Spitzer pre launch mission operations system – the road to launch

Charles P. Scott[a], Robert K. Wilson[a]
[a]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA, USA 91109-8099

ABSTRACT

Spitzer Space Telescope was launched on 25 August 2003 into an Earth-trailing solar orbit to acquire infrared observations from space. Development of the Mission Operations System (MOS) portion prior to launch was very different from planetary missions from the stand point that the MOS teams and Ground Data System had to be ready to support all aspects of the mission at launch (i.e., no cruise period for finalizing the implementation). For Spitzer, all mission-critical events post launch happen in hours or days rather than months or years, as is traditional with deep space missions.

At the end of 2000 the Project was dealt a major blow when the MOS had an unsuccessful Critical Design Review (CDR). The project made major changes at the beginning of 2001 in an effort to get the MOS (and Project) back on track. The result for the Spitzer Space Telescope was a successful launch of the observatory followed by an extremely successful In Orbit Checkout (IOC) and operations phase. This paper describes how the project was able to recover the MOS to a successful Delta (CDR) by mid 2001, and what changes in philosophies, experiences, and lessons learned followed. It describes how projects must invest early or else invest heavily later in the development phase to achieve a successful operations phase.

Keywords: Observatory, Spitzer, Mission Operations, Development

1. INTRODUCTION

In mid 1998 the Space Infrared Telescope Facility (SIRTF, now known as the Spitzer Space Telescope) began Phase C/D in the development of the Project. The Project began this phase by successfully completing a Project Critical Design Review (CDR). Following the Project CDR, various areas of the Project conducted individual CDRs for their specific areas. The CDR for the Mission Operations System (MOS) portion of the Mission was not conducted until late 2000 (~18 months later). This CDR was unsuccessful and was a major problem for the project to address.

The Project addressed this problem with changes in management, organization, and philosophies. The Project used seasoned operations personnel to mentor the current Project personnel. This group of personnel was called the Red Team. The idea was to have the Red Team not only mentor the MOS personnel, but to also "jump start" their areas in the MOS to get the MOS on the right track. Finally, the Red Team was also responsible for laying out a plan to follow, and presenting this plan at the Delta CDR.

This paper describes how the project was able to recover the MOS to a successful Delta (CDR) by mid 2001, and what changes followed in philosophies, experiences, and lessons learned.

2. CRITICAL DESIGN REVIEW (CDR)

SIRTF had a MOS CDR in September 2000 in preparation for entering Phase C/D of the project. The results of the CDR were a failure and resulted in 97 Requests for Action (RFAs). The Project was already having issues with the spacecraft (S/C), the Cryogen Telescope Assembly (CTA), and the instrument. This was a high-stress time for almost everyone on the project. However the Project Manager tackled the issues with the MOS CDR head-on, knowing that the MOS had to be ready for not only launch, but IOC and nominal operations, prior to launch.

So what were the deficiencies found in the MOS CDR report? There were 13 major themes to the MOS CDR failure, in the following areas:

1) Organization; Roles and Responsibilities
2) Integrated Critical Path Schedule
3) Operational System Test Laboratory's (OSTL) Fidelity, Operations Capability, Schedule for Use
4) Operational System Documentation Baselining and Configuration Management
5) Virtual Machine Language (VML) Compiler Completion, Validation and Operations
6) Training and Anomaly Scenarios
7) Need for Database Configuration Management (CM) Across Project
8) Command Sequence Development and Verification
9) Mission Operations Testing at Assembly, Test, and Launch Operations (ATLO)
10) Constraints and Flight Rules
11) Data Distribution to Spitzer (SIRTF) Users
12) Lockheed Martin Support Area
13) In-Orbit Check Out

Basically, there was a lack of organization, and there were issues regarding SIRTF's distributed operations.

