Paper for SpaceOps 2000 in Toulouse, France

Lessons Learned On Operating and Preparing Operations for a Technology Mission From the Perspective of the Earth Observing-1 Mission

Dan Mandl
(301) 286-4323 e-mail: dan.mandl@gsfc.nasa.gov
EO-1 Ground System Manager/Mission Director
Code 584
NASA/GSFC
Greenbelt, Md. USA 20771

Joe Howard
(301) 286-9507 email: jhoward@pop500.gsfc.nasa.gov
EO-1 Flight Operations Team Lead
Honeywell, Inc.

I. Introduction

The New Millennium Program's first Earth-observing mission (EO-1) is a technology validation mission. It is managed by the NASA Goddard Space Flight Center in Greenbelt, Maryland and is scheduled for launch in the fall of 2000. The purpose of this mission is to flight-validate revolutionary technologies that will contribute to the reduction of cost and increase of capabilities for future land imaging missions. In the EO-1 mission, there are five instrument, five spacecraft, and three supporting technologies to flight-validate during a year of operations. EO-1 operations and the accompanying ground system were intended to be simple in order to maintain low operational costs. For purposes of formulating operations, it was initially modeled as a small science mission. However, it quickly evolved into a more complex mission due to the difficulties in effectively integrating all of the validation plans of the individual technologies. As a consequence, more operational support was required to confidently complete the on-orbit validation of the new technologies.

It is interesting to note that the realization was made late in the mission, that a point in time is quickly reached, whereby changes on the spacecraft and instruments are constrained and that the only viable area to retain a margin of flexibility is in the area of operations. Therefore, since it is much easier to de-staff than to find and train knowledgeable personnel, it would have made sense to overstaff operations from the beginning of the project with the idea that any extra cost accrued by operational personnel pales in comparisons to changes required on the spacecraft and the instruments. This in effect becomes a cost-effective risk management approach. More on this topic will be discussed later in the paper.

II. Scope of Paper

This paper will explore some key drivers which changed the mission from being modeled as a small science mission to one modeled as a more complex mission. First an overview of the spacecraft, ground system and operations is presented to provide some background. Then, four areas are explored that drove the need for increased operational support as follows:

1. Change of risk tolerance as the mission proceeded

2. Single string approach to the spacecraft design
3. Compression of mission timeline
4. Increased controls needed due to transition from a small agile mission team to a more complex medium mission team

Next, some manpower estimates for development of operations and the actual operations are shown from a review in 1997 and compared to actual estimates now. Finally, conclusions are drawn as to what we would do differently on future technology missions that are similar to EO-1.

III. Mission Background

EO-1 is responsive to the Land Remote Sensing Policy Act of 1992 (Public Law 102-55) wherein NASA is charged to ensure Landsat data continuity through the use of advanced technology. In particular, EO-1 addresses this as follows:

1. Multispectral Imaging Capability – traditional Landsat users
2. Hyperspectral Imaging capability to address Landsat research oriented community with backward compatibility essential
3. Calibration test bed to improve radiometric accuracy
4. Atmospheric corrector to compensate for intervening atmosphere

