Appendix A

The Technology of Newsgathering From Space[1]

Stillman C. Chase, Hughes Santa Barbara Research Center; and Matthew Willard, Earth Observation Satellite Co.

Introduction

Remote sensing of the Earth from space began in 1960 with the launch of the first TIROS weather satellite. The U.S. environmental satellite program has since expanded to provide low-resolution, broad-scale data from both low-Earth polar orbits and from geosynchronous orbit. These data have been widely used by the media for more than two decades to illustrate the form and motion of large-scale weather patterns.

Higher resolution multispectral images of the Earth from space first became available to the civilian user in 1972, when NASA launched the first Landsat satellite into a near-polar orbit.[2] That spacecraft carried a sensor called a multispectral scanner (MSS), which produced experimental data in four spectral bands that could be used to aid cartography; agricultural inventories; mineral, oil, and gas exploration; and land-use planning. The media have found these images of little interest primarily because the data provide a spatial resolution of only 80 meters (262 feet). Although the images generated with MSS data reveal some cultural features, including large road ways such as the interstate highways, and even large buildings, such as the Pentagon, or the shuttle assembly plant at Cape Canaveral, the identity of smaller features cannot be discerned.[3] In addition, because the first three Landsat spacecraft passed over the same longitude at the Equator only once every 18 days, and because the interval between data collection and subsequent delivery to the user (the turnaround time) could be as great as 2 months, any information they might have provided was not timely enough for media use.

In 1982 NASA launched Landsat 4, which, in addition to the MSS, carried an improved sensor, the Thematic Mapper (TM). When Landsat 4 began to fail in 1984, an identical Landsat 5 was launched. Landsats 4 and 5 are still providing data from both MSS and TM sensors, although the ability to transmit data from the TM on Landsat 4 is limited. The TM is capable of providing images of 30 meters (98 feet) resolution in seven spectral bands. The TM senses a swath 185 kilometers (115 miles) wide directly under the spacecraft. Its relatively high resolution provides images that have already proved useful for news reporting. Data are sold in the form of computer-compatible tapes or black and white or color photographs.

Each spacecraft crosses any particular longitude at the Equator only once every 16 days,[4] which means that its chance of passing over a part of the world in which a newsworthy event is taking place is low. However, because Landsats 4 and 5 are 8 days apart in their cycles, the two together can provide better coverage. For example, although the TM of Landsat 5 was able to provide an important image of the failed Chernobyl reactor, it passed above Chernobyl on April 29, 3 days after the first explosion, and could not return until Soviet technicians had extinguished the fire. In other words, it was unable to monitor the detailed progress of the fire, although it did show that the fire had been extinguished. The thermal band on the TM demonstrated that only one reactor had burned. Eight days later, Landsat 4 was able to acquire an additional image of the reactor site.

Over the years, 11 other countries (table A-1) have built data-receiving stations. Landsat 4 and 5 are capable of transmitting data directly to these foreign stations when the satellites are within range, or transmitting data to Earth via the Tracking and Data Relay Satellite System (TDRSS). Basic processing by the EOSAT Corp. corrects the data for geometric and radiometric distortions.

The Landsat system, which was originally developed and operated by NASA, was transferred to the National Oceanic and Atmospheric Administration in 1983.[5] In order to transfer land remote-sensing technology to the private sector, the Federal Government turned over operation of the Landsat system and marketing of its data to the EOSAT Corp. in December

[1] This appendix is adapted from a paper originally prepared for the OTA workshop on Newsgathering From Space

[2] It was then called Earth Resources Technology Satellite (ERTS)

[3] Objects just below the limit of resolution, generally can be discerned as objects on the images, but their identity generally cannot

[4] Because the Landsat orbit is a polar orbit it can 'revisit' areas north of the Equator more often The exact number of days between overhead passes varies according to latitude

[5] NOAA assumed operational responsibility for the TM sensor in 1984

Table A-1 .—Foreign Landsat Ground Stations

Actively receiving data (MOU signed with NOAA):
Australia
Brazil
Canada
European Space Agency (Sweden, Italy)
India
Japan
Thailand
Peoples Republic of China
Saudi Arabia
South Africa

Not *presently receiving data:*
Argentina
Pakistan (under construction)
Indonesia (no signed agreement)
Bangladesh (no signed agreement)