There were five primary contributing factors in the SIRTF environment which caused these major deficiencies:

a) Inexperienced personnel… The personnel planning/developing the MOS had little to no operations experience. This led to lack of planning and organization.
b) Better, faster, cheaper… SIRTF was running (and had planned) to run operations very lean. Automation was high on the list to help achieve a lean MOS, but little effort was being expended on developing or testing of the automated capabilities.
c) JPL Philosophy (Planetary vs. Observatory)… JPL's experience is mostly in planetary deep space missions, which are significantly different in approach from observatory missions. Capabilities in the flight software (FSW) or MOS are typically deferred. As a result the cruise phase acts as the MOS Phase C/D before the push is on for encounter. Also in planetary mindset, if there is a problem during orbital operations, there is another opportunity to get it next orbit. For planetary missions, MOS is not a pressing issue in Phase C/D. These conditions do not hold true for observatories.
d) Lack of commitment… The industrial partner was not fully committed or engaged in running the Observatory in Operations. This reduced staffing contributed to plans that were either not developed or were inadequately developed.
e) Reluctance to deliver (polishing the cannonball). There were groups of development people who felt that MOS/ Science Operations System (SOS) entities should not be delivered unless they were 100% complete/tested.

At this time there was no MOS. There was only an Operations Counsel made up of the Flight Operations System (FOS), SOS, and Observatory System Engineering (OSE). No one manager was responsible for Operations, and the counsel members had little to no flight operations experience (they were all development managers). Therefore, the highest priority recommendation from the failed CDR was to put in place immediately a manager with flight operations experience. This action was resolved by the Project Manager by appointing a manager for Mission Operations called the

Mission Manager. The Project Manager consolidated MOS responsibilities under the Mission Manager and disbanded the Operations Counsel.

3. DELTA CDR

In order to keep the Project on track for launch in January 2003, a delta CDR was setup for mid 2001.

SO… how did we solve the issues above, and what did we learn from them? Before you can correct the major themes, you first need to correct the contributing factors (or else you will be caught in a vicious cycle).

a) Add experienced MOS personnel. Augment the current operations (OPS) teams with experienced team members who bring two things, their previous experience and a willingness to break a subset of JPL philosophy.

b) Determine MOS state. Re-evaluate the cost and work to go with this new team, and get JPL and NASA HQ to buy into it.

c) Impress a new philosophy. Change the MOS team attitude to that of an Observatory (from that of a Planetary focus) by impressing on the MOS team that the critical activity is the launch.

d) Strengthen partnerships. Resolve with the industrial partner the commitment to provide an experienced Observatory Engineering Team (OET), or find an alternate solution.

e) Compromise to move forward. Change the philosophy of the MOS from cannonball polishing to accepting an 80% solution—Meaning, it was better to accept a portion of the MOS to be integrated/evaluated rather than wait for the perfect product.

When the contributing factors had been eliminated, the next thing to do was attack the 13 themes from the top down:

1) Reorganize Operations. Reorganize the operations to be centralized at JPL, and with four primary technical areas reporting to the Mission Manager. These four areas were Flight Engineering Office (FEO), Multi-Mission Support Office (MMSO), System Engineering and Coordination (SE&C), and Science Operations. (See Figs. 1 and 2)

2) Establish an MOS Master Integrated Schedule. This includes tracking of major Project, MOS, and Flight System milestones. This schedule must include MOS (processes, procedures, and training), ATLO activities, and Ground Data System (GDS) (including S/W and H/W deliveries). (See Figure 3)

3) Create a plan for OSTL utilization. Including rules of scheduling. Criteria for when it can/should be used. Place OSTL usage onto the MOS Master Integrated Schedule.

4) Establish MOS CM. For all MOS elements (H/W, S/W, supporting documentation, processes, procedures, Operational Interface Agreement (OIA), Software Interface Specification (SIS)) and anomalies into MOS CM, and captured in a centralized way creating an “everything and no exceptions” mentality.

5) Develop/test the virtual machine language (VML). Dedicate more workforce to develop/test the VML used in sequencing, with subsequent delivery through MOS CM.

6) Establish a Verification and Validation (V&V) Plan, including an incompressible test list. Then create Operational Readiness Tests and team training. Place all items on the MOS Master Integrated Schedule. Establish and grow MOS team interfaces, including them on the MOS Master Integrated Schedule and with formal deliveries to MOS CM.

7) Create a plan for handling changes to the FSW. These include FSW patches and flight configuration files using item 4.

