High-Resolution Imaging From

A World-Wide Survey (Part I - North America)

My two previous overview articles on high-resolution imagery from space were published in the March 2001 and September 2002 issues of GeoInformatics. These were concerned mainly with the commercial providers of such imagery - since the vast majority of the readers of the magazine (and users in general) do not have access to the high-resolution imagery obtained from military reconnaissance satellites. However it has been apparent for some time that the largest consumers of high-resolution space imagery world-wide are those government agencies involved in intelligence gathering and in mapping for military purposes. Within this particular context, the commercial space imagery supplements the imagery gathered by dedicated reconnaissance satellites. At the recent ISPRS Workshop on "High Resolution Mapping from Space" held between 6th and 8th October 2003 at the University of Hannover, I was invited to present an overview on current developments and future trends in imaging and mapping from space covering the high-resolution imagery acquired from both commercial and military satellites. The present article is based on this presentation. Because of its length, the article has been divided into three main parts - concerned with developments in North America, Asia and Europe respectively. For the purposes of this overview, high-resolution imagery has been defined as that having a ground sampled distance (SD) or ground pixel size of 5m or smaller.

By Gordon Petrie

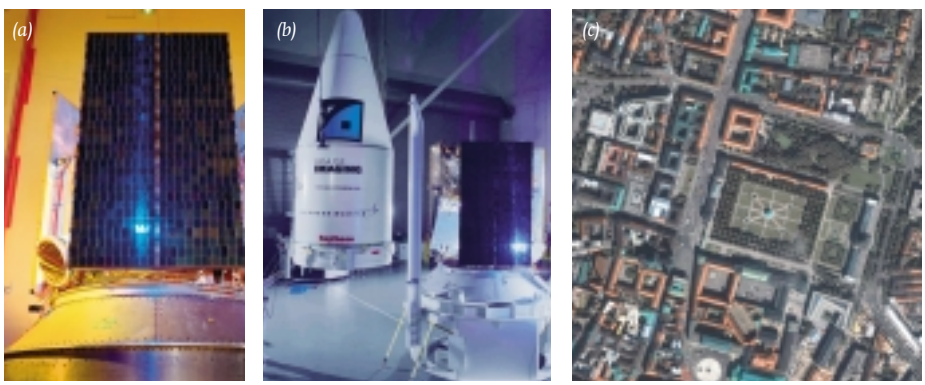

Figure 1: (a) An IKONOS satellite being checked out in a clean room at Lockheed Martin. (Source: Lockheed Martin) (b) An IKONOS satellite sitting alongside its protective nose cone. It was the failure of this protective cover to separate from the Athena launcher that caused the loss of the IKONOS-1 satellite in April 1999. (Source: Lockheed Martin), (c) A multi-spectral IKONOS image of part of the city centre of Munich, Germany. (Source: Space Imaging)

1.1 U.S. Commercial High-Resolution Imagery

It would seem appropriate to start by considering the situation in respect of the three American commercial companies - Space Imaging, DigitalGlobe and ORBIMAGE - that are offering high-resolution space imagery as a commercial product. The first two of these companies have been selling such images for some time; the third, ORBIMAGE, is about to do so. However up-till-now, this whole sector has been one in which at least two of these three companies have experienced very considerable financial losses. These losses have deterred investors. In fact, currently there are no commercial high-resolution satellites under construction in the U.S.A. It is worth analyzing the various factors that have caused this situation to come about.

Reliability Issues

Of the seven American satellites that have been launched with the objective of providing high-resolution space imagery on a commercial basis, four of them - EarlyBird (in 1997), IKONOS-1 (in 1999), QuickBird-1 (in 2000) and OrbView-4 (in 2001) - failed either at launch or very soon after. Only two - IKONOS-2 and QuickBird-2 - have been operational for any length of time and they have now been joined by OrbView-3. So the launch record has been poor to say the least, with large financial losses being suffered both on the part of the companies themselves and by their insurers. Besides which, the loss of these satellites resulted in considerable cutbacks in the staff employed by each of the companies concerned.