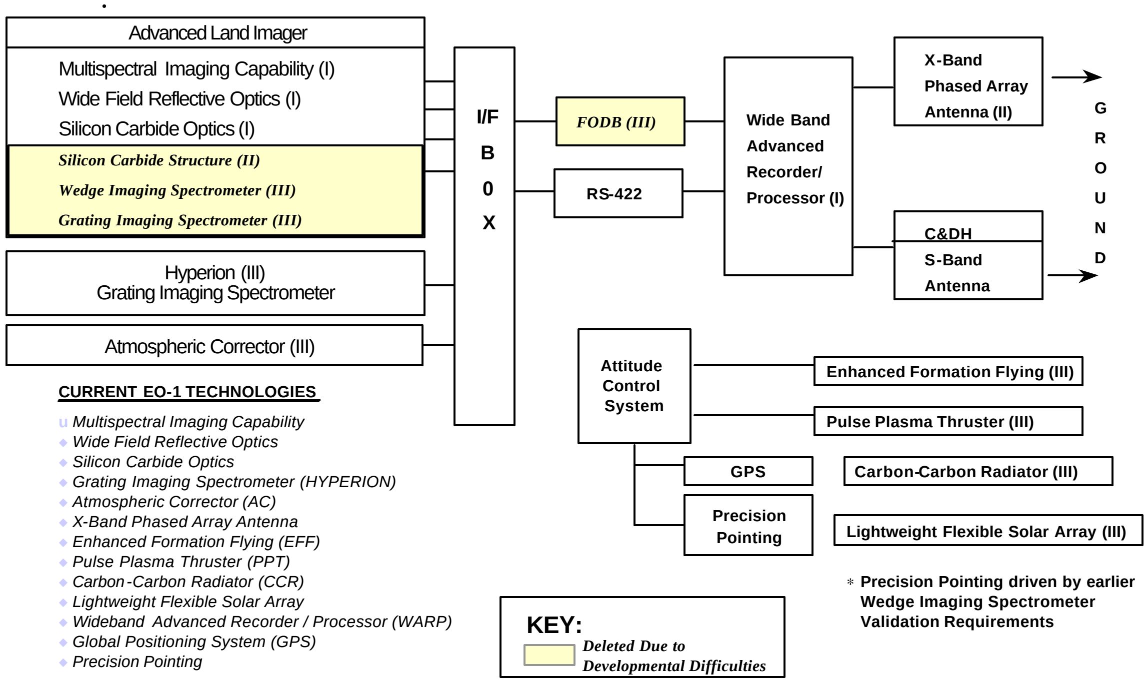

figure 1 EO-1 Technologies

Figure 1 shows the EO-1 technologies which include supporting technologies. The technologies are labeled category I, II or III. Category I indicates that the technology is critical and the basis for the mission. Category II indicates an essential supporting technology. Finally, Category III indicates that the validation requirements for these technologies are fulfilled once the Category I and Category II are fulfilled. Figure 2 depicts the location of key technologies on the spacecraft. Figure 3 shows the deployed EO-1 satellite with salient features.

