XVI. LOW EARTH ORBIT, MULTI-SPECTRAL IMAGING SATELLITE

A. BACKGROUND

According to the Systems Engineering and Integration (SEI) Integrated Concept of Operations discussed in Chapter VII, "an essential aspect of successful execution of future, multi-faceted, expeditionary operations is combining enhanced firepower and improvements in information technology with agile, adaptive command organizations to operate within an adversary's sensor and engagement timeline. Command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems and processes must exploit the benefits offered by *network-centric* operations which link shooters, sensors, and commanders seamlessly, and in real time, thereby permitting effects-based planning in order to provide the knowledge required to rapidly attack an adversary's critical vulnerabilities, avoid strengths, and destroy centers of gravity. Similarly, there must be an equally reliable and efficient C4ISR organization and system to link all supporting elements. This is particularly crucial in order to achieve Operational Maneuver from the Sea (OMFTS), Ship-to-Objective Maneuver (STOM), and Sea Basing."

ISR play a critical role in creating the ability for the force commander to exploit enemy vulnerabilities. Further, the ISR operational concept for the ExWar Force entails decentralized execution whereby subordinates are provided with the latitude to accomplish assigned tasks in accordance with the commander's intent. As a result, organic ISR systems must be adapted to function in any environment, whether afloat, transitioning ashore, or on the move. ISR data must be made available to allow command and control elements to facilitate decentralized decision-making and enhanced situational awareness at all echelons [Jones, 2001, 11] while protecting operational security.

The ExWar Force must have the capability to collect, process, and disseminate intelligence. The ExWar Force must also be able to coordinate and conduct tactical surveillance and reconnaissance OTH with forces ashore. This will include the ability to exploit national, theater, and allied assets, and provide intelligence to all levels of command in contribution to a common tactical and a common operational picture. The current expeditionary force commander does not possess an organic asset that allows them to conduct OTH ISR operations in support of forces ashore.

The aim of this enhanced C4ISR capability is to enable the ExWar Force to access, manipulate, and use information in near real time, developing a common tactical and operational understanding of the battle space. This will support fully integrated, collaborative planning efforts during both deployment and employment. The end product should be a scalable, sustainable, interoperable command and control system combined with a seamless, organic intelligence, surveillance, and reconnaissance capability linked to joint assets and, as much as is feasible, combined partners.

STOM doctrine calls for the insertion of ground forces directly from the ships of the Sea Base to a series of objectives without an operational pause to build up a logistical base that telegraphs the impending assault to enemy forces. These forces are re-supplied directly by air and surface craft as the tactical situation permits. Information is at a premium in these operations. Detailed knowledge of the terrain and enemy disposition around the objective areas is required in order to successfully plan and execute the operation. Small units moving through hostile terrain must be kept informed about enemy movements and concentrations to avoid being surprised by superior enemy forces. Failure to provide this information can turn a STOM operation into a costly defeat in detail.

In response to these needs, the SEI Team developed a three-tiered ISR system of systems. It is designed to provide the commander with an organic comprehensive ISR services. The first tier consists of tactical UAVs with limited range, endurance, and coverage area. These assets provide intelligence information on enemy disposition and movement at the tactical, small unit level. The second consists of high altitude, long range, high endurance UAVs such as the Sea Spectrum UAV designed to support PROJECT CROSSBOW. It is a shipboard compatible, twin engine, joined wing UAV with 12 hour endurance at 60,000 ft at a range of 300 NM from the host ship and carrying a payload of 3000 lbs. The Sea Spectrum will provide wide area and point target coverage throughout the area of operations, and the information received will be used at the operational, or large unit level. The satellite system discussed in this chapter is the system's top tier and must have the capability to perform three basic missions: provide wide area mapping and terrain coverage information to update tactical maps and supply detailed foliage and ground cover reports for use in rehearsal and operational planning; conduct wide area surveillance for the movement of enemy troops and supplies as well as civilian refugees; and provide high resolution intelligence coverage of specific military facilities, positions, and infrastructure sites to provide enemy order of battle information to the operational commander.

B. REQUIREMENTS

The following requirements were generated using the Burma scenario, discussed in Chapter V, to generate the required target area and missions to be performed. The Indonesian and Columbian scenarios, also discussed in Chapter V, were used in orbit and constellation design.

