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Building, Launching and Operating an Earth-Imaging High-Resolution Satellite: The Earth Watch EarlyBird Satellite Evolution from Design through Launch to On-Orbit Operation

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ABSTRACT

This paper discusses the design, construction, and operational aspects of the first commercial high-resolution earth-imaging satellite system, including sensor and band selection, image capture pointing system, satellite launch, on-orbit satellite startup, and ground tracking operations.
Operational characteristics, orbit architecture, and the general business decisions that preceded the startup of a commercial high-resolution satellite venture will be the main topics of discussion for this presentation. Specific technical sensor and satellite issues will be addressed, as well as ground tracking and data transfer issues following satellite launch and downlinking.

1. A BRIEF HISTORY

Since the introduction of digital orthophotography in the late 80's, increasing demand has been seen in the mapping and GIS marketplace for timely, high-quality and cost-effective image data. In 1992, WorldView Imaging Corporation was formed with the idea of converting space-based weapons system technology into a viable earth-observation system, which would operate as a commercial business enterprise. That meant the technology had to be cost-effective, the product line and data characteristics had to be usable across a wide variety of applications, and a market potential had to be realistic to support further development.
While technically feasible from a sensor, satellite and launch vehicle standpoint, it was not until the US government relaxed the restrictions on remote sensing data acquisition that commercial satellite operation became a viable business option. Granted a 3-meter resolution license in January 1993, WorldView moved ahead with satellite design, sensor selection and spacecraft construction to meet the goals of the company.
Ball Aerospace, recognized as a major player in defense and research aerospace operations, applied for and was granted a 1-meter resolution commercial remote sensing license in 1994. An agreement was reached in 1995 to merge the commercial remote sensing efforts of Ball Aerospace and WorldView to pursue the high-resolution satellite image market as EarthWatch Incorporated, using the 3-meter and 1-meter programs as the basis for the EarlyBird and QuickBird satellite series.

2. CONSTRUCTION

A low-cost approach was decided upon for a viable commercial market entry of a satellite system. Instead of using older space-qualified systems mounted in large, heavy existing satellite platforms, a lesson was taken from the Strategic Defense Initiative (SDI) and “Brilliant Pebbles” research, which was based on small, inexpensive lightweight satellite platforms, using off-the-shelf state-of-the-art hardware and systems for low-cost and reliable operations.
Earth Watch began assembly of the first commercial EarlyBird system using a small spacecraft architecture, a unique Ball-developed agile pointing mirror and gimbal mount, a folded mirror optical telescope, and a series of Kodak CCD arrays for panchromatic and multispectral image capture. Imagery is collected with a dynamic range of 8 bits and then transferred to a 2GB Odetics solid-state recorder for store-and-forward data download.

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The satellite bus and peripheral processing systems were built by CTA in Maryland. The sensor payload, designed and built by Earth Watch in California, forms a spacecraft configuration totalling 7 feet long and weighing 700 pounds. In contrast, the LandSat satellite series weigh roughly 2100 pounds, requiring a much larger launch vehicle for orbital insertion, and have been built with specialized space-qualified hardware, increasing construction costs significantly.
As a point of interest, a second and third EarlyBird satellite are currently under construction, with one satellite slated for use by NASA as the Clark vehicle. Designed to evaluate the commercial market for high-resolution imagery, Clark does not have the same onboard storage capacity as the EarthWatch EarlyBird, and is constrained somewhat in total image capture capacity due to a different gimballed mirror system.

3. LAUNCH AND ORBIT

The launch vehicle chosen to lift the payload to a nominal 470 km altitude orbit is the Russian Start-1 single-stage system, formerly used for ballistic missile service. While first impressions may lean towards the thought that it is unusual that a US firm would use a former Soviet weapons system to launch a commercial satellite, several factors led to the decision to launch in this manner. A primary consideration was the reliability of the Start-1, with very few failures over an extended time period. Cost was another issue, with the Russian launch option coming in several millions of dollars below a comparable US-based launch vehicle.
The EarlyBird has been designed for a service life of 3 years, but will have enough fuel onboard for orbital maintenance and correction for 5 years of operation. The orbit inclination will be set at approximately 97° from the x-axis of the earth to establish a sun-synchronous polar orbit, with a nadir revisit period of 20 days, and an off-nadir revisit capability of 4-5 days.
A 97° orbit inclination was chosen to maximize coverage of the earth surface, with a constant overhead repeat time of approximately 10:30 a. m. local time at the equator and a 90 minute orbital period. A polar orbit such as this allows imaging an area with a constant sun angle, thereby generating consistent shadows when imaging the same area over time.