8) Develop/test blocks and sequences. Dedicate more work force to block and sequence development and validation (including Astronomical Observation Request (AOR), Instrument Engineering Request (IER), Spacecraft Engineering Request (SER)) Processes/Procedures and Testing (and place them on MOS Master Integrated Schedule).

9) Develop MOS V&V. Identify and establish a set of MOS V&V Tests for ATLO using MOS personnel. These are not ATLO tests, but MOS tests. Also, include the Flight Control Team (who will actual do real-time support of the Observatory) to participate actively in ATLO.

10) Create Flight Rules and constraints. Place more effort on establishing, developing, and testing Constraints and Flight Rules. Place these activities on the MOS Master Integrated Schedule.

11) Establish Downlink Processing Processes/Procedures. Including product tracking to increase downlink processing efficiency.

12) Build Mission Support Areas. Negotiate with Lockheed to move operational support from Lockheed Martin Missiles and Space (LMMS) in Sunnyvale, CA, to the more operations-experienced Lockheed Martin Astronautics (LMA) in Denver, CO. Create a plan for establishing Mission Support Area (MSA) facilities at LMA and JPL, including their inclusion on the MOS Master Integrated Schedule.

13) Create an IOC Plan. Finally based on having the above infrastructure, establish an IOC Plan that utilizes this infrastructure and capabilities. Products for supporting IOC were added to the MOS Master Integrated Schedule.

