Deep Impact Extended Mission Challenges for the Validation and Verification Test Program

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The Deep Impact Spacecraft was launched on January 12, 2005 as part of NASA's Discovery Program as a radical mission to excavate the interior of a comet. The Spacecraft consisted of two separate entities known as the Flyby and the Impactor, which were commanded to separate prior to comet rendezvous with comet 9P/Tempel 1. The overall mission was deemed a success on July 4, 2005, as the 370-kg Impactor collided with the comet at 10.2 km/s. This event was captured using the camera and infrared spectrometer on the Flyby spacecraft, along with ground-based observatories. Since this event, the Flyby spacecraft has been in hibernation mode and has received only a small amount of maintenance. The Deep Impact Program was managed by the Jet Propulsion Laboratory (JPL), led by Dr. Michael A'Hearn from the University of Maryland in College Park, and built by Ball Aerospace & Technologies Corp. in Boulder, Colorado.

The Deep Impact Spacecraft was selected for a Mission of Opportunity under the NASA Discovery Program. The Flyby Spacecraft will be used to conduct two new scientific investigations called the EPOXI Mission. This mission was selected based on two proposals, which were merged under the 2006 Discovery Program. The EPOXI Mission, its name being derived from the two proposals, EPOCh and DIXI, will use the deep Impact spacecraft and its instruments to study a comet in our solar system and to investigate planets around other stars.

On September 24, 2007, the spacecraft was taken out of hibernation mode in preparation for the EPOXI Mission. The assembled flight team is a mixture of Deep Impact prime mission veterans and new members. In order to command the spacecraft, the entire team has been recertified using the only resources available: the test benches. However, when the Deep Impact Primary Mission ended, much hardware was put in storage. The overall state of the other JPL test benches was not known until they were re-commissioned into the designated JPL EPOXI Mission test bed facility. There are two test benches at Ball and only one has been kept at the ready during the entire hibernation period. Prior to bringing the spacecraft out of hibernation and initial checkout, this test bench failed, leaving the project with no test platform. The test benches served as a key tool in the overall success of the Deep Impact Primary Mission and they continue to be a key element in the extended mission.

The benches were deemed a valuable resource for the success of the EPOXI Mission and it became a challenge to the selected Test Team at both the Jet Propulsion Laboratory and Ball Aerospace & Technologies Corporation to get them operational and recertified. This paper will focus on the lessons learned and challenges associated with getting the test facility

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back on-line for spacecraft validation and verification for in-flight activities and training of the EPOXI Flight Team.

Nomenclature

ADCS	=	Attitude Determination and Control Subsystem
AMMOS	=	Advance Multi-Mission Operations System
ADCS	=	Attitude Determination and Control Subsystem
AutoNav	=	Autonomous Optical Navigation
BATC	=	Ball Aerospace & Technologies
CDS	=	Command Data Subsystem
COTS	=	Commercial Off The Shelf
DI	=	Deep Impact
DIXI	=	Deep Impact Extended Investigation
DSN	=	Deep Space Network
DSS	=	Dynamic Spaceflight Simulator
EOM	=	End of Mission
FE	=	Flight Equipment
FSW	=	Flight Software
GDS	=	Ground Data Subsystem
H/W	=	Hardware
HRI	=	High Resolution Instrument
LASP	=	Laboratory for Atmospheric and Space Physics
MRI	=	Medium Resolution Instrument
OASIS	=	Operations and Science Instrument Support
RIU	=	Remote Input Unit
SCU	=	Spacecraft Control Unit
SIRU	=	Scalable Inertial Reference Unit
SSTB	=	Subsystem Test Bench
SWTB	=	Software Test Bench
TCM	=	Trajectory Change Maneuver
UUT	=	Unit Under Test