4. OPTICS AND SENSORS

A Kodak staggered-array CCD focal plane assembly was chosen to capture both panchromatic and multispectral imagery, using a “step and stare” methodology to image terrain features. The CCD sensor arrays are 1048 x 1080 pixels each, with 4 sensors creating a frame. As the satellite passes overhead, a unique 2-axis gimbal mirror system directs the surface scene to the focal plane assembly, and the sensors record a frame at 2/1000ths of a second for transfer to the solid state recorder. The gimbal assembly then steps and swings to capture subsequent overlapping frames, moving in both X- and Y-directions to fill out a compete image scene.
The high-resolution panchromatic camera sits in the optical path of a folded-optic mirror telescope, and captures imagery with a ground sampling distance of 3,2 meters at nadir. The wide-field multispectral camera uses a scraper mirror situated in the primary optical path to direct the surface scene to a multiple detector assembly, with three of the Kodak CCD focal plane arrays capturing the scene in green, red and near infra-red through a dichroic beam splitter. Because the effective focal length of the multispectral detector assembly is roughly 1/5 the length of the high-resolution camera optical path, the resulting ground sampling distance for multispectral imagery is 15 meters at nadir.
A fifth star tracker camera has been included onboard the spacecraft to image a field of stars for precise satellite orientation information, helping to refine the positional accuracy of the spacecraft and the resulting imagery for subsequent geopositioning and orthorectification as required. Consisting of a single 1K x 1K Kodak CCD, identical to those found in the panchromatic and multispectral cameras,

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the star tracker images the star field concurrently with ground scene capture to aid in further postprocessing and georeferencing.

5. DATA PROCESSING AND MANAGEMENT

Once the sensors have captured imagery of the requested areas, the data is transferred from the sensors to an Odetics solid-state recorder for storage until the satellite comes into view of a ground station. Currently, EarthWatch has established two operational ground stations for data transfer to support initial EarlyBird operations; one in Fairbanks, Alaska, and the other in Tromso, Norway. A centrally located ground control station has been established at EarthWatch headquarters, linking Satellite Operations and Mission Control to the two ground stations via the ComSat geosynchronous satellite. That link enables both command upload to the satellite and data transfer from Alaska and Norway to a central repository in Colorado.

The repository and gateway, commercially known as the Digital Globe™ database, is supported by several SGI Challenge servers, and three terrabyte-level storage devices for rapid access and processing throughput. Access to the database is possible following client registration via the InterNet, with image browsing and online ordering capability. Delivery of data is possible through conventional media, including 8 mm and 4 mm tapes, as well as CD-ROM format. An ftp data transfer capability and increasing electronic distribution capabilities are also being planned.

Once data is received at Longmont, various levels of processing are applied according to client requirements. That processing can include simple missing pixel mapping and contrast adjustments, uncontrolled mosaicking and radiometric balancing across the scene, or full differential orthorectification, mosaicking and rigorous radiometric adjustment for true image map capability. The resulting raw or processed data would then be introduced into the Digital Globe™ database, becoming available for order and download.

6. LOOKING FORWARD

The EarlyBird-1 satellite is scheduled to launch in the 2nd half of 1997, with a 1-month comissioning, calibration and test period following immediately after launch. Raw data capability will be available at launch + 1 month, with additional capabilities being brought online in stages after that.

The launch vehicle is the Russian Start-1 vehicle provided by STC Complex. A conventional polar orbit will provide a wide base of coverage for broad applications development, with an agressive revisit capability.

Subsequent launches will focus on the Ball-developed QuickBird satellite system, a .82-meter resolution pushbroom sensor system mounted in an agile-bus satellite. The satellite bus will tip an tilt via inertia wheels to point the sensor at tasked areas for collection, and supports a 22 km swath width for image acquisition at 0,82 m.

The QuickBird series will use a 52.5° orbital inclination in a non-sun-synchronous orbit, focusing collection capability on the highly populated portions of the Earth to support GIS and mapping operations. Revisit times will be 1-2 days with one system in orbit, and twice a day when both QuickBirds are in orbit. With such a low inclination, additional ground stations will be situated in Tokyo, Longmont and Rome to support the large data transfer and storage requirements stemming from 0.82 meter sensors.

The two QuickBirds are scheduled for launch in late 1998 and early 1999, with EarlyBird-2 following later, either as a replacement for EarlyBird 1 or to add additional collection and revisit capacity in support of customer demand if necessary.

Overall, given the rapid inclusion of digital orthophotography at increasing resolutions into widespread GIS systems since the late 80's, the future for high-resolution space-based imagery is looking very

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positive, with the GIS, agriculture and natural resource markets standing to benefit from readily available image data to fit a wide variety of operational and monitoring functions.