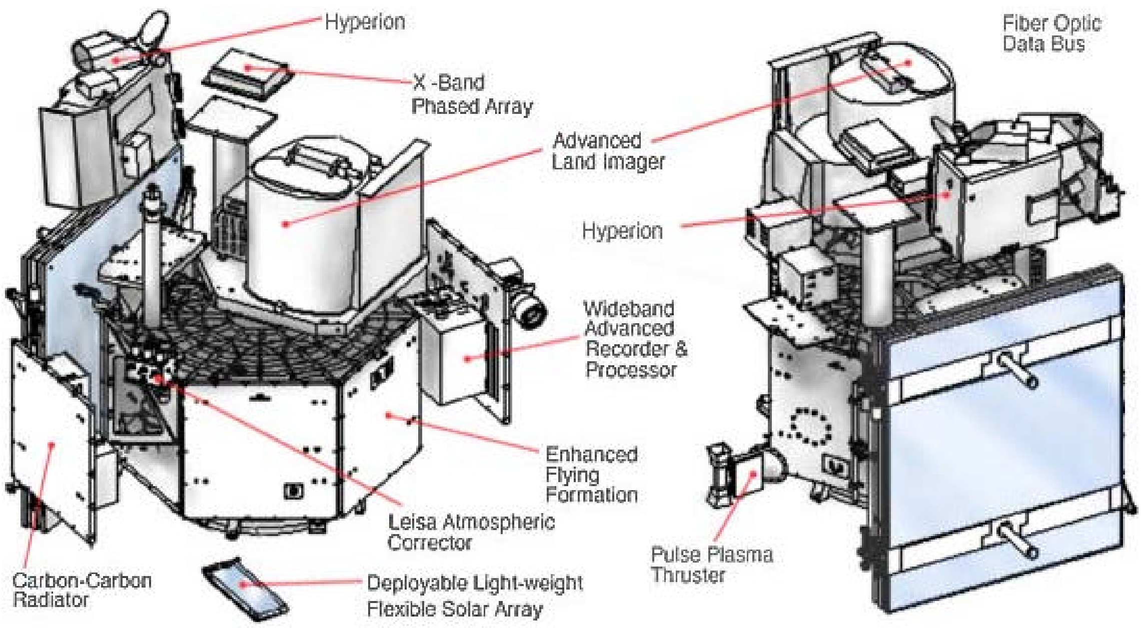

figure 2 EO-1 Technologies Located on Spacecraft

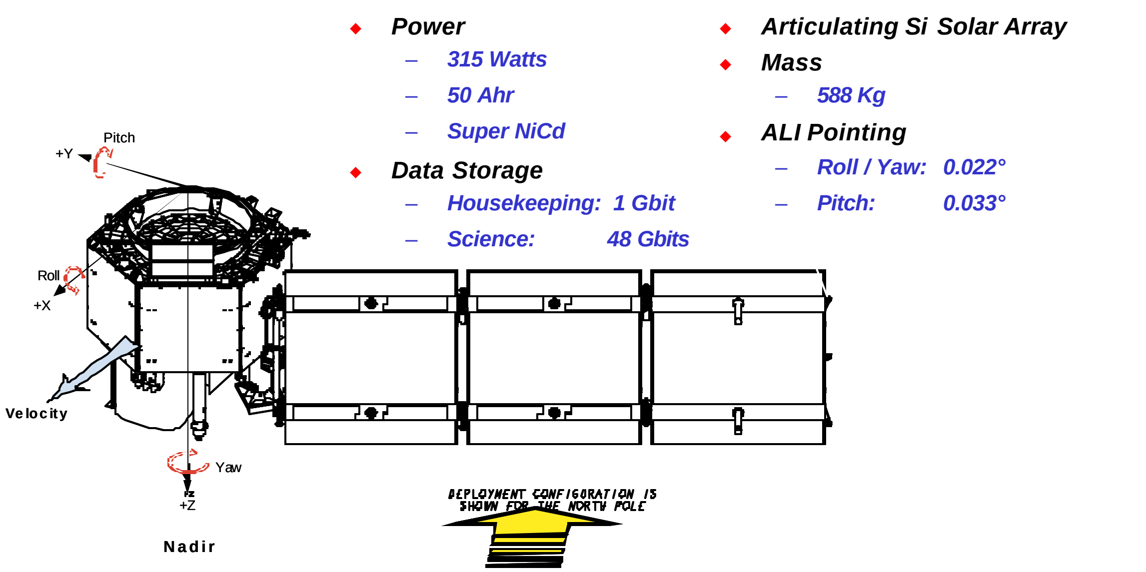

figure 3 EO-1 Spacecraft with Salient Features

Highlights of the spacecraft subsystems are as follows:

1. Guidance, Navigation & Control
   a. Three-axis stabilized

   b. Pointing accuracy of 0.022 ° (3σ) in all three axes
   c. Jitter is <5 arcseconds (3σ)
   d. Star camera
   e. GPS
   f. Independent safehold processor
   g. Partial MAP design
2. Power
   a. Deployable three panel solar array; 633W EOL
   b. 300W orbital average requirement
   c. NiCd battery 50Ahr, XTE/TRMM heritage
   d. Bus=28 ± 7 VDC
   e. MAP Design
3. Command and Data Handling
   a. Mongoose V processor @ 12 Mhz
   b. 1773 fiber optic data bus
   c. MAP design
4. Propulsion
   a. Hydrazine
   b. Used for orbit maintenance, formation flying, and correcting insertion errors
   c. Four thrusters @ 0.2 lb each/2.2 Newtons
5. Structure
   a. Aluminum
   b. Mass = 370 Kg
   c. Hexagonal Right Prism
   d. Equipment panels serve as radiators
6. Payload Interface
   a. Alignment measured to 20 arcseconds
   b. Thermally coupled to spacecraft

IV. Operations and Ground Overview

Key high level ground requirements are as follows:

1. X-Band
   a. Receive up to 80 Gbits of science data each day at 105 Mbps
   b. Record data to hard media (AMPEX Tape) and mail to GSFC
2. S-band
   a. Receive data at selected rates up to 2 Mbps
   b. Backup science data (up to 10 Gbits/day) will be sent to GSFC post pass as needed.
3. Process ALI, Hyperion and AC science data to provide at least 200 paired scene comparisons with Landsat 7
4. Maintain an orbit of sufficient precision for scene comparisons; follow Landsat 7 ground track, ± 3 km cross track, 1 minute behind ± 6 seconds, 1 minute later than Landsat in mean local time at the descending node
5. Provide mission planning and command management for
   a. Image operations
   b. Other technology validation operations
   c. Calibration operations
   d. Contingency operations

Figure 4 depicts the top level ground architecture to fulfill the requirements.