Financial Aspects - Space Imaging

The initial financial investment needed for the construction of the satellites and their imagers and the supporting infrastructure (ground stations, processing facilities, etc.) has been very high. In the case of Space Imaging (SI), several sources have quoted an overall investment of $700 million. The principal shareholders in SI are three major corporations - Lockheed-Martin (46%), Raytheon (33%) and

Space

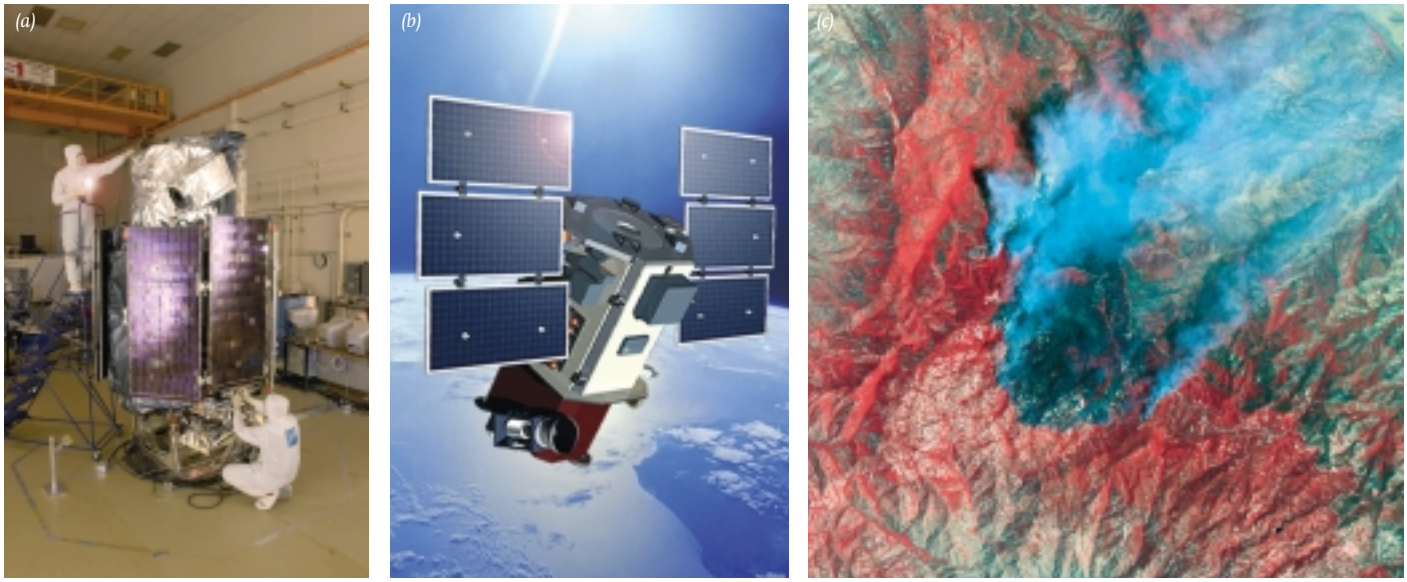

Figure 2: (a) A QuickBird satellite being checked out in a clean room at Ball Aerospace. (Source: Ball Aerospace), (b) An artist's impression of the QuickBird satellite in its operational orbit. (Source: DigitalGlobe), (c) A false-colour multi-spectral image of a forest fire in the southern part of Arizona acquired in June 2003, showing the burned area from which smoke is still rising. The unburned vegetated area shows up clearly in red. (Source: DigitalGlobe)

Mitsubishi - who could afford to make the huge initial investment that was required. Besides which, the actual operations involved in operating a high-resolution satellite and in acquiring, processing and distributing the resulting imagery also result in substantial financial overheads. A staff of 400 people was being employed by Space Imaging in 2002, though this has since been cut considerably. However it does seem that, so far, there has only been a relatively limited return on this large investment. As well as the direct capital investment, large credit facilities (loans) amounting to $300 million have been used to keep the Space Imaging company running. These credit facilities were guaranteed by Lockheed-Martin and Raytheon. According to the published accounts of these two corporations, by the end of 2002, Space Imaging had drawn on $277 million of these credit facilities. When the repayment of these loans fell due in March 2003, the sums were paid off by the guarantors, Lockheed-Martin and Raytheon. Thus Lockheed-Martin recorded a charge (loss) of $163 million and Raytheon, a charge (loss) of $175 million in respect of their investments in Space Imaging, as declared in their annual reports and accounts for 2002. Both companies declared that "they would not be providing additional funding at this time in order to fund replacement satellites" - though they still retained their controlling interests in the company. So the SI company has a single satellite, now four years old and, as yet, no money to fund the projected Block 2 IKONOS satellites, which will take at least 2 years to build.