The SEI Team began the requirements generation process with the following mission profile: a circular, sun synchronous orbit to bring the satellite over the target at roughly the same time of day and orientation to reduce the amount of post processing required to compare images between consecutive passes; a fixed sensor, although off nadir pointing was permitted in the design; and the target areas from the three scenarios discussed above. To meet the demands of the Burma scenario, the system needed to be capable of imaging over a wide area for detection of troop and material movement, imaging a discrete set of installations such as military barracks, airfields, naval bases, and road and rail junctions; and collecting intelligence images of specific targets such as aircraft and ships, both in port and underway. Using these initial requirements, the team built a Satellite Tool Kit software model employing a single imaging satellite in a sun synchronous, circular orbit at 500 km with an inclination of 98 deg carrying a sensor modeled as a simple conic with a field of view (FOV) of 45 deg and targets at 0 deg, 60N deg, 60S deg, and 12N 98W deg each with a viewing constraint of ± 10 deg to ensure image passes would remain above the horizon. The model was not intended to limit the choice of orbits or number of satellites, but was used only to validate the requirements set presented below. The requirements were presented to the Space Systems Operations design class and iterated over the first three weeks of the quarter to produce the requirements discussed below.

1. Key Requirements

a. *Target Area to be Covered*

The minimum target area coverage was defined in terms of latitude and set to between 60 deg N and 60 deg S latitudes. This provides coverage of all potential sea based expeditionary operations sites with the exception of extreme northern regions, which are icebound a significant portion of the year and thus unavailable for sea based operations.

While a sun synchronous polar orbit would provide coverage from pole to pole, the 60 deg N to 60 deg S requirement was intended to broaden the number of potential orbits under consideration.

b. *Coverage Area*

Coverage area was one of the most difficult design criteria to meet. The 250×250 nm box was based on the requirement to detect troop and material movement from roughly Rangoon to south of Moulmein in the Burma scenario.

c. *Resolution*

Resolution was based on the need to collect high-resolution imagery for intelligence analysis and planning operations against specific targets. The system resolution was set at 5.0 m as the threshold with 2.0 m as the objective at any point in the coverage area. This requirement included the edges of the area for an off-nadir pointing or scanning imager, which tends to have lower resolution at the far points of its scan than at nadir.

d. *Target Revisit Time*

Target revisit time proved to be the other major driver of constellation design. In order to provide the required wide area surveillance data, the entire coverage area had to be revisited every 48 hours (threshold), but preferably every 24 hours (objective). Subsequent passes needed to occur the same time of day (± 2 hours) and with elevation greater than 60 deg above the horizon, measured from the target, to ensure sufficient image quality.

e. *Spectral Content of Imagery*

In order to meet the requirements of the three different imaging missions, the satellite had to be capable of taking pan-chromatic images, with the 2.0-5.0 m resolution described above, as well as multi-spectral, red/green/blue and IR images at a resolution two (objective) to four (threshold) times lower than pan-chromatic.

2. Additional Requirements

a. *Timeliness of Image Data*

In order to meet the commander's imaging requirements, the system ust provide images to the Sea Base in near real time. Images can be transmitted from the satellite via near real time cross-linking and download to a ground station (objective), or stored onboard and dumped to multiple ground sites (threshold). Real time cross-linking generally provides a faster means of transmission than store and dump because it eliminates the need to wait until a ground station is in view to transmit the image data. It also reduces the amount of image data storage capacity onboard the satellite. On the other hand, cross-link and download requires access to either the U.S. Air Force's or NASA's satellite network, and resolution of the attendant bandwidth sharing and availability issues. The system's Image Distribution System then becomes central processing and image distribution via secure ground or satellite link to the Sea Base and other sites.

b. *Acceptable Delay Time From Initial Imagery Request*

The system must be capable of providing images of the required coverage area within 48 hours of initial tasking.

c. *Service Life and Availability*

The system must have a useful on orbit life of 3-5 years. Availability must be 98% with a maximum downtime of 48 hours for planned and unplanned failures.

C. DESIGN CONSTRAINTS

Evaluation of the requirements led to the identification of several system design constraints.

The need for images at roughly the same time of day drove the design team to use a sun synchronous orbit for the constellation. This orbit met the time of day within 2 hours and 60 deg N to 60 deg S requirement. Use of sun synchronous orbits also allowed the design team to add satellites, one per orbital plane, by varying the right ascension of the ascending node for each additional satellite. This ease of constellation construction allowed to team to quantify the amount of coverage provided by satellite for use in trade studies and cost effectiveness analysis.

The wide area coverage required a controlled scanning, vice a fixed imager and the ability to point the image off-nadir. This greatly increased the amount of area covered per pass as well as the number of passes on which data could be gathered; however, the amount of post processing required to integrate images taken from a variety of different look angles and elevations increased for this configuration.

The other major design constraints were the need for battery power sufficient for eclipse imaging, the elimination of an on-station propulsion requirement (other than deorbit), a separation mass less than or equal to 1000 kg in order to determine launch vehicle, and the inability to use foreign launch services.