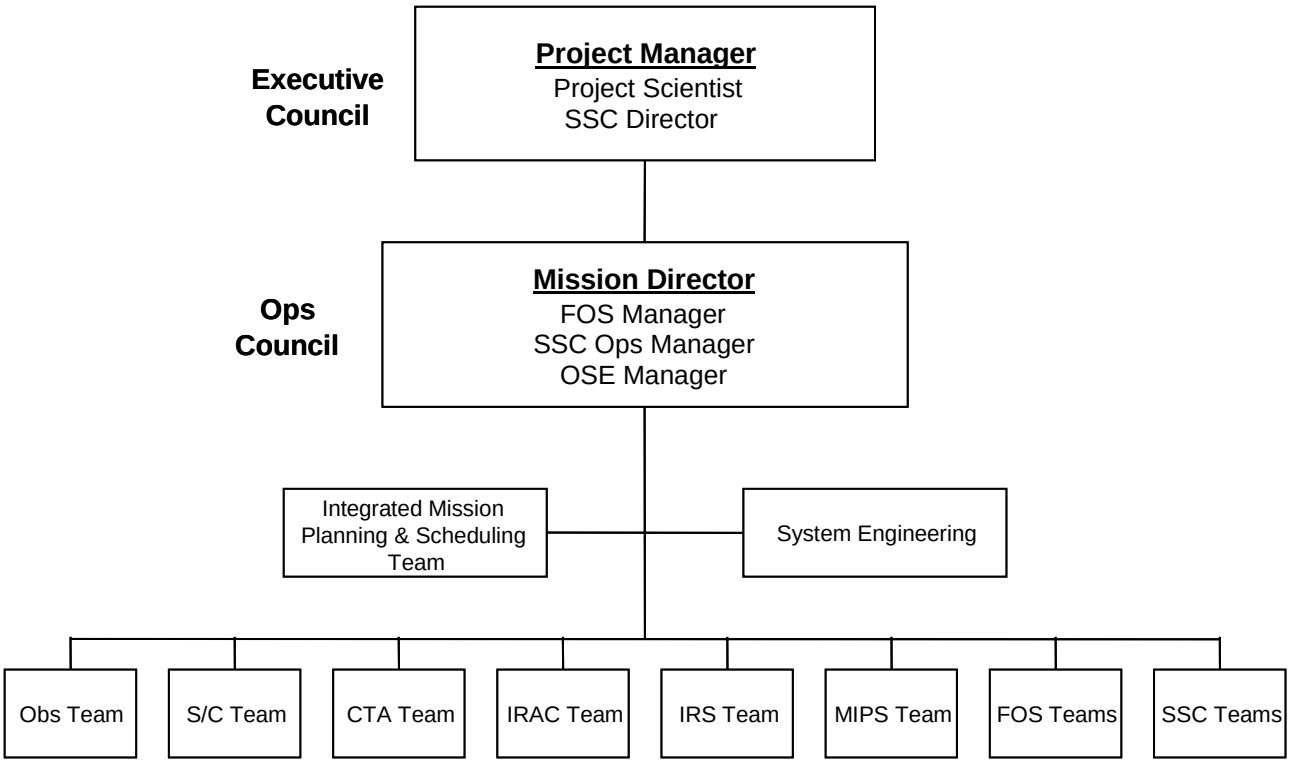

Figure 1 – OPS Council Pre CDR

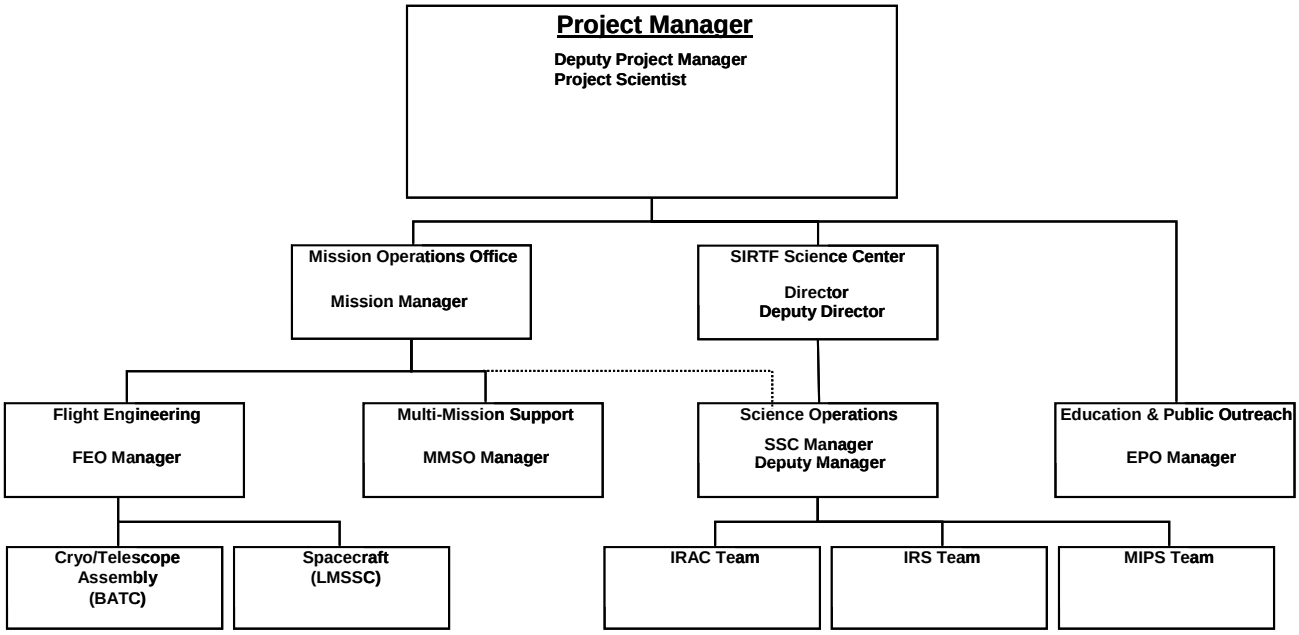

Figure 2 – New MOS Organization Post CDR

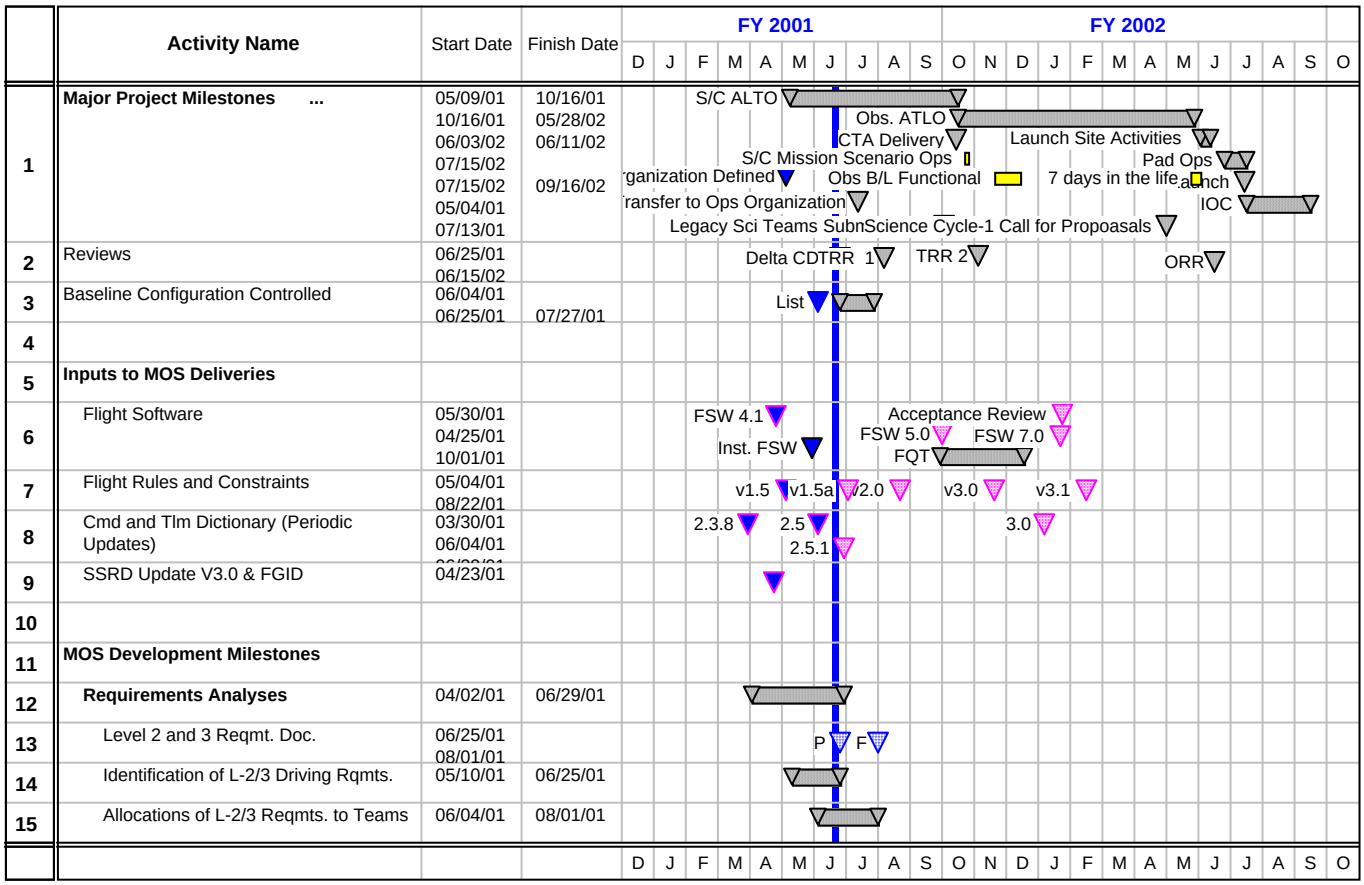

Figure 3 – First Page of MOS Integrated Schedule

Once the 13 themes were addressed with plans to complete, the Delta CDR was conducted in June 2001. In ~9 months, 58 of 97 RFAs were closed (with plans in place to close the remaining 39). The Delta CDR generated a set of 30 RFAs (many overlapped the set of 39 RFAs left open from the CDR).The Delta CDR was declared successful, and the new MOS team pressed on to close the remaining actions.

4. EXECUTING THE INTEGRATED SCHEDULE

Executing the integrated schedule led the MOS team from the Delta CDR to the Operational Readiness Review (ORR) and on to launch. However, the ORR was scheduled for November 2002 (17 months after the Delta CDR), which was a limited amount of time for the MOS reorganization/development and for closing the remaining 69 RFAs (from both the CDR and the Delta CDR).

In executing the integrated schedule, the MOS team still found additional areas that needed to be improved with in the thirteen themes:

1) Reorganize Operations. Further changes in the MOS organization had to be made due to the lack of confidence in the GDS. Therefore GDS System Engineering, Integration and Testing were moved from one technical area to another (where there was a mentor seasoned in GDS). The GDS Team was also increased with experienced personnel from various areas of GDS. This team became very effective, increasing GDS throughput by an order of magnitude.