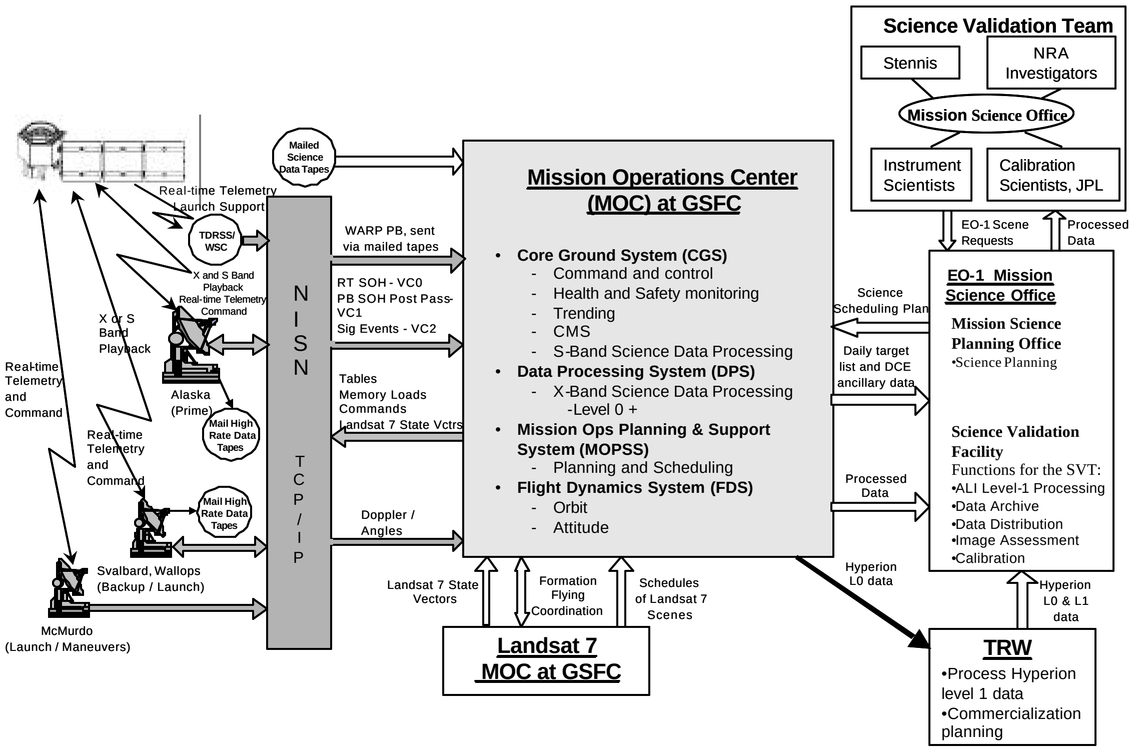

figure 4 Top level ground architecture

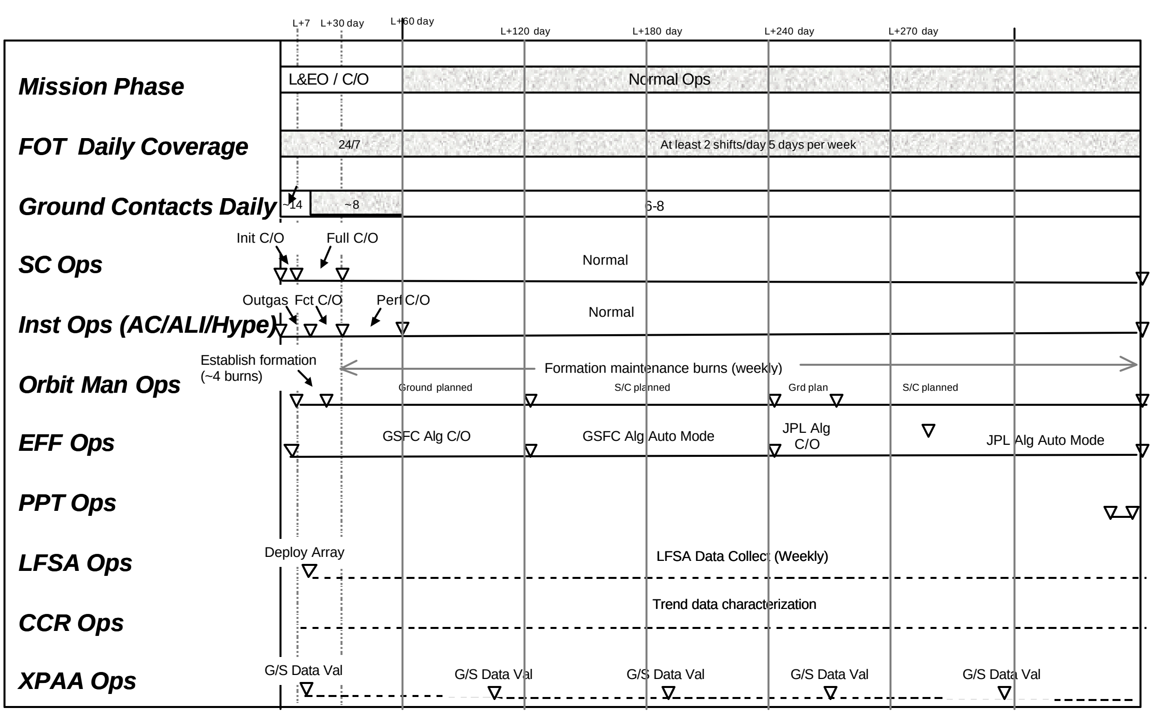

figure 5 Baseline Validation Timeline

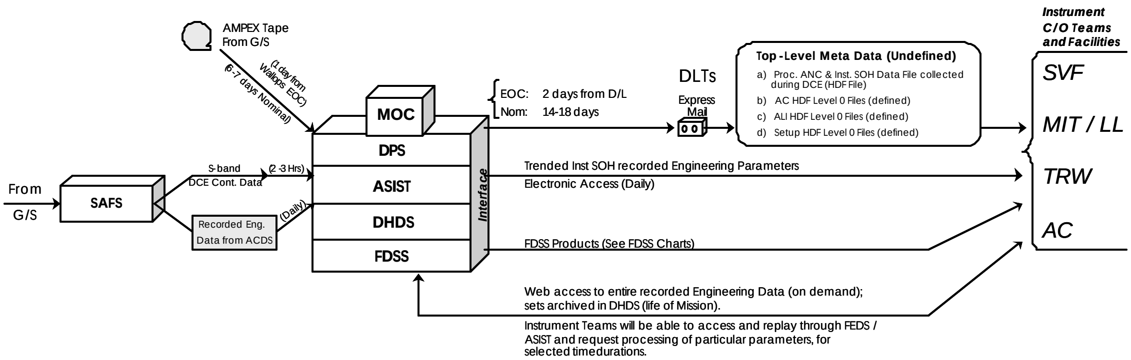

figure 6 Science Processing Data Products and General Timeline

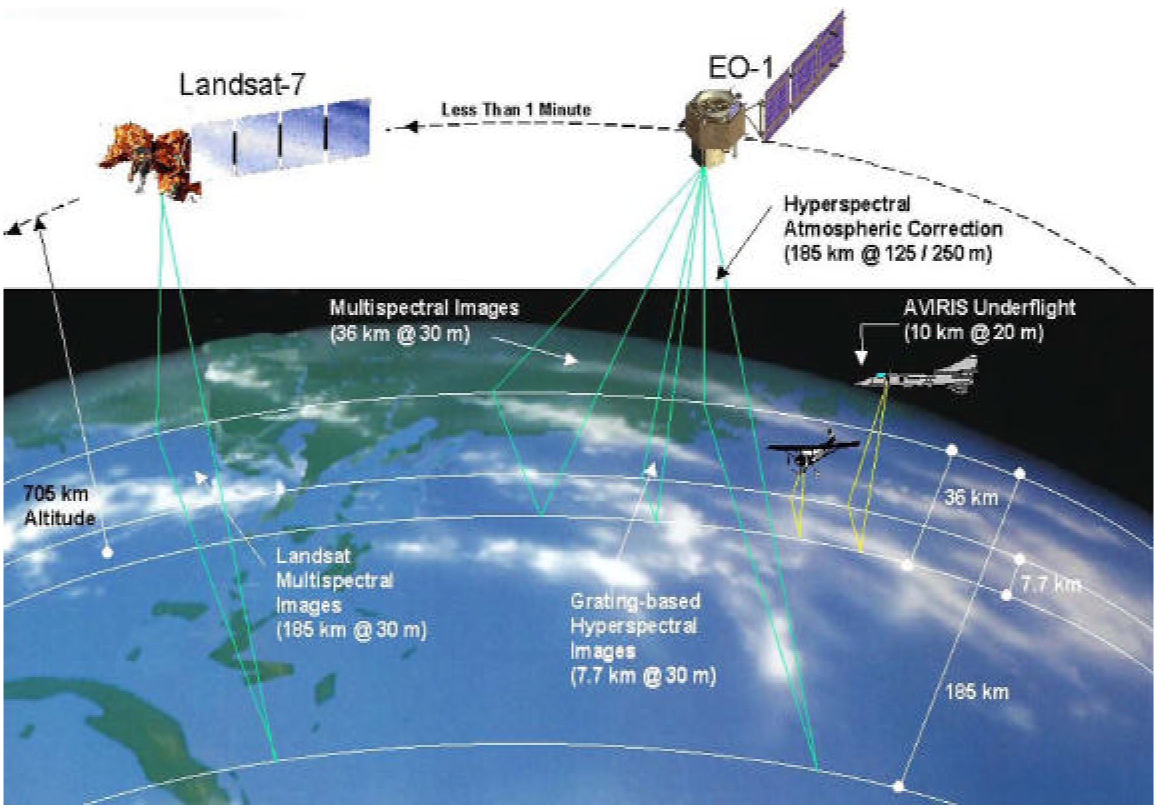

fig 7 Pictorial Depicting Combined Imaging Approach

Note that key activities in this mission, as depicted in figures 5, 6 and 7, are the taking of images by the three instruments and the processing and distribution of the science data. In addition to the three instrument groups who need to validate their instruments individually, there are over 40 validation scientists that are working with the Science Validation Facility (SVF)/Mission Science Office(MSO) to get images to validate their science concepts. To minimize the work done by operations, it was decided that for the majority of the time, all three instruments would image simultaneously and all the data which included meta-data (engineering data about science data), would be included on a one DLT tape which would be duplicated and distributed to everyone. This approach required that there be tight coordination between all of the scientists and instrumenters to work a