SOURCE National Oceanic and Atmospheric Administration

1985. ' In return for a government subsidy of ***$250*** million, ' EOSAT was to build and operate Landsat 6 and 7. However, because EOSAT has received only part of the agreed-upon subsidy, it has been forced to stop construction of Landsat 6. The future of civilian land remote sensing in the United States is in serious doubt.8

In February 1986, France successfully launched its own system, called the Systeme Probatoire d'Observation de la Terre (SPOT). SPOT provides 20 meter data in three spectral bands, as well as 10 meter panchromatic (black and white) imagery of Earth's surface. Although the SPOT satellite recrosses the same longitude only once every 26 days, its sensor is capable of viewing at an angle, or off-nadir, making it possible to gather images from a particular surface area 7 out of 26 days. '

A Mediasat System

Although attention generally focuses on the sensors and their capabilities, the imaging instrument itself would be a small component of an overall satellite system capable of providing the data for media use. A remote-sensing satellite system consists of four major tasks, each of which is critical to producing useful images:

1. data acquisition—the spacecraft, sensors, and transmitters;
2. data collection and delivery—the receiving station and other communication components; and
3. initial image processing; and
4. interpretative analysis.

In addition, a launch vehicle is required to place the spacecraft in orbit.[10]

Media proponents of using remotely sensed data have suggested the following key requirements:

- high spatial resolution (5 meters or less);
- sensors operating in at least three spectral bands, or colors;
- frequent revisit of each area (1 to 2 days);
- relatively narrow field of view (10 to 15 miles); and
- quick delivery time to the media (24 hours or less).

For purposes of discussion, OTA has selected a baseline system capable of 5 meters resolution that would satisfy most of the conditions the media say they need for a mediasat (table A-2 and table A-3). For comparison, OTA also selected a less capable, but less costly minimum system capable of 10 meters resolution that could serve the interim needs of the media (table A-4). The sensor and associated electronics of the second, less capable system might be carried as an auxiliary package on a large spacecraft similar to the Omnistar satellite proposed by EOSAT. This step would allow news agencies to gain experience with using remotely sensed data in preparation for constructing a much more capable, but more costly, baseline system.

'See U S Congress, Office of Technology Assessment, *Land Remote Sensing and the Private Sector: Issues for Discussion* (Washington, DC U S Government Printing Office, March 1984, for an extensive discussion of the history behind transfer of the Landsat system to the private sector. See also *International Cooperation* and Competition in *Civilian Space Activities* (Washington, DC: U S. Government Printing Office, July 1985; and U.S. Congress, 'The Commercialization of Meteorological and Land Remote-Sensing Satellites, Hearings before the Subcommittee on Natural Resources Agriculture Research and Environment and the Subcommittee on Space Science and Applications of the House of Representatives Committee on Science and Technology, 1983 [No 53]

'Not including launch costs, which were estimated to be $50 million to $70 million

"Theresa M Foley, "Reagan Asked to Intercede To Save Landsat Program, *Aviation Week and Space Technology,* Apr 6, 1987, pp 29-30.

'Note that viewing objects at an angle causes the resolution to decrease In addition, objects in the shadow of tall structures will generally not be visible

'Until at least 1090 the ability of the United States to launch payloads will be severely constrained The first flight of the refurbished shuttle may not take place before late 1988 In addition, because building an expendable launch vehicle takes 2 years or more even if a launcher were ordered in May 1987 it would not be ready until mid to late 1989

Table A-2.—Moderate and High-Performance Concepts Drive Sensor Cost

Concept	Minimum	Baseline
Push broom optics	Refractive	Reflective
Focal length/f-number	60 cm; f/4	212 cm; f/6
Resolution at nadir	10m	5m
Number detectors and spacing	512, 7µM	5,120, 15 m
Swath width at nadir	5 km	25 km
Pointing mechanics	One axis gimbel	One axis gimbel
System power/data rate	10-30W 8.3 Mbps	50-100W 166 Mbps
Sensor size (1XWX H)	30" X 30" x30"	60" x30" x30"
Sensor weight	<100 lbs	-500 lbs
Sensor cost	$5-10 million	$60-80 million

SOURCE Hughes Corp Santa Barbara Research Center

Table A-3.—Estimates of Baseline Mediasat System Costs[a]

Component	One satellite-system	Two satellite system
Sensor	$60-80 million	$100-140 million
Launch	$35-50 million	$70-100 million
Spacecraft	$40-50 million	$70-90 million
Data collection (TDRS with dual tape recorders)	$40-50 million	$70-90 million
Ground segment (data capture facility Image processing spacecraft management and control	$40-50 million	$40-50 million
Total	$215-280 million	$350-470 million

[a]These are rough estimates, based on general knowledge of what such systems might cost. They are not based on a particular engineering design. Estimates do not include insurance or operating costs.