I. Introduction

THE Deep Impact Mission was an overall success when it impacted comet 9P/Tempel 1 on July 4, 2005. The Deep Impact Spacecraft was very unique in that it was made of two separate spacecrafts, known as the Flyby and Impactor, that were commanded to separate prior to encounter. Once separated the 370-kg Impactor autonomously guided itself to collide with the comet at 10.2 km/s, while the Flyby was positioned to record the event. This event was captured using onboard instruments along with ground-based observatories. Deep Impact observed the nucleus of comet 9P/Tempel 1 before, during and after impact, returning a significant amount of image data of the event. The following images (Figure 1.0) document some of the results obtained from the encounter with 9P/Tempel 1. The image on the left was taken by the Flyby's medium-resolution camera 16 seconds after impact. The image shows the initial ejecta that resulted when the Impactor probe collided with the comet. The next image (right), taken by the Impactor targeting sensor, shows the view from the Impactor 90 seconds before it was pummeled by the comet. This event was not only captured by the Deep Impact spacecrafts and orbiting telescopes, but many observatories around the world observed the collision or its aftermath. The Deep Impact mission was designed to have some of its mission-critical science done from Earth-based telescopes (Figure 1.1). These Earth-based telescopes enable scientific experiments to be performed in wavelength regimes and timescales that are not possible for the spacecraft.

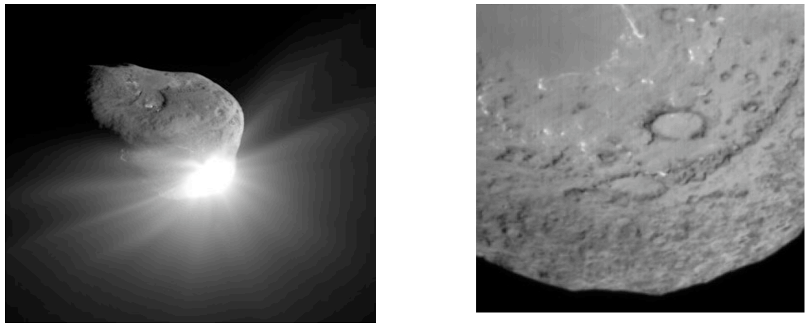

Figure 1.0 Encounter images from the Flyby (left) and Impactor (right) Spacecraft[3]

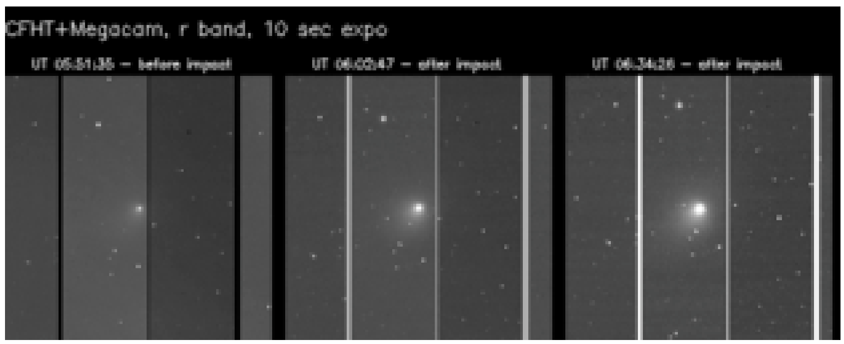

Figure 1.1 Ground Observed Event: This series of images was taken at the CFHT (Canada France Hawaii Telescope) equipped with the Megacam camera, pre- and post-impact.[4]

The success of the mission has produced a wealth of science data for the Deep Impact Science Team. Initial science data yielded unexpected results about the structure and composition of comets. Mission scientists found evidence of water ice on the surface of the comet and analysis of data revealed that the surface of 9P/Tempel 1 is of a fluffy consistency. The Science Team for the Deep Impact Mission is led by Dr. Michael A'Hearn of the University of Maryland and all results obtained from the spacecraft are in the process of being analyzed. Some results have been published and are available from proceedings[4,6]. Since this event the Deep Impact Flyby spacecraft has been placed in hibernation mode and has received only a small amount of maintenance. Hibernation mode was necessary to keep the spacecraft alive and online for its next assignment. Even though the spacecraft was placed in hibernation its health status was monitored and maintained until it was needed for a new mission.