master scene list which prioritizes the most valuable scene. The planning process then places the scenes that the most scientists will benefit from early in the mission earlier in the mission. This means that in general, if there is a scene that two or more scientists need, it would be taken before one that only serves one scientist

Figure 5 depicts the EO-1 activities through the first year. Note that instrument operations is just one line of activities. These activities must be folded into the other technology validation efforts and the corresponding data transmitted to the technologists. But the instrument activities are still the bulk of the operation activities. Figures 6 shows the basic science data processing flow while figures 7 and 8 depict the typical imaging activities.

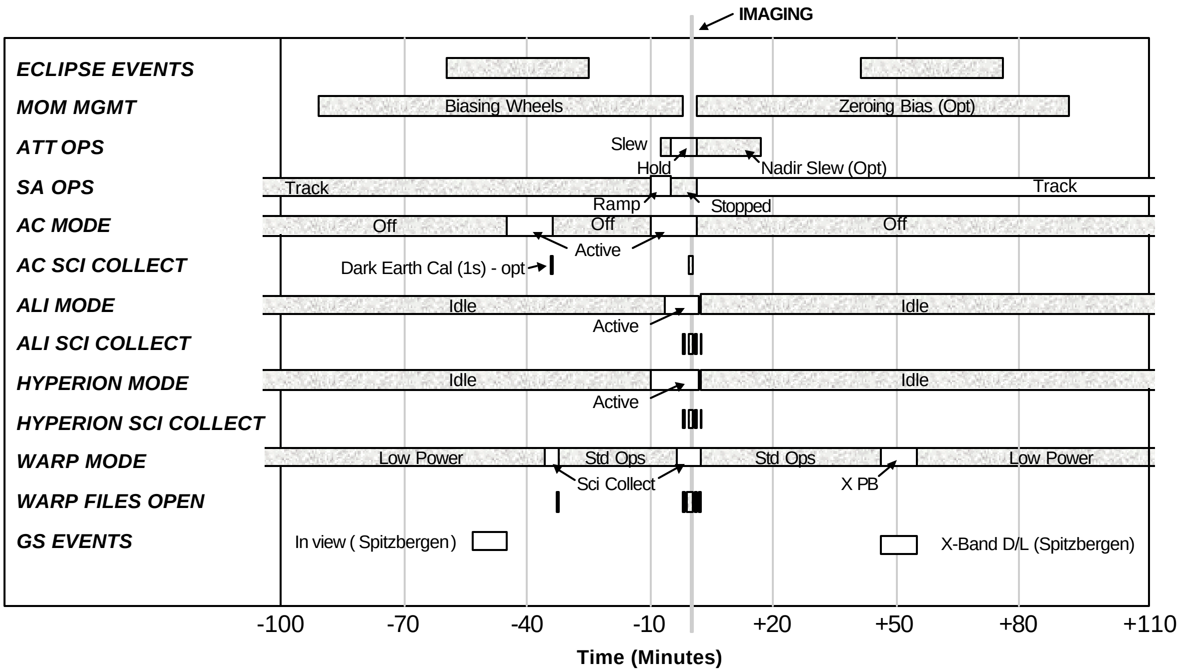

figure 8 Representative Combined Ground Image Timeline

V. Change drivers

For EO-1, as is the case for any technology mission, there is less dependence on flight data and more on extensive ground-based validations of the assigned technologies before launch. In the case of EO-1, 70% of the validation is done before launch. Furthermore, another driver for the quicker turn around of the mission is the necessity of timely validation due to the desire for maximal technology infusion opportunities. To operations, this originally translated as "quickness is more important than risk". With this in mind, and trying to keep costs very low, other technology activities were tightly folded in between imaging activities. Further complexity was added with a proposal on the table to compress the base mission into 120 days instead of one year to take advantage of the increased reliability of the spacecraft early in the mission. The increases in operational staffing resulted from the following drivers:

1. Change of risk tolerance

In an early review, the project manager stated, "Risk is what the EO-1 mission is about.". The original conception of EO-1 was that by taking high risk, cost could be kept low. For example, the original operational concept called for running EO-1 with only two Flight Operations Team (FOT) members. But events conspired to change that directive. In particular, after the announcement of opportunity, there was more interest in the science community than anticipated which provided international exposure. As customer interest increased, risk tolerance decreased. Furthermore, this was further amplified by recent mission failures.