SOURCE: Office of Technology Assessment, 1987

Table A-4.— Estimates of Low-Cost, Minimum Mediasat System Costs[a]

Component	One satellite system	Two satellite system
Sensor	$5-$10 million	$10-$15 million
Launch	Not applicable	
Spacecraft (Incremental marginal costs)	$2 million	$4 million
Data collection (Incremental marginal costs)	$2 million	$3 million
Ground segment (image processing)	$10-$20 million	$10-$20 million
Total	$19-$34 million	$27-$42 million

[a]This concept assumes that the sensor would fly as an additional sensor on a remote sensing satellite. It also assumes that a dedicated ground system would be necessary to process data in a timely manner. These are only rough estimates based on general knowledge of what such systems might cost. They are not based on a particular engineering design. Cost estimates do not include insurance or operating costs.

SOURCE: Office of Technology Assessment, 1987

Data Acquisition

The Spacecraft.—A relatively small three-axis stabilized spacecraft, equivalent in capability to the spacecraft used for the polar-orbiting TIROS environmental spacecraft, could serve the needs of a mediasat. It would be flown in a near-polar, Sun-synchronous orbit having Equator crossing times in the morning when shadows are generally strong to provide good image definition. To achieve daily coverage, two spacecraft would be flown.

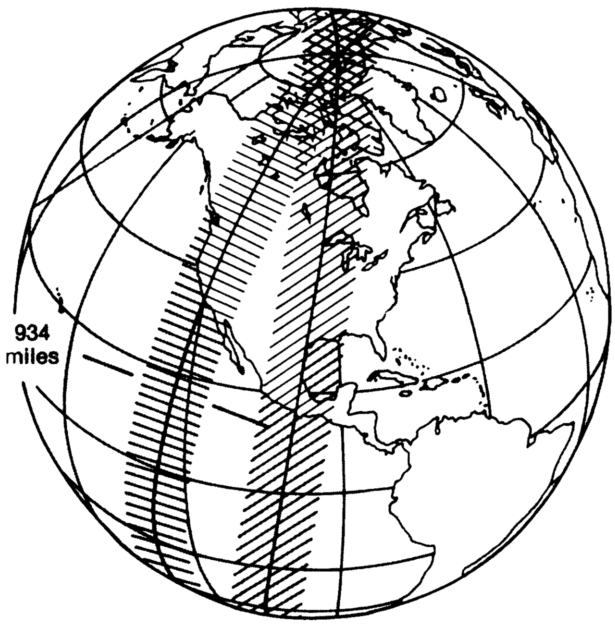
Sensor Design. —High spatial resolution is the principal performance requirement for a mediasat. Neither a conventional television camera nor a specialized high-resolution (875 or 1,200 line) camera are capable of serving as the mediasat sensors, even when fitted with adequate optics, primarily because they **are** not sensitive enough and lack the appropriate field of view. A mediasat would require specialized sensors and optics similar to those being developed for the next generation Landsat or SPOT systems (so-called multispectral linear arrays). The sensor itself would be simpler to build and cheaper than the TM, as it would have no rapid scanning or cooled detectors.

For purposes of illustration, OTA has selected a goal of 5 meters spatial resolution at the nadir. This represents a factor of 6 improvement (or a factor of 36 in areal resolution) over the resolution of the TM, or a factor of 2 (4 in areal resolution) over SPOT. However, in order to revisit a spot on Earth within 2 days of overflight, the sensor must have the capacity to point off-nadir by at least 45 degrees (figure A-1).[11] Therefore, the sensor chosen in this design would be capa-

[11]By increasing the off-nadir pointing angle to 58 degrees, it is possible to achieve one-day revisit capability. However, the resolution of the image would be degraded to a rather large 34 meters. In addition the haze and obliquity of the viewing angle would further degrade the image and reduce the photo-Interpreter's ability to delineate details