2) Establish an MOS Master Integrated Schedule. The integrated schedule was a great foundation and coordination tool, but when building an S/C and MOS, things can and do change rapidly. To keep this under control the MOS Manager required a daily meeting with the technical area managers to insure the MOS stayed on track/schedule.

3) Create a plan for OSTL utilization. Having LMA Denver participate with LMMS Sunnyvale was great from many aspects. One aspect being that the quality and quantity of tests run on the OSTL improved tremendously. Basically there needed to be better (more dedicated) management and scheduling of the OSTL. Further work was done in creating a consistent test startup for the OSTL, to ensure a consistent environment was used for all tests conducted.

4) Establish MOS CM. There was a reluctance to have a central CM down to the source-code level, so a compromise was reached that the distributed team had to maintain source-code version control. However the S/W could only be used if the distributed team delivered executables through the MOS central CM. All teams used the Change Request (CR) process for handling all MOS changes. Also all development teams were required to submit a standardized format for Release Description Documents (RDDs) with all S/W deliveries.

5) Develop/test VML. More personnel were placed on development and test of the VML. A consistent regression test was developed to test both the Block Libraries for use on board, and to test the VML. This regression suite was run in its entirety whenever there was a block library change.

6) Establish V&V Plan. All V&V Plans were placed on the schedule and were given equal (or greater) weight compared to other scheduled items. During the MOS V&V Tests, we found issues with not only MOS processes/procedures that needed to change, but also with testing artifacts that actually effected operations. For example, after the OSTL is started, there is residual data from the start up that needs to be cleared, so the test starts from a known environment. This revealed that not all Mass Memory Card (MMC) data is deleted when running “Packet Select Delete” commands (producing orphan MCC Storage Units (SUs)), so a Flight Control Team (FCT) procedure had to be added to take care of cleaning up orphan SUs on a regular basis. Pre CDR there was a lack of strong MOS System Engineering, and the OPS teams had not been supportive in coordinating. After the Delta CDR, the OPS teams collaborated better, MOS system engineering was made stronger, and items placed on the schedule (e.g. OIAs, Processes, and Procedures) were delivered on time.

7) Create a plan for handling changes to FSW. Starting after the Delta CDR, all pre-launch changes to FSW (including configuration files) were coordinated through MOS CM, but they were approved by the development organization. Post-launch, the FSW changes were not only placed through MOS CM, but are approved by the Mission Change Control Board (MCCB).

8) Develop/test blocks and sequences. More effort was placed on validating the Block Libraries, and sequence development. For operations, the Mission Sequencing Team (MST) was used to create all ATLO and Operational Readiness Test (ORT) sequences. During this process it was found that the original two-pass sequence build would not work, so the sequence build was changed to be a three-pass process.

9) Develop MOS V&V. During the MOS V&V Tests, the OPS teams were used to support the ATLO testing. The Flight Control Team (FCT) sat in on all ATLO tests, and participated in the transmission of commands for ATLO. All telemetry data was processed by the Multi-Mission Support Office (MMSO) teams, and was sent to the Spitzer Science Center (SSC) during the tests. This allowed testing of the actual OPS environment.

10) Create Flight Rules and constraints. More workforce was made available to the Sequencing and System Engineering areas to establish and develop Flight Rules and Constraints. A separate LMA supported effort was used to validate all Flight Rules and Constraints that were being checked by the sequencing system. This was a successful effort with the Flight Rules and Constraints validation becoming part of the regression test suite insuring consistent test re-executions.

11) Establish Downlink Processing Processes/Procedures. Downlink processing was in disarray. Any data run from the OSTL or from a Deep Space Network (DSN) station would take days if not weeks to process. The MOS established the Data Products Working Group (and a product tracking web site) to be sure data was processed in a timely fashion. The requirement was 12 hours from DSN receipt of data to delivery to SSC in Flexible Image Transport System (FITS) format. Within a couple test runs, the time had improved to less than 24 hours. With the launch version of the GDS delivered, and with all teams full staffed, this time to deliver data was reduced to a period of 8–10 hours!!