This translated into a number of new activities that were not originally planned for as follows:

a. Generation of a spacecraft user's guide by the FOT with the support of the subsystem engineers
b. Training of the FOT on all of the subsystems by subsystem engineers
c. Implementation of ISO 9000 documentation standards including generation of a product plan
d. More formalized documentation which was placed on a website and then required a significant web effort
e. Implementation of network security. Originally, the MOC was on open Ionet, however, we have now developed a plan whereby remote access to the MOC is achieved by having a firewall which checks a password that changes every minute in addition to validating that the IP address from which the user is logging in is a valid one.
f. Implementation of dedicated 256 kbps lines to TRW and Lincoln Lab so that they could monitor instrument activities remotely with an ASIST workstation (same as in the MOC)
g. Increased trending requirements
h. Leaning away from use of automation as originally planned to allow for 5 day x 8 hour operations. This mode of operations will be evaluated post-launch + 30 days to examine its viability
i. Going from what originally was two seats with two workstations and one front end in a portion of the MOC for ESDIS to a facility which has 10 workstations, 8 or so X-Terminals, a separate data processing room. FOT staffing increase from the original proposal of 2 to the present 13 for normal operations.

There were also the traditional discussion on whether to test safehold on orbit with the fear that once in safehold, we my not be able to get out. But due to the fact that EO-1 is single string, it was decided that safehold would be tested early while all of the subsystem engineers were still around and easily accessible.

2. Single string spacecraft design approach

EO-1 was originally conceived as a single string mission and was modeled for purposes of budgeting and sizing, as a small science mission. It was designed as a single string mission with the idea that less complexity would mean shorter schedules and lower cost. But despite the fact that time was saved in Integration and Test of the spacecraft, almost no time was saved for operational testing because the major part of operational testing occurs with the first box while the second backup box is cookie cutter.

But where the single string approach impacted operations the most was in the development of contingency procedures. Because there were less safeguards built in, more knowledgeable, higher level operational personnel had to be hired in addition to more bodies. This allowed for contingency procedures to be more stringently designed and better tested. Also, this drove the need for more training and simulations than would otherwise not be deemed to be necessary.

3. Compression of mission timeline

As mentioned earlier, the present proposed approach (as of 4-28-00) is to complete the basic mission in 120 days. This translated into taking more scenes per day and then downlinking those scenes than the baseline plan had called for. Originally, when the number of scenes to be taken and processed was to occur in one year, it was felt that there was enough flexibility that automation could allow an 8 hour by 5 day operation. This included a portion of a person to do planning. However, with this revised plan of taking up to 8 scenes a day, the scientists are even having trouble finding enough targets per day from the available ground track of the spacecraft. They have requested that we take a look at taking multiple scenes on an orbit whereas before we would only take one scene per orbit. The complexity in trying to achieve this is that momentum management to control jitter takes up to 17 minutes per scene, downlink opportunities are liomited and EO-1 only passes over the U.S. on 3 of its 14 orbits per day. As a result, it has taken 3 people to do planning thus far in the simulations, and we anticipate the possible need for a fourth planner.

4. Increased controls needed due to transition from a small agile mission team to a more complex medium mission team

EO-1 originally was designed as a small tightly knit team with a high level of communication between the various elements such as operations, subsystem engineers, instrumenters and scientists. For a small group this allows for great cost savings and avoidance of some documentation and management controls such as Change Control Boards (CCB). But as the team grew and risk tolerance diminished, there came a threshold whereby the need arose for more formalized mechanisms of control. This resulted in the creation of four Configuration Control Boards (CCB); a Project Level CCB, a Flight Software CCB, an Operations CCB and Integration and Test CCB. Needless to say, many team members are required to attend multiple board meetings. Furthermore, contractor personnel are to be added to help process the paperwork.

The team still retains a high level of informal communications between I&T , Ops and the instrumenters due to the fact that the same people worked side by side in both I&T and now the ongoing simulations. This was necessitated by the fact that whereas for most missions the spacecraft manufacturer runs the launch, for EO-1 the Mission Systems Engineer and Mission Technologist have led and will lead the launch effort. This has added an overhead burden on EO-1 personnel but adds a higher degree of confidence that some small change will not impact the mission.