Figure A-1 .—Mediasat Two-Day Repeat Coverage With One Satellite

Earth coverage at ±45° from 705 km orbit

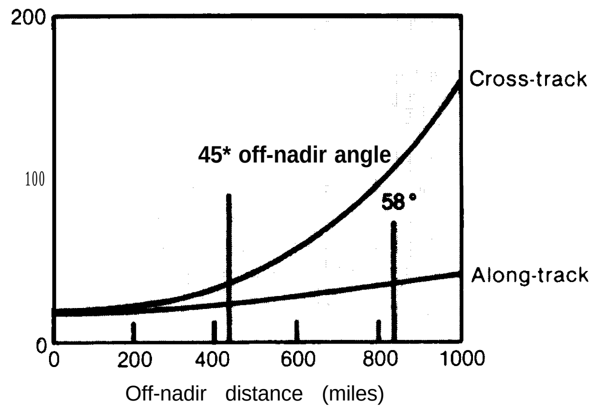


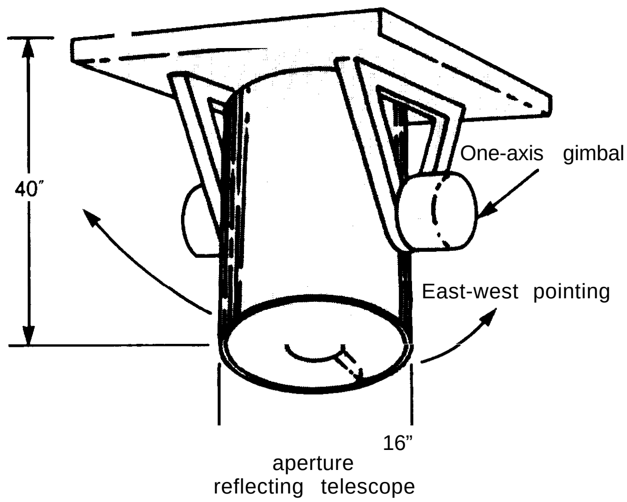
- Footprint is 5 m (16.4 ft) at nadir, 12.2 m (40 ft) at edge of field (450,
- Swath is 25 km (15.5 miles) at nadir, 60 km (37.3 miles) at edge of field

SOURCE Hughes. Santa Barbara Research Center

Figure A-2.—The Baseline System Has High Performance

• Image footprint grows with off-nadir view





SOURCE Hughes, Santa Barbara Research Center

ble of resolutions from 5 to 13 meters in off-nadir viewing (figure **A-2), At high latitudes, this design** would allow daily coverage, because the ground tracks of the sensor would overlap from day to day (figure **A-2 and figure A-3)**

The choice of sensor resolution constitutes a critical design compromise, for the costs of bettering the resolution increase at a nonlinear rate. A system achieving 5 meters resolution at 45 degrees off-nadir would have to be capable of reaching nearly 2 meters resolution at the nadir. However, the costs of providing a system capable of resolving objects as small as 2 meters are much greater than five-halves of the cost of a 5 meter system, because improvements in the resolution or sensitivity of the sensors would also require substantial improvements in the other parts of the system such as the data transmission components (see below). Overall costs of the system therefore are extremely sensitive to the capability of the sensors.

For television use, and for additional analytical capacity, the media requires sensors capable of producing images in three spectral channels in order to present a color image to the public. In addition, the sensor would provide a panchromatic (black and white) band having the same resolution but higher sensitivity in order to sense the Earth at low light level. A 25-km by 25-km instantaneous field of view (approximately a 15-mile by 15-mile image) would provide approximately 10 television screens of data in each satellite image.