Commercial Aspects - Space Imaging

Furthermore IKONOS imagery is extremely expensive to buy, especially for those non-military users located outside North America. Originally for the most basic Geo imagery with minimum processing and no correction for terrain relief, a single scene of 11 x 11km = 121 sq. km cost $35 per sq. km, amounting to $4,235 for such an image. After the competition brought about by DigitalGlobe's QuickBird satellite coming into service in 2002, the price was cut to $25 per sq. km, which still amounts to $3,025 per scene. In the case of the Precision and Precision Plus products - which require the use of ground control points and DEMs - these images can cost up to 5 to 10 times the price of the Geo imagery (Fraser et al 2002). All of these difficulties were compounded by the initial refusal of Space Imaging during the first two years of operating IKONOS to supply stereo-imagery to non-government users. Besides which, there was the company's refusal to supply the calibration data and the measured in-flight orientation data for the IKONOS imagery. This was followed by an attempt to force users to use rational polynomials instead of an exact photogrammetric solution for the geometric rectification of IKONOS imagery. All of which amounted to an attempt to ensure that value-added processing such as DEM generation or orthophoto production from IKONOS imagery could only be carried out by Space Imaging or its affiliates. These commercial policies and practices did not go down well with many civilian users or potential users.

Summary - Space Imaging

In summary, it would appear that sales of IKONOS imagery to civilian users have been smaller than expected. According to the re-sellers and various industry analysts, the biggest customer of all remains the U.S. government, while other major customers are foreign governments and military agencies, especially those based in the Middle East and in South and East Asia. Various sources have quoted the total annual income for Space Imaging as being $100 million in 2000 (Space News); $170 million in 2001 (Space News); and over $200 million in 2003 (Space Imaging). Whether this is enough to meet salaries, running expenses, etc. and still give an adequate return on the initial financial investment is an open question. The staff, which reached 400 at its peak, has now - according to the Denver Post - been cut

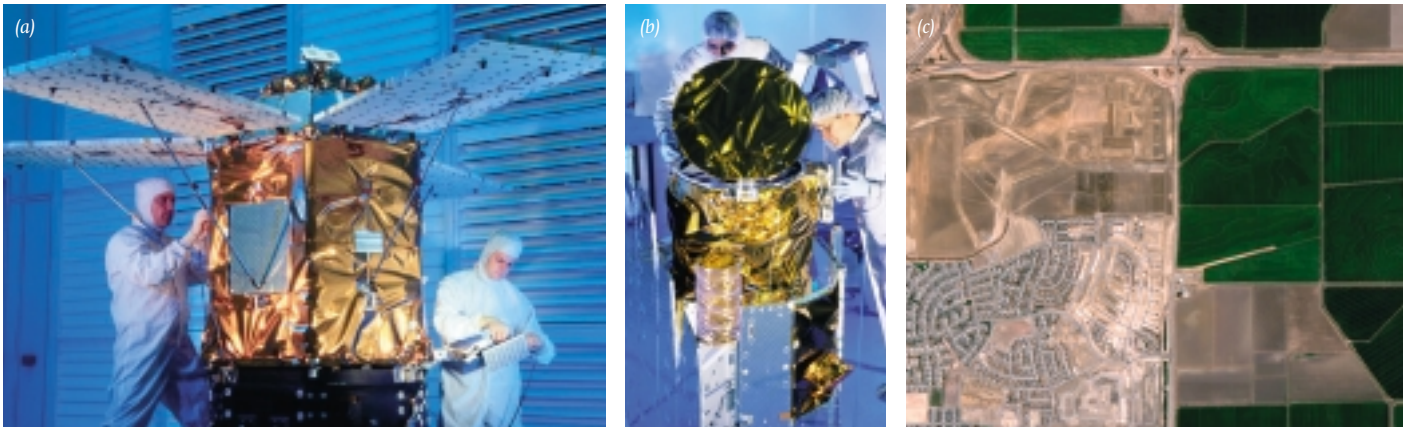

Figure 3: (a) The OrbView-4 satellite being checked out in a clean room at the Orbital Sciences Corporation. This particular satellite was lost at launch in September 2001 due to the malfunction of its Taurus launcher. (Source: Orbital), (b) The OrbView-3 satellite being checked out at the Orbital Sciences Corporation. This satellite was launched successfully in June 2003. (Source: Orbital), (c) A multi-spectral image of a part of Sacramento, California that was acquired by the OrbView-3 satellite in August 2003. (Source: ORBIMAGE)

back to 270. In particular, the applications division (formerly the Pacific Meridian company) has been scaled down considerably.