[3] http://deepimpact.umd.edu/gallery/images.shtml
[4] http://deepimpact.umd.edu/collab_pub/images/impact_CFHT.gif

Since the encounter, the Deep Impact Spacecraft has been considered for reuse on another mission. The Deep Impact Spacecraft was selected for a Mission of Opportunity under the NASA Discovery Program. The Flyby Spacecraft will be used to conduct two new scientific investigations under the EPOXI Mission. This mission was selected based on two proposals, which were merged under the 2006 Discovery Program. The EPOXI Mission, its name being derived from the two proposals, EPOCh and DIXI, will use the surviving Deep Impact Spacecraft and its three working instruments (two visible cameras and an IR spectrometer) [Figure 1.2] to study a comet in our solar system and to investigate planets around other stars. Like Deep Impact, Deep Impact eXtended Investigation of Comets (DIXI) will be a partnership between the University of Maryland, NASA's Jet Propulsion Laboratory (JPL), and Ball Aerospace & Technologies Corporation. The DIXI mission will conduct a mission to a second comet to collect images of its nucleus to increase the understanding of the diversity of comets. At the time that this paper was being written the comet that was being targeted was 85P/Boethin. However, due to a lack of observations of comet 85P/Boethin during the allocated timeframe, insufficient orbital data was obtained to construct a Trajectory Correction Maneuver necessary for targeting comet 85P/Boethin. As a result comet 103P/Hartley 2 was chosen as an alternative target. There were two 103P/Hartley 2 options that were proposed for the DIXI mission. One, with a period of about 1.5 years, required fewer maneuvers but arrived with a higher approach phase angle (121º) which was unacceptable for science and AutoNav considerations. The selected option, with a period of about one year, required more maneuvers, but provided a more favorable phase angle (97º) for science and autonomous pointing control.