D. THE PERSISTENT PEEPERS SYSTEM

The Persistent Peepers (Polar Enhanced Electro-optical Package for Expeditionary Reconnaissance) payload took as a baseline the payload of two existing satellite systems, IKONOS and Quickbird, a pair of imaging satellites designed to provide commercial high-resolution images, collecting 1 m panchromatic and 4 m multi-spectral imagery and 61 cm and 2.44 m multi-spectral resolution, respectively.

Excel spreadsheet and Satellite Tool Kit models were employed to generate orbit that produced the desired 2.0 m resolution across the target area every 48 hours. Area coverage was assessed at the equator vice the Burma latitude and longitude, as the equator represents the most stressful case for analyzing coverage by polar orbiting satellites.

The final design concept was a three axis stabilized, off nadir pointing satellite system in a sun synchronous orbit with 101.8 deg inclination.

1. Payload

The visible light/near IR imaging device for the Persistent Peepers system will have the following specifications:

Spectral Range:	0.45-0.90 microns
Resolution (nadir)	2.00 m (pan)
Resolution (30 deg off-nadir)	2.48 m (pan)
Swath width:	54 km at nadir
Power:	350 Watts
Mass:	400 kg
Dimensions:	2.2 m × 1 m × 1 m

Table XVI-1: Persistent Peepers Optical Payload Parameters (Source: Amber, 2002).

These specifications meet or exceed the needs set forth in the requirements document.

The imager was made up of a linear charge coupled devices focal plane executing a + 30 deg to − 30 deg look with a pushbroom scan.

The focal plane unit itself consists of silicon charge coupled device arrays capable of generating 27,000 pixels at 12 micron pitch for panchromatic images and 6750 pixels at 48 micron pitch for multi-spectral images. The pixel readout rate, driven by the need to image a 250 × 250 nm box is rather high at 20 Mhz (Mpix/sec). This is an extremely high rate that pushed the limit of current technology and was caused, again, by the requirement to take multi-spectral images over a 250 × 250 nm area. The main driver for the number of pixels was the need to capture red/green/blue images. Similar images of a 54 × 54 km area, corresponding to the sweep width of the satellite, for example, require only 3 MHz rates. This data rate had a significant impact on the satellite's data transmission scheme.

The 54 km sweep width required 8 passes to cover the entire target area. The constellation described below provided for 12 daylight passes every 48 hours, which was more than required to meet the 48 hour revisit time requirement.

2. Constellation

Persistent Peepers will be deployed in a constellation of six satellites, the minimum number of orbiters required to provide the 48 hour revisit time. Reduction of the revisit time from 48 to 96 hours would reduce the number of satellites by two and the costs by a third, but the Systems Engineering Team decided to leave the 48 hour revisit time in place.

The constellation had one satellite per orbital plane, with the right ascension of the ascending node separated by 30 deg for each plane. This constellation provided a revisit time over the target area every 117 minutes, meaning the constellation accessed a portion of the target area every two hours.

The orbits were circular and sun synchronous at an altitude of 1470 km and an inclination of 101.8 deg. The orbital period was 115 minutes and the ground scanning velocity was 1486 m/s. Satellite Took Kit Visualization Option captures of the constellation as a whole and a single satellite view with respect to the target area are presented as Figures XVI-1 and XVI-2, respectively.

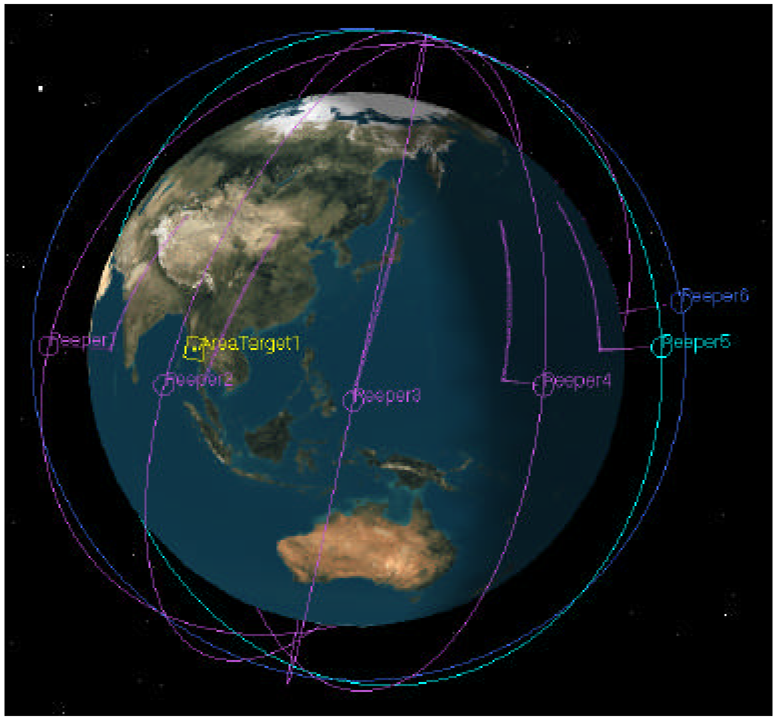

Figure XVI-1: The Persistent Peepers Constellation (Source: Amber, 2002).