DigitalGlobe

DigitalGlobe (DG) is (or was) a smaller and lower-cost operation than Space Imaging. It had considerably lower start-up costs; and it does not run the world-wide network of affiliate companies operated by Space Imaging. In this respect, the downlinking of QuickBird data takes place only at two stations in Norway and Alaska, now to be supplemented by a third station located in Pennsylvania. Besides which, all the processing of the image data is centralised at DG's Longmont headquarters in Colorado. I have looked at the annual accounts of two of the biggest industrial investors in the original Earthwatch/DigitalGlobe company - Ball Aerospace and ITT Industries - but could find no comparable figures or indeed any reference to their current investments in DigitalGlobe. From this, one could infer that they have been satisfied with their investment - though this inference may not be correct! In any case, with the recent increased capitalization of DigitalGlobe, the investment of each of these two companies has now fallen to under 10% in each case. As for the staff numbers, according to the Denver Post, this has now been increased from 200 to nearly 300 people.

ORBIMAGE

ORBIMAGE presents yet another different and somewhat confusing story. Initially the company was largely funded by and run as a subsidiary of the Orbital Sciences Corporation. The first two satellites - OrbView-1 (from 1995) and -2 (from 1997) - were scientific satellites whose low-resolution images have mainly been used by NASA, NOAA, universities, etc. For the construction of the two high-resolution satellites, OrbView-3 and -4, a large amount of additional capital was raised in the form of senior notes (loans) provided by venture capitalists. Originally the two satellites were supposed to be orbited in 1999. However many delays were experienced during their construction. Eventually, in September 2001, an attempt was made to launch the larger OrbView-4 satellite on which the USAF's WF-1 hyperspectral imager had been mounted, alongside ORBIMAGE's own 1m pan and 4m multi-spectral imagers. Unfortunately, this launch attempt failed. Immediately afterwards, the ORBIMAGE company tried to enter bankruptcy protection (under Chapter 11 of the U.S. Bankruptcy Code) and eventually it was able to do so in April 2002.

Re-Structuring ORBIMAGE

Essentially the ORBIMAGE company was taken over and re-structured by its financial backers who had provided the loans. They formed a creditors' committee and provided a new top management. They also instituted litigation against the parent Orbital Sciences Corporation for the delays incurred in building and launching the OrbView-3 and -4 satellites. Further litigation was instituted against Macdonald Dettwiler Associates (MDA) for the delays in launching Radarsat-2, for which ORBIMAGE was the principal distributor for the U.S.A. These legal procedures have now been settled and have resulted in Orbital Sciences providing a substantial additional working capital and MDA a lump sum ($10 million) as compensation in respect of its failure to launch Radarsat-2. When added to the substantial insurance pay-out received after the failure of OrbView-4, gradually some of the main creditors have been paid off and the company has now emerged from its bankruptcy protection. Orbital Sciences has also been able to complete OrbView-3 and to launch it successfully on June 26th 2003. The first images from the satellite have just been released.

Summary - U.S. Commercial High-Resolution Space Imagery

So what now? Space Imaging and ORBIMAGE have both suffered well-documented financial losses and traumas. However the U.S. government has now entered the arena to give its support to the troubled commercial high-resolution space imaging business. This is being done through two different programmes:-

(i) ClearView - which provides guaranteed purchases of imagery from the existing satellites for the next 3 to 5 years; and

(ii) NextView - which aims to provide further assured purchases of still higher-resolution imagery from the commercial operators, so encouraging them to build new satellites providing the still higher-resolution (0.5 to 0.25m ground pixel) imagery required by U.S. intelligence and military mapping agencies.