12) Build Mission Support Areas (MSAs). An Observatory Engineering Team was assembled at LMA with an extensive contingent on temporary duty at Sunnyvale. An LMA Denver MSA was constructed to support SIRTF. The JPL MSA facility plans/construction proved to be very challenging considering the SIRTF Project was competing with the Mars Exploration Rover (MER) Project for JPL infrastructure services. SIRTF used the MER work to our advantage, by scheduling our work to be in concert with MER work. For example: If MER was having walls reconstructed on another floor, we had the same company perform reconstructing walls for us (after they were complete with MER). This meant we did not run into any facilities or scheduling conflicts.

13) Create an IOC plan. IOC planning used all the MOS established OPS teams, procedures/processes, and products. The one exception was in the IOC event planning, which was done using Activity Plan Generator (APGEN) instead of Spitzer Integrated Resource and Scheduling System (SIRPASS). All changes to the IOC schedule/content was captured using the CM System and all products were run though all OPS teams

The ORR was conducted in November 2002. In ~17 months all (180) RFAs had been closed. The ORR was declared successful, and the MOS team pressed on to close the new actions and prepare for launch. The ORR generated a set of 9 RFAs (only 7 accepted):

1) Block Library testing concern. The concern was that not all the blocks would be fully validated pre launch. There was a schedule to complete testing, and the schedule was met.

2) Pointing Calibration and Reference Sensor (PCRS) Operations concern. The concern was PCRS knowledge at SSC for health and status of PCRS. This was resolved by making OET/LMA responsible for PCRS.

3) Nominal Operations ORT Problem Reporting concern. The concern was that the standard "Incidence Surprise Anomaly" (ISA) system was not used for problem reporting during the Nominal Operations ORT. This was resolved, by routing all problem reporting through the ISA system starting from the ORR forward (i.e., pre launch)

4) Integrated Schedule concern. This concern was that the IOC/ be integrated into the MOS Integrated Schedule. IOS/SV activities were placed on the integrated schedule, and work with OSTL usage.

5) In-flight FSW load concern. The concern was if the procedure to reload FSW in flight had been validated. A Category C Contingency Plan was developed in lieu of performing an FSW load.

6) Ventilating IOC concern. There was a concern that there were no time margins in the IOC schedule. This was addressed by adding time throughout the IOC schedule to have a 19% time margin.

7) MST Editing procedure concern. The concern was that there was no MST procedure for editing sequences (if needed). This was resolved by creating a sequencing editing policy.

These seven RFAs were resolved fully by the Launch Readiness Review (LRR) in March 2003.

Everything was GO for an April 18, 2003 launch. Unfortunately problems with the solid rocket motor boosters, and MER's need to launch, delayed the SIRTF launch until August 2003. This allowed MOS to make one last set of FSW and GDS deliveries pre launch which contained minor fixes that had been planned for post launch.

5. CONCLUSION

The key to Spitzer's (aka SIRTF's) lifetime is directly related to amount of liquid helium on board. It is important that we were ready to begin Science Operations as soon as possible after launch. This contributed to maximizing the amount of science obtained. It was also important that we reach a maximized efficiency at the beginning of Science Operations. The efficiency goal was 90% observation time, with the cryogen to last 5 years.

Spitzer was successfully launched August 25, 2003 with great MOS support. This support was made possible by the hard work of a real team that pulled together. This real team was made up of several talented individuals, but would not have been possible without the great leadership from Project Management. The team rallied around these talented individuals, and was able to pull the MOS development from the jaws of defeat. This successful journey from CDR to launch was accomplished by an MOS team that had made improvements in the Operations System, the Ground Data System and the Flight System.

Since launch Spitzer has achieved efficiencies of more than 90%, and with fewer personnel than other missions (or observatories). With the efficiency being greater than 90%, the observatory is expected to continue operating at that efficiency level for more than five years.

So this paper is dedicated to all the hard working MOS personnel who made the MOS successful for Spitzer launch. Launching this great observatory would not have been possible without you. Your hard work will give the science community, the world, and future generations a better understanding of the universe. This is only the beginning… the best is yet to come.

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