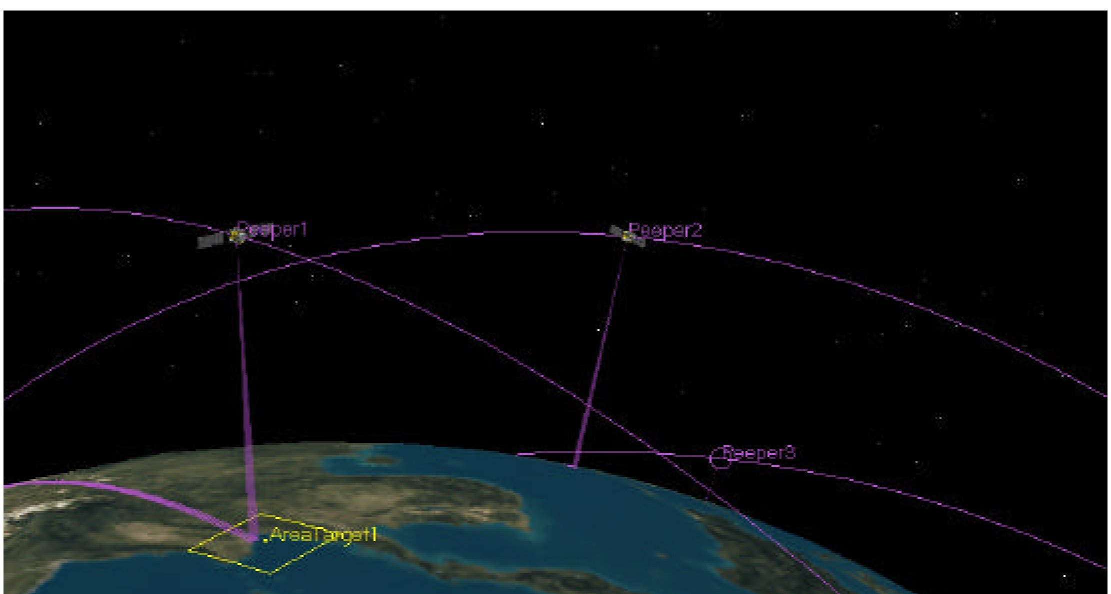

Figure XVI-2: Persistent Peeper Satellite over Burma target area (Source: Amber, 2002).

3. Launch Vehicle

The following basic launch numbers apply to a Persistent Peeper satellite:

Weight	1000 kg
Length	5.1 m
Diameter	1.4 m

The satellite does not require a dedicated propulsion source, such as an apogee kick motor, for orbit shaping or insertion at the desired 1472 km altitude.

Based on these parameters, the Delta II 7300 was selected as the launch vehicle of choice for the Persistent Peepers constellation. The Delta II, shown in Figure XVI-4, can carry a 1250 kg mass with a height of 5.1 m and a diameter of up to 3.0 m to the desired 1472 km altitude and 101.8 deg inclination with a demonstrated 97.8% reliability (out of 250 launches). The Delta II was considered a proven system, used to launch the Global Star, Iridium, and Quickbird satellites. Further, with its family of payload fairings, the Delta II provided options in the event of subsequent payload changes or requirements creep. Launching the constellation would take six launches spread out over 2.5 years.

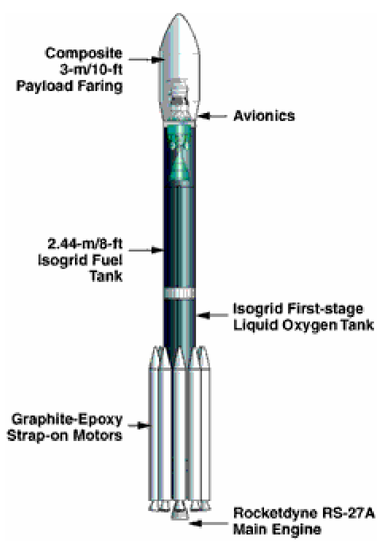

Figure XVI-3: Delta II launch vehicle (Source: Amber, 2002).