1.2 U.S. Military High-Resolution Imagery

Again this provides an interesting story - as far as it is known. The U.S. military reconnaissance satellite capability is provided by its National Reconnaissance Office (NRO). Currently this capability comprises six satellites - three KH11/12 optical satellites and three Lacrosse radar satellites. The KH11/12 satellites are fitted with very long focal length optical telescopes - like that on the Hubble Space Telescope but pointing towards the Earth instead of space. Reputedly these optical imagers can provide images with 10 to 15cm ground pixel size. The Lacrosse radar satellites provide additional day/night and all-weather imag-

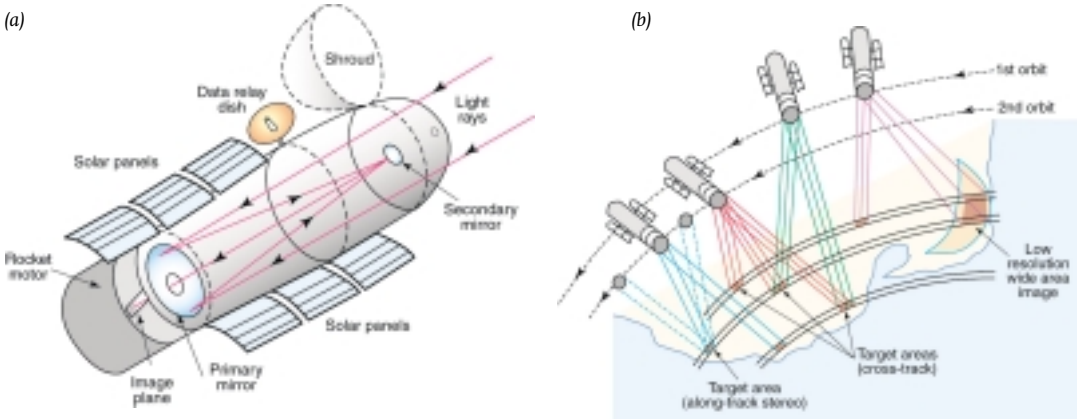

Figure 4:
(a) A sketch of the KH-12 satellite, three of which are operated by NRO.
(b) A diagram showing the different operational modes of the KH-12 satellite. (Drawn by Mike Shand; adapted from original drawings by C.A. Vick of the Federation of American Scientists)

ing capabilities giving images with 1 to 3m ground pixel size. However most of these satellites are now quite old. The three KH11/12 satellites that are currently in operational service were launched in October 1995 (now 8 years old), December 1996 (7 years old) and October 2001 (2 years old) respectively. The three operational Lacrosse satellites were launched in March 1991 (now 12 years old), October 1997 (6 years old) and August 2000 (3 years old). There are suspicions that the latest NRO satellite launch on 7th August 2003 might be that of a new Lacrosse satellite, but some commentators think that it could be an electronic monitoring (i.e. eavesdropping) satellite.

Future Imaging Architecture (FIA)

Preparations for the replacement of this now ageing fleet of reconnaissance satellites started in the mid-1990s with NRO presenting its programme to the Department of Defense in 1996. A number of potential contractors were invited to enter the competition and bid for the programme, but eventually only the two largest contractors, Boeing and Lockheed-Martin, made final bids. Although Lockheed-Martin had built every U.S. high-resolution reconnaissance satellite over the 40 year period of their operation, Boeing were awarded the contract for the satellites to be built under the so-called "Future Imagery Architecture" (FIA). Reportedly, this would comprise a relatively small number of optical satellites, which would operate from a higher altitude than the KH11/12 series, so ensuring slower speeds and a longer dwell time over the ground. Of course this would then require longer focal length optics to obtain the high-resolution imagery that is required. The second main component of the system would comprise a constellation of smaller radar satellites that would provide more frequent coverage of the ground with all-weather and day/night capabilities.

FIA(SCO)

Originally, the FIA satellites were supposed to be operational from 2003 onwards. However the whole FIA project has been beset by technical and financial difficulties. So much so that critics have renamed the project as FIASCO! Reportedly the satellites are too heavy with lots of technical problems still unresolved. Costs have spiralled virtually out-of-control resulting in a massive financial overrun. The U.S. Congress has been asked to find $4 billion to meet the shortfall. The first FIA satellites will not now appear until 2005/2006. So the U.S. Congress has directed the inspectors-general of the Department of Defense and the CIA to investigate the matter and report on what has gone wrong.