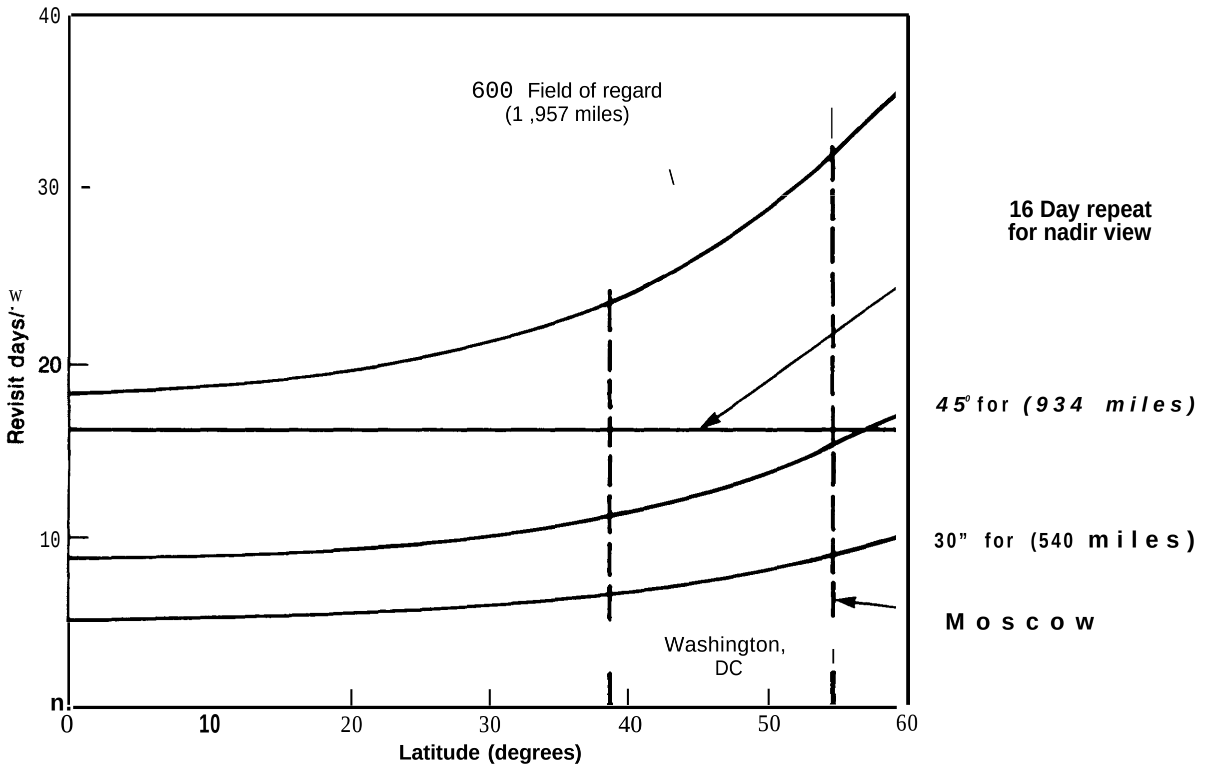
Spacecraft Management and Control.—Either at the receiving station, the image processing facility, or some other location, a facility would have to be built to communicate with the satellite. This station would support the receiving facility, overall mission management and spacecraft scheduling, including sending commands to the spacecraft, as well as monitoring spacecraft health and status. A facility of this sort could cost on the order of $20 million to $30 million.

Data Collection and Delivery

Rapid data delivery from the spacecraft to the media (approximately 6 to 8 hours) is essential for timely media use. The collection and delivery system is composed of two major components: transmission to a receiving facility; and delivery to the processing facility.

Transmission From the Spacecraft .—The transmission components of the spacecraft would consist of a sophisticated special-purpose computer for organizing the sensed data, a transmitter, and pointable antennas for transmitting data to a communication satellite or directly to Earth. Here again, the costs of a remote-sensing system increase much faster than the increase in resolution. In particular, costs could increase by as much as the inverse square of the resolution because, as the pixel size decreases, the number of pixels in an area increase by the square of the change in pixel size. Thus, halving the size of the resolution element quadruples the number of pixels in the image. Improving the resolution to 5 meters (and reducing the area covered in each image frame) could lead to transmission data rates of 100 to 150 megabits per second (Mbps). For comparison, the current TM data rate is 85 Mbps,

Figure A-3.— Mediasat Revisit Time Improves at Higher Latitudes



SOURCE Hughes, Santa Barbara Research Center

and the SPOT sensors approximately 50 Mbps. However, data compression techniques used on the spacecraft could reduce the data rate well below 100 Mbps.

Data Collection.—Remote-sensing systems have used three different methods for collecting global imagery from polar-orbiting satellites:

1. a system of ground stations spread around the world,
2. the NASA Tracking and Data Relay Satellite (TDRS), or
3. tape recorders onboard the satellite to store data until they can be transmitted to a single Earth receiving station located on home territory.

A Worldwide System of Earth Receiving Stations.— In developing the Landsat system, the United States encouraged other nations to build and operate their own data-receiving stations (table A-l). In part this was an attempt to spread the use of remotely sensed data to countries where conventional map and aerial photographic techniques were limited. These stations have also supplemented the acquisition of data from the Landsat series of satellites, which have either carried tape recorders or a TDRS transmitter. For a fee, EOSAT transmits data from the Landsat satellite as it passes within range. In return, these stations are licensed to sell data to customers, but must provide it on the same nondiscriminatory basis as EOSAT. However, because these stations are under the control of foreign governments, in practice customers have sometimes experienced considerable delays in receiving requested data.[12] This fact, and the considerable cost inherent in receiving timely data from a scattered set of receiving stations, make this option infeasible for a mediasat system.