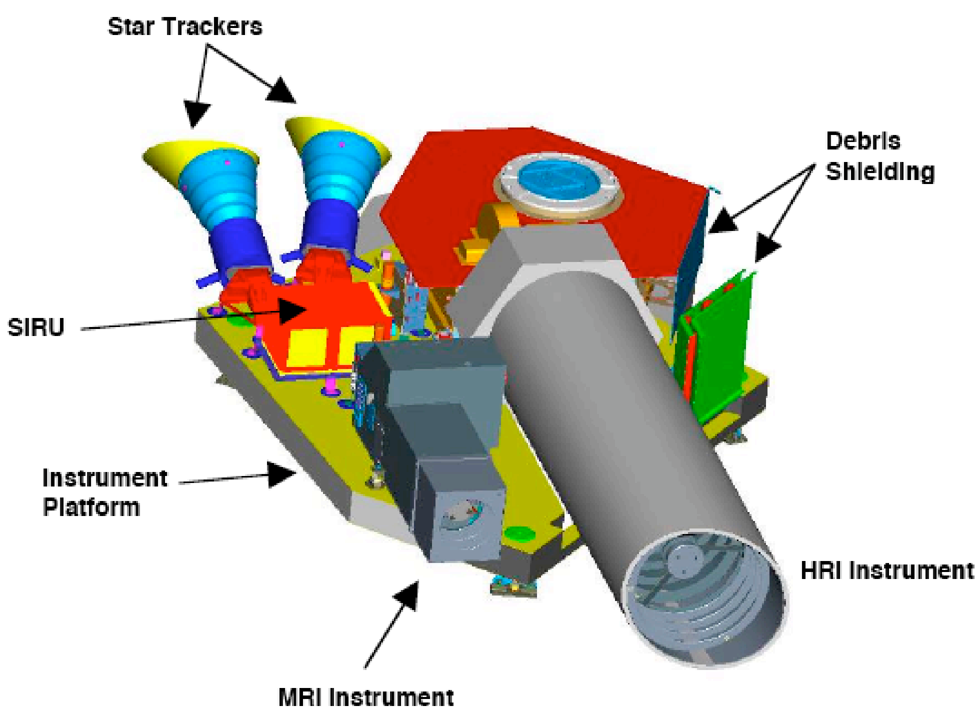

Figure 1.2 Deep Impact Flyby Spacecraft

The second portion of the EPOXI mission, Extrasolar Planet Observations and Characterization (EPOCh), is led by Drake Deming of Goddard as the principal investigator in collaboration with the Deep Impact science team. Like DIXI, it is a partnership between NASA's Jet Propulsion Laboratory and Ball Aerospace & Technologies Corporation. EPOCh will observe previously discovered Jupiter-like planets orbiting nearby stars and search for evidence of Earth-sized planets. The HRI will be used for the EPOCh science observations as a precision photometer to observe the transits and eclipses of stars by planets by measuring the light from stars in repeated images. During these observations the Flyby spacecraft is close enough to earth to return data at the maximum downlink rate. The Earth will also be observed using all HRI filters and IR spectrometer for a complete rotation to characterize it as an analog for extrasolar terrestrial planets.

Using the Deep Impact Spacecraft for the EPOXI mission provides a proven flight system, ground system and overall reduction in risk and cost. Not only is there a cost savings due to reuse of an existing spacecraft in-flight but combining the EPOCh and DIXI observations, significantly reduces the overall science costs. The costs are reduced by using the same data processing pipeline for imaging data for both observations through the Science Processing Center at Cornell University. The EPOXI mission will also use the flight operations concept and some experienced personnel to mitigate other risks. The overall health of the spacecraft since the encounter of comet 9P/Tempel 1 indicates that it continues to provide full functionality of all prime components within its dual-string architecture. It has also proven to be capable of long-duration autonomous operation in both high-precision and low-cost hibernation mode. It has sufficient resource margins and propellant to support the EPOXI mission.

Not only does the EPOXI mission have a proven spacecraft but it will also use the Deep Impact test venues. The EPOXI mission will use the existing test benches from the Deep Impact program that consist of 3-single string test benches of which two can be interconnected to form a better representation of the Flyby Spacecraft. Each Test bench includes a hardware representation of the actual Spacecraft Control Unit, celestial mechanics, dynamics and a software representation of its peripherals. Only the Subsystem Test Bench (SSTB) includes a hardware representation of the Remote Interface Unit (RIU - Engineering Module). These test benches have the capability of simulating the uplink and downlink data paths using the actual Ground Data Subsystems that are used during flight operations. Using the actual GDS during testing provides a better end-to-end product and process verification before execution on the actual flight vehicle. These test benches also serve as a training platform that allows for certification of Flight Operators and dress rehearsals for Mission Critical Events. The following figure [Figure 1.3] is an illustration of the Deep Impact Test Bench configuration.