NIMA

The current situation is that the NRO has only a few over-committed and mostly quite old high-resolution reconnaissance satellites with limited consumables (propellant, batteries, etc.). These are therefore being reserved for the imaging of high-priority targets. NRO is really in a crisis situation - it hasn't launched an imaging satellite since 2001. This has caused the intelligence agencies to turn to the commercial high-resolution satellites to make up the shortfall in imagery. In June 2002, the head of the CIA, George Tenet, ordered the National Mapping & Imagery Agency (NIMA) to make maximum use of commercial high-resolution space imagery for mapping purposes - "it should be the primary source of data used for government mapping, regardless of whether the production work is performed by NIMA or is outsourced .... The NRO satellites should only be tasked for mapping under exceptional circumstances". So large additional sums of money have now been provided to NIMA specifically to buy commercial high-resolution space imagery.

ClearView

In January 2003, NIMA awarded three-year contracts to both Space Imaging and DigitalGlobe for imagery and mapping under its ClearView programme. Space Imaging's contract is for a guaranteed minimum purchase of $120 million of imagery over a three-year period. DigitalGlobe received a similar contract guaranteeing the purchase of $72 million (also reported as being $96 million) worth of imagery. These base contracts are for three years initially, with two additional one-year options. Each contract has a ceiling of $500 million over the five years of its operation. ORBIMAGE will also receive a similar contract, once it has shown that the OrbView-3 satellite is fully operational and is producing imagery of an appropriate image quality.

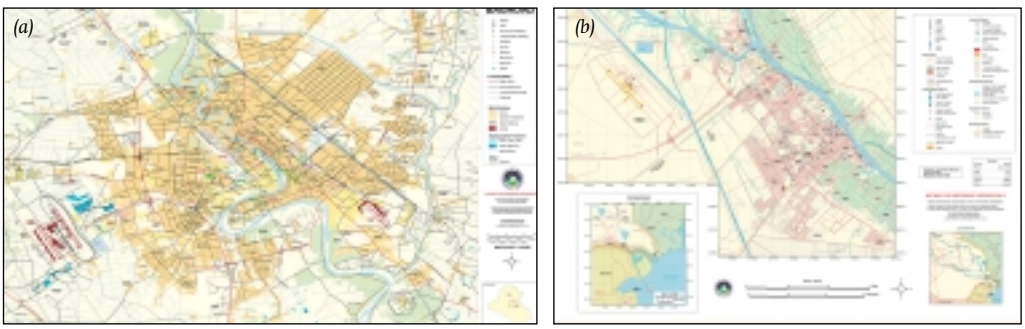

Figure 5: (a) The new 1:40,000 scale map of Baghdad issued in February 2003;
(b) The new 1:30,000 scale map of Basra issued in April 2003. Both maps have been produced by NIMA based on high-resolution space imagery and are available over the Web without cost from the Map Library of the Perry-Castaneda Library of the University of Texas. (Source: NIMA)

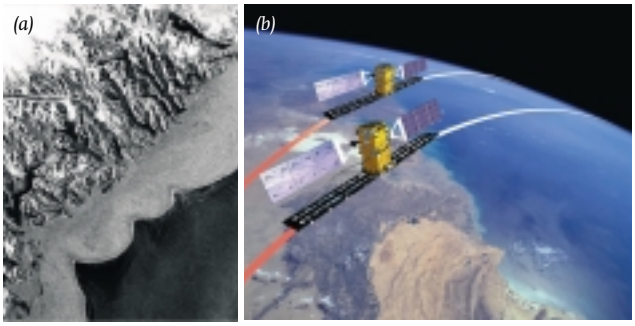

Figure 6: (a) A radar image of the east coast of Greenland acquired by the C-band SAR on board the Radarsat-1 satellite.
(b) An artist's impression of the proposed Radarsat-2/3 tandem mission to acquire interferometric SAR imagery. (Source: Radarsat International)

U.S. Commercial Space Remote Sensing Policy

Shortly afterwards, in March 2003, the White House issued its new National Security Presidential Directive 27, entitled "U.S. Commercial Space Remote Sensing Policy" and signed by President Bush. Under this Directive, the U.S. government will:-