The Tracking and Data Relay Satellite .—TDRS consists of two or three satellites in geosynchronous orbit and a single Earth receiving station. The TDRS relays data from the remote-sensing spacecraft to NASA’s TDRS reception facility at White Sands, New Mexico. From there the data can be re-transmitted via a domestic communications link to a processing center. Using a system like TDRS allows a remote-sensing satellite to avoid reliance on onboard tape recorders or

“Interviews with NOAA officials, 1985, Workshop paper by Peter Fend Ocean Earth Corp , 1986.

foreign ground receiving systems. EOSAT currently uses the TDRS system on a limited basis for collecting Landsat data of areas outside of the footprint of EOSAT's data capture facility at the Goddard Space Flight Center.

Use of TDRS has several major drawbacks. First, the annual cost for this service varies according to the volume of data transmitted, and could reach $5 to $6 million per year. In addition, using the TDRS system requires adding a TDRS communication package to the spacecraft at a cost of approximately $25 million.

Second, because only one TDRS is currently operating, imagery cannot be relayed from the Far East or Pacific Basin. A second TDRS is on the manifest of the first shuttle scheduled to fly after shuttle flights are resumed. [13] This will provide global coverage except in a narrow zone of exclusion over India. However, the currently operating TDRS has developed technical problems that may shorten its lifetime.

The third, and potentially most serious, drawback is that because TDRS was developed primarily to serve NASA and DOD missions, it operates on a priority basis. Many of the system users have much higher priority than a private sector corporation would have. Thus, during flights of the space shuttle and some DOD space missions, the media might have little or no access to TDRS.

Tape Recorders.—Tape recorders can be used to store data on the spacecraft until they can be transmitted to Earth. A space-rated tape recorder of the necessary data capacity currently costs about $5 million. A fully redundant system would require three tape recorders per satellite. Each tape recorder weighs about 150 pounds, and therefore also substantially increases the weight of a spacecraft.

A receiving station is most effective when located at a northern latitude so the data capture facility is within transmission range of the satellite more often. For instance, the receiving station EOSAT plans to build in Norman, Oklahoma, will "see" about 34 minutes of data per day. A facility in Fairbanks, Alaska, would "see" approximately 80 minutes of data per day and therefore be able to receive substantially more data, more frequently. A data-receiving station might cost as much as $10 million.

A tape recorder system would be completely self-sufficient and the capital and operating costs would be quite a bit less without the cost of the TDRS communication package. However, space-rated tape recorders capable of high data rates have proved unreliable in the past and have failed, or suffered operational limitations, before the sensors failed. Moreover, in some instances there would be delays in transmitting data to the media, depending on the area of interest being imaged and the time at which the satellite next comes in view of the receiving station. Even at northern latitudes, for example, delays in transmitting data to the receiving facility could be as much as 5 to 6 hours. Generally, most of these time delays would be tolerable.

Delivery to the Image Processing Facility.—Once collected, the data must be re-transmitted to the mediasat data processing facility where the raw data could be transformed into usable images for television and newspapers. Because the data would need to be transmitted quickly for media use, it is likely that they would be sent via a domestic communication satellite. A dedicated transponder for this purpose would cost about $2 million per year.

Image Processing

The cost and complexity of the processing system depends on a variety of factors, including data rate, the number of scenes to be processed per day, and the speed with which data would need to be turned into images usable by the media. These and other desired data processing requirements must be considered before a detailed cost estimate of the image processing facility can be made, A fully operational ground processing facility might cost on the order of $10 to $15 million.

Image Interpretation

Obtaining the image is only the first step in the process of making use of imagery from space. The images are often of very little use until they are integrated with other data, enhanced, and analyzed by expert photo-interpreters. For example, computer processing may make it possible to improve the image's resolution, or to analyze one of the color bands for particular information. In the civilian realm the need for such expertise in oil, gas, and minerals exploration; crop assessment; land planning; map making; or archaeological research" has encouraged the development of an industry (the so-called value-added industry) to make the data more useful. The media will have to rely on experts from the value-added industry to interpret mediasat images for the public.

[13] The first shuttle flight is scheduled to occur in spring 1988, but may be delayed until late 1988 or possibly early 1989

[14] U.S. Congress, Off Ice of Technology Assessment, *Technologies for Prehistoric and Historic Preservation,* OTA-E-319 (Washington, DC U S Government Printing Office, September 1986)