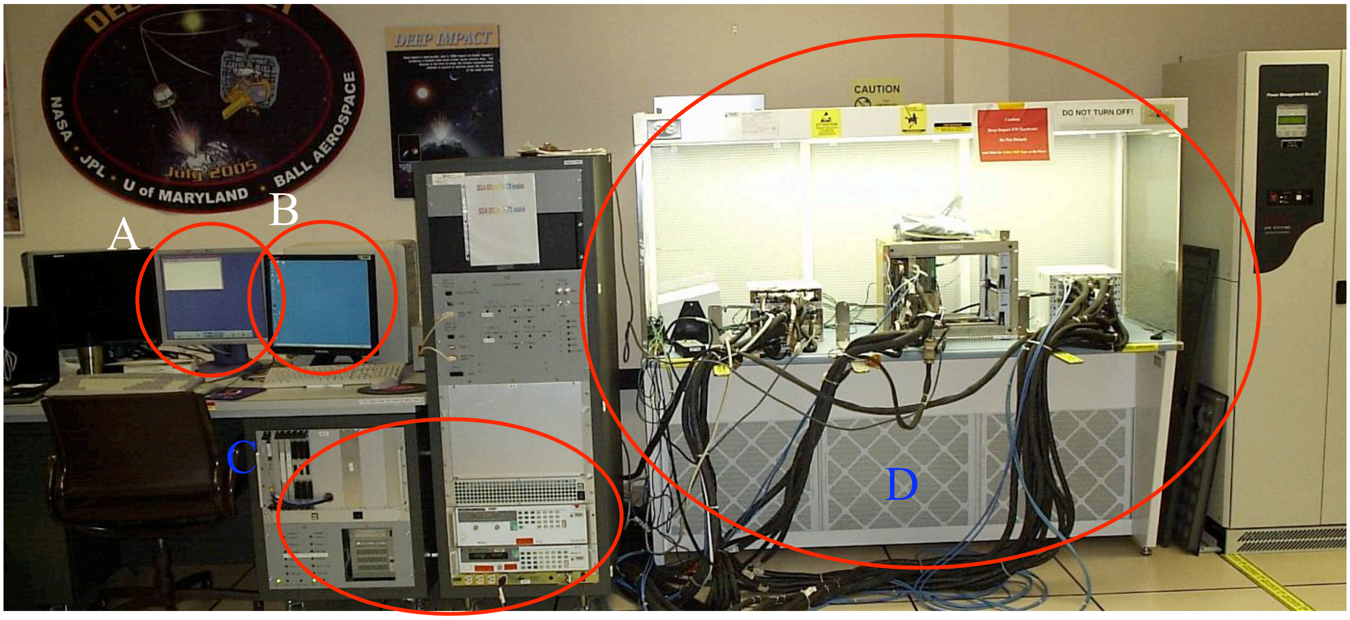

Figure 1.3 System Software Test Bench shown in dual string configuration; A) AMMOS work station, B) OASIS work station, C) GSE Real-Time Racks, D) EPOXI Hardware (Flight Computer and Uplink/Downlink Boards)

Throughout the Deep Impact mission the test benches were an integral resource in the achievement of a successful mission. These test benches were deemed important for training on the EPOXI mission since there are several new members holding prime positions. The test benches became a key tool for off-loading key experienced Deep Impact members from the day-to-day training of the new members. The new members would run test cases on the benches to become familiar with the overall process, flight software, and ground data system (GDS), monitoring and spacecraft dynamics. The GDS that is used with the test benches is a copy of what is used for spacecraft operations making it a viable tool for the dress rehearsal and generation of predicts for spacecraft activities. This paper will address the issues and challenges in getting the necessary test benches configured and certified for the EPOXI mission without the developers.

II. Test Bench

The test benches were designed and built by Ball Aerospace and Technologies Corporation (BATC) located in Boulder, Colorado, for the Deep Impact mission. There were two varieties of test benches developed for the mission. One is the Subsystem Test Bench, built as a hardware certification platform capable of simulating the redundant capabilities of the Flyby flight system. The other is the Software Test Bench that can be configured to represent a variety of configurations of the flight computer. The following sections will describe in detail the overall test environment and how each test bench differs.

A. Test Bench Software Simulation Environment

The simulation software is known as the Dynamic Spaceflight Simulator (DSS) and it is BATC core test environment software that can be extended and/or modified to accommodate specific mission requirements. The DSS is an extension of the Attitude Control Performance Simulator (ACPS), which is BATC proprietary core software and provides dynamic mode for closed loop simulation of spacecraft dynamics. When the DSS is engaged in dynamic mode it essentially closes the loop between the flight software's sensory inputs and command outputs by simulating the spacecraft dynamics and the physical environment. The DSS is designed with the flexibility to allow sensor/actuator/flight-box component simulations to be replaced with flight-like hardware.

The dynamics simulation provided by the DSS is a very elaborate simulation that models all aspects for the Attitude Determination and Control Subsystem (ADCS). It contains the following models: 6-degree of freedom (DOF), environmental, sensor, actuator, tank pressures, mass depletion, reaction wheel friction, telecom, power, and instrument. These models are still valid for the EPOXI mission. Since the delivery of the DSS to Deep Impact it has evolved to service other BATC missions. The DSS is configured to be commanded using the Operations and Science Instrument Support (OASIS) software package developed by the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado at Boulder. The OASIS interface provides a method for commanding and displaying telemetry from the SCU under test as well as injecting parameters and faults into the DSS. It uses an interpreted scripting language, Colorado System Test and Operations Language (CSTOL), which allows for automated test procedures to be written and automatic verification and limit checking on the received telemetry.