VI. Some resource expenditure comparisons

Figure 9 depicts original the MOC facility which consisted of three console positions in the Terra MOC, in effect, a tiny corner of their MOC. Data processing was to be done on a table in the back room. EO-1 had no separate room. Now the MOC consists of a separate room, in a different building, with 4 workstations, 4 X-Terminals and two front ends; a back room for data processing; and an overflow facility for launch.

Figures 10 and 11 depict the manpower presented 11/7/97 for the FOT over the life of the mission and the revised estimates given the launch slips and added work. Note, that in both cases, staffing includes flight dynamics and data processing work included in the FOT work..

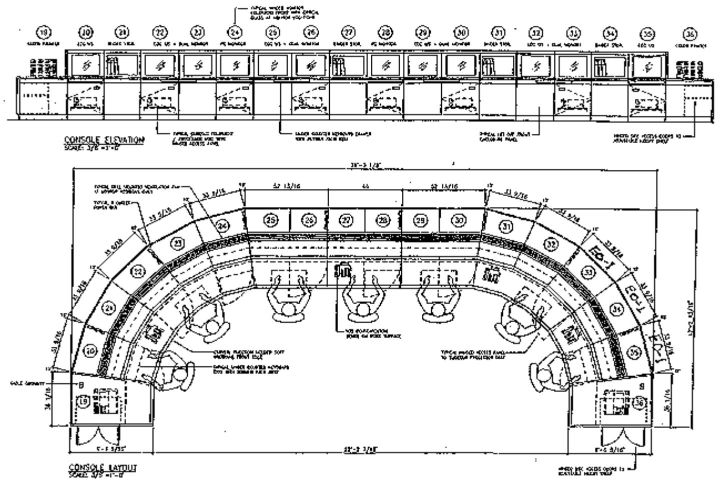

Fig 9 MOC as presented 11/7/97 was two seats of a console cluster which was part of Terra MOC. Now MOC consists of multiple rooms in different building

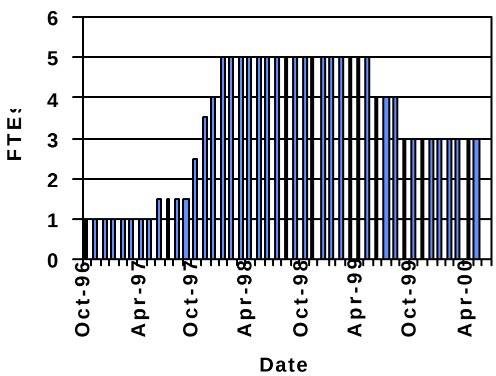

Figure 10 FOT Staffing presented 11/7/97

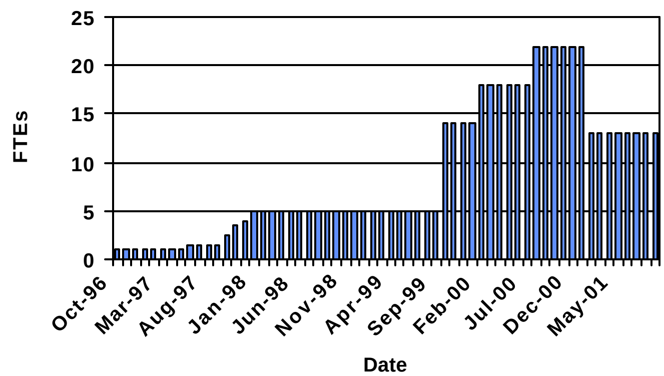

Fig 11 FOT Staffing as of 4-28-00 for Accelerated Mission

VII Conclusion (What we would have done different if we did this mission over)

After discussing some of these lessons learned with the project manager, it was agreed that the first thing to do on this type of mission up front is to do a reliability assessment using such tools as Failure Mode Effects Analysis (FMEA), fault trees and probability assessment. Then based on the analysis, design the spacecraft with selective redundancy to minimize risk where it is cost effective. Once this was done we would then do the following:

1. Estimate the operations staffing needs and then overstaff to provide a risk management buffer as discussed earlier. It is easier to destaff when contractors not needed than it is to get rapid expertise due to the learning curve problem.
2. Estimate range of operational activities depending on risk events and provide adequate flexibility through contract mechanisms such that as the need arises additional help is easy to get. e.g get FOT members from organization that have large pool of that skill set as opposed to smaller companies who only can get a few people with the salient operational skills.
3. Set up facilities so that they can easily be expanded. In the case of EO-1, facilities used in the building 14 significantly increased from original expectation, however, luckily, the extra space was available next to the original facility.
4. Gain early access to Web based management tools to allow for flexibility to transition to a more rigorous team control mechanism as needed.