(1) rely to the maximum practical extent on U.S. commercial space remote sensing capabilities for filling imagery and geospatial needs for military, intelligence, foreign policy, homeland security and civil users;
(2) focus U.S. Government space remote sensing systems on meeting needs that cannot be effectively, affordably and reliably satisfied by commercial providers because of economic factors, civil mission needs, national security concerns or foreign policy concerns;
(3) develop a long-term, sustainable relationship between the U.S. Government and the U.S. commercial space remote sensing industry;
(4) provide a timely and responsive regulatory environment for licensing the operations and exports of commercial space remote sensing systems; and
(5) enable U.S. industry to compete successfully as a provider of space remote sensing capabilities for foreign governments and foreign commercial users, while ensuring appropriate measures are implemented to protect U.S. national security and foreign policy interests.

NextView

With this backing, NIMA then opened discussions with the two main companies - SI & DG - on a new programme called NextView. Under this programme, the commercial companies would build a new generation of satellites with NIMA pre-purchasing time on them, so acting as "anchor customers". Essentially NIMA would be underwriting the construction and launch of the new satellites, but would not own or operate them. They could be used to collect commercial imagery as well as being used for government and military mapping and intelligence purposes. Space Imaging was allied with Lockheed-Martin and Raytheon in its bid for NextView with ORBIMAGE also forming part of the team. DigitalGlobe was allied with Ball Aerospace, ITT and BAE Systems.

NextView Contract Award

On 30th September 2003, NIMA announced that it had awarded a five-year contract to DigitalGlobe under its NextView programme

(i) to assure the availability of high-resolution imagery from the next series of U.S. commercial imagery satellites.
(ii) The contract affords greater access and priority and advanced capability and capacity to government customers, while providing DigitalGlobe with long-term commitments and capital for its satellite development.
(iii) The NextView award is a contract with a potential to award more than $500 million over the period of the contract.
(iv) This contract will transform how NIMA provides geospatial intelligence by assuring availability of 0.5m commercial imagery.
(v) Simultaneously NIMA is pursuing further discussions with Space Imaging regarding a contract to continue development of a follow-on system to provide NIMA with an additional source of commercial imagery.

Summary - U.S. High-Resolution Space Imagery

In summary, the U.S. government (Uncle Sam!) has come to the rescue of the commercial high-resolution space imaging providers through the ClearView and NextView programmes, backed by a Presidential Directive. Simultaneously, through these two programmes, it is helping to solve its own problems with the very high-resolution military reconnaissance satellite programme. Nevertheless it does seem that there will be a hiatus period - of at least two years - before (a) the new commercial satellites are designed, developed, built and launched; and (b) the FIA problems are resolved and the military reconnaissance satellites are also launched.

1.3 Canada - Radarsat

The original Radarsat-1 was launched by NASA on behalf of the Canadian Space Agency (CSA) in November 1995. It provides a variety of imaging modes that produce images with 8m to 100m ground pixel sizes depending on the mode that has been selected. Now eight years old, it is still operational. The follow-on Radarsat-2 satellite is being funded as a public/private partnership between CSA (originally providing $225 million) and MDA (providing $80 million). More recently, these sums have been revised upwards to $400 million and $90 million respectively. The new satellite is designed to use an improved C-band SAR that will provide images over the range 3m to 100m in terms of their ground pixel sizes. This planned capability resulted in a long running and much publicised dispute with the U.S. government - which did not wish such high-resolution (3m) radar images to be sold publicly. The supply of certain U.S. sourced radar components was stopped and the offer by NASA to launch Radarsat-2 (as it had with Radarsat-1) in return for the supply of a certain amount of radar imagery was withdrawn. In response, the proposed CSA contract with Orbital Sciences for the supply of the satellite platform was withdrawn and awarded instead to Alenia Spazio in Italy. Originally Radarsat-2 was to be launched in 2001, but this was delayed by the dispute. The CSA then had a re-think and decided that changes needed to be made to Radarsat-2 to support a Tandem mission along with a projected Radarsat-3 satellite in order to generate interferometric SAR imagery for DEM generation. The Radarsat-2 launch was shifted first to 2003. Currently it is scheduled for the end of 2005 using a Boeing Delta-2 launcher, which the Canadian partners are now having to pay for.

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