The BATC developed simulation was later enhanced by JPL to include an image simulation [developed by Brian Kennedy at JPL] so that the auto-navigation routine of the Deep Impact flight software could be fully validated. The code that was developed for the image simulation was delivered to BATC for integration with the rest of the DSS. The image simulation allows for simulation of image sequences to test the system performance based on the navigation camera and target body characteristics (comet, asteroid, planets, star-fields). Canned simulated images [Figure 2.0] are generated using a MATLAB function and loaded into the DSS. The test bench hardware was also reconfigured for use with the actual Ground Data Subsystem that is used at JPL for flight operations. This allowed for the flight team to be trained and actual uplink products to be tested prior to radiation to the spacecraft.

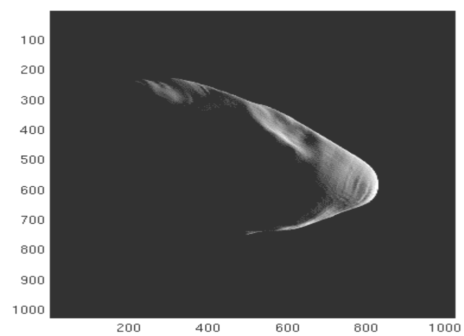

Figure 2.0 Image Simulation Picture

During Deep Impact flight operations the spacecraft hardware was characterized as it was flown and flight hardware values were incorporated into the simulation so that it better represented the flight system. The test bench simulation is fully validated for the Deep Impact spacecraft; its idiosyncrasies are fully understood. The EPOXI activities are similar to Deep Impact activities, therefore the test bench simulation provides an accurate model in the validation and verification of EPOXI mission activities. The only things that needs to be altered in the test bench simulation are changes in mass properties due to the loss of the Impactor, fuel consumption and sun sensor coefficients. Any simulation alteration is simply performed using configuration files that are executed at initialization for any desired test.

B. System Software Test Bench (SSTB)

The SSTB is a high fidelity hardware-in-the-loop test platform that provides closed loop testing. It consists of a software simulation of all the Deep Impact Spacecraft peripherals, celestial mechanics and the science instruments. This test bench has dual string capability and when configured with a Software Test Bench it simulates the intercommunications between both Deep Impact spacecrafts: Flyby and Impactor. Since the Impactor Spacecraft is hitchhiking on 9P/Temple 1, the EPOXI mission does not need to join two test benches for simulation. Therefore the Impactor Ground Support Hardware has been removed so that the test bench only represents the Flyby

Spacecraft. The test bench is set up in conjunction with the DSS to run both the OASIS and AMMOS ground system as the test console. The hardware that is provided as the Unit Under Test (UUT) contains two copies of the flight system Spacecraft Unit (SCU) and the Remote Interface Unit (RIU). The SCU consists of the flight processor (RAD750), non-volatile memory (NVM), command & telemetry board (CTB) and the instrument control board (ICB). The test bench ground support equipment also simulates flight software autonomous power switching.

The capability of dual string support in the SSTB was removed after the Deep Impact prime mission ended due to a contractual agreement between JPL and Ball. However, for the EPOXI mission dual string capability is necessary and it was made possible by configuring the Prototype (PT) SCU from one of the SWTBs with the SSTB. The only limitation is that the PT SCU cPCI chassis does not simulate autonomous power switching. In order to properly simulate power cycles on the PT SCU, the power is manually cycled by a test operator when necessary.

C. Software Test Bench (SWTB)

The SWTB only contains single string support and its UUT is composed of a PT SCU and a simulated RIU. The PT SCU contains all hardware, but its chassis is not flight like and does not support automatic power switching. However, it does allow for