4. Operational Architecture

The operational architecture called for image data to be transmitted from Persistent Peepers orbiters via the Tracking and Data Relay Satellite System (TDRSS). TDRSS is a NASA communication relay system which provides links between low earth orbiting spacecraft and the ground. The system provides extended view times for low earth orbit (LEO) satellite communications links, and is capable of transmitting to and receiving data from any LEO spacecraft over at least 85% of its orbit. The TDRSS space segment currently consists of six first generation tracking and data relay satellites (TDRS) located in geosynchronous orbit, of which three are available for operational support at any given time. The TDRSS ground segment, the White Sands Ground Terminal located near Las Cruces, New Mexico, controls the TDRS satellites and receives/transmits data from/to customers' low earth orbit satellites through the TDRS satellites. NASA missions supported by the system include the Hubble Telescope, the Space Shuttle, GRO, Landsat, TOPEX, EUVE, and the International Space Station. The U.S. Air Force also maintains a satellite tracking and relay network, but the Persistent Peepers bandwidth requirement was too high.

Despite the intent to crosslink image data to TDRSS for relay to ground sites, the design team included an on board memory requirement for 64 Gb of memory as a backup in the event a Persistent Peeper was unable to access TDRSS. There were many advantages to using TDRSS: its high data transfer capability and the use of a proven system not limited by pass times over ground stations. Limiting the downlink to the in-view time of ground stations would have required extremely high data rates in the transmission bursts and large memory capacity onboard to store the images until downlink. On the other hand, using TDRSS made the transmission architecture more complex, creating more nodes between the sensor and the user. The Persistent Peepers operational architecture is presented in Figure XVI-4.

E. CONCLUSIONS

The ISR information provided by the three-tiered system is required in STOM operations to allow the precision application of combat power to the enemy's center of gravity while simultaneously avoiding having friendly forced pinned down and defeated in detail. This system, consisting of tactical UAVs, the Sea Spectrum high altitude-high endurance UAV, and Persistent Peepers constellation provide the commander with a set of organic or dedicated assets to gather the required information.

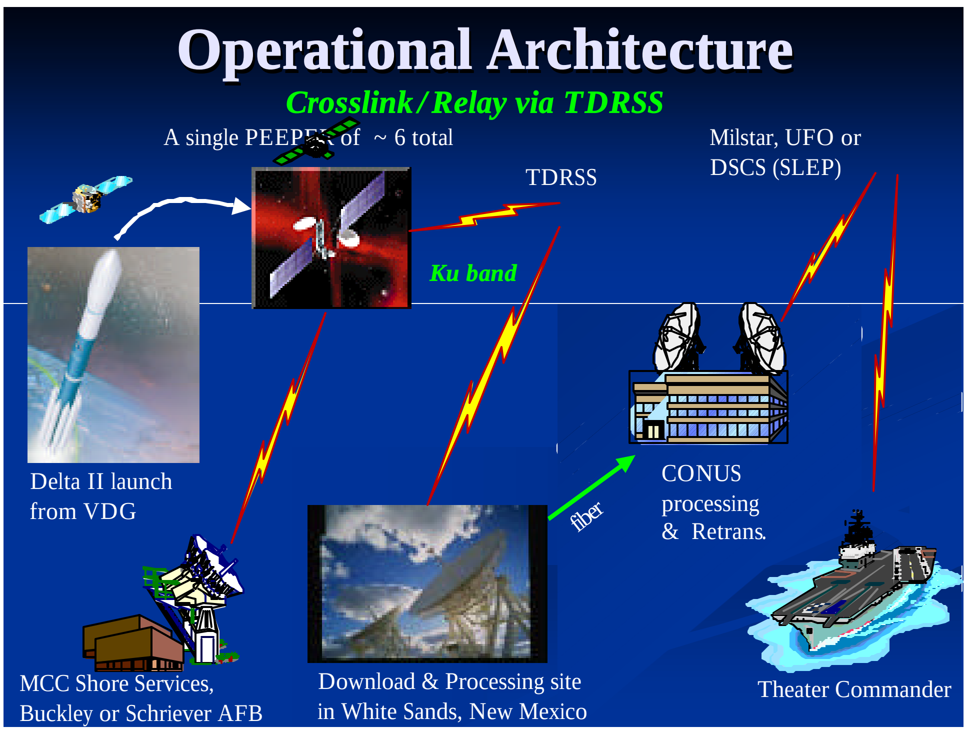

Figure XVI-4: Persistent Peepers operational architecture (Source: Amber, 2002).