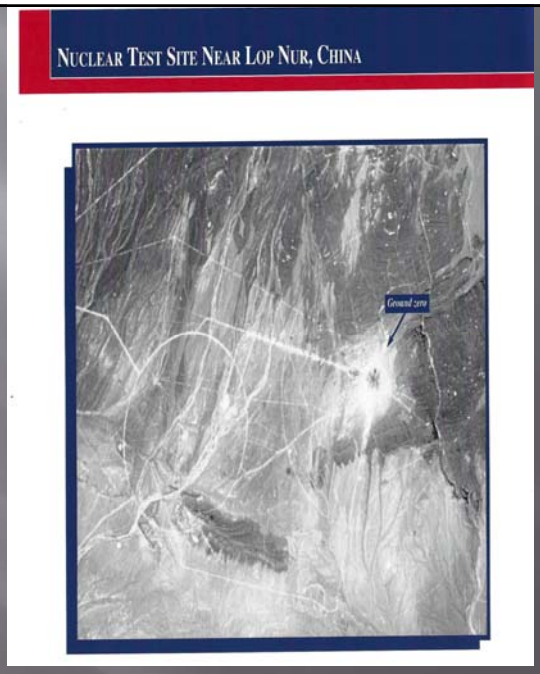

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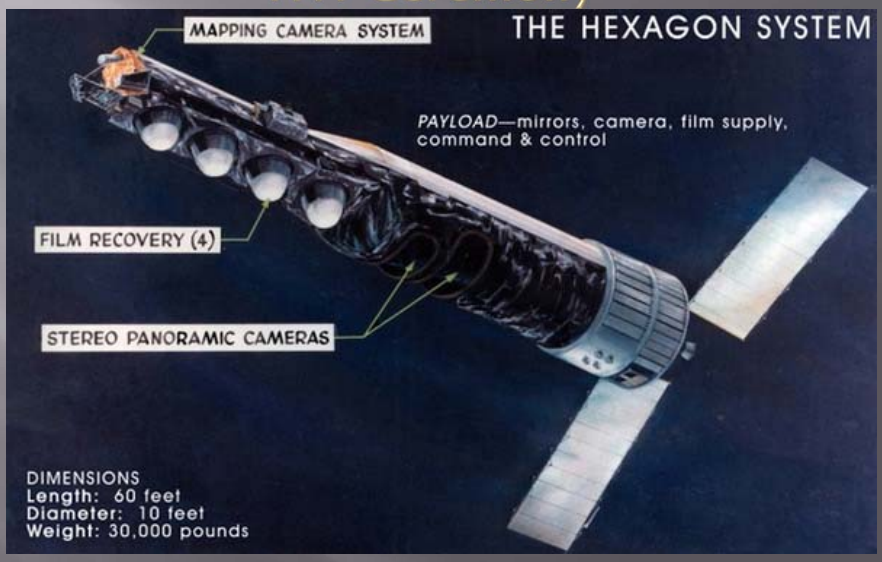
NRO 50th Anniversary (2010)
???? Ceremony



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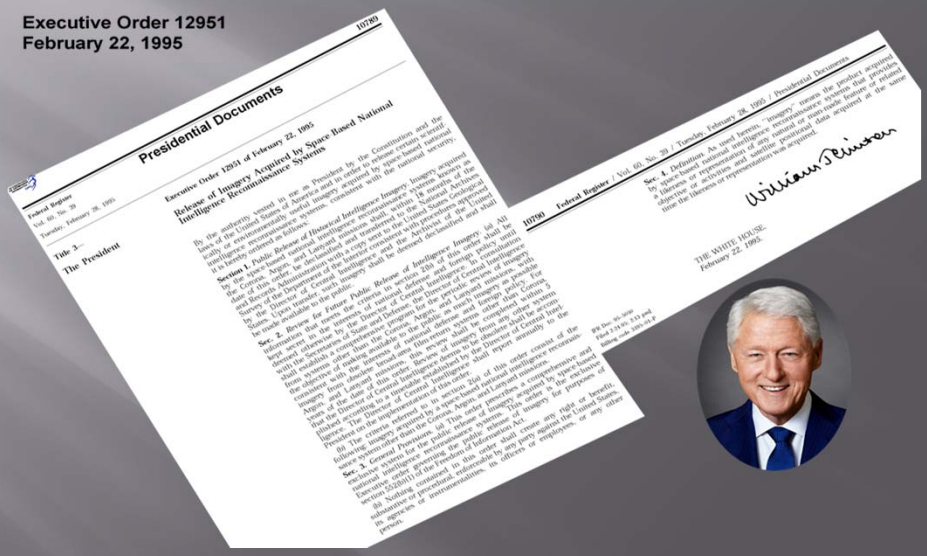
CORONA Program Declassification

Executive Order 12951
February 22, 1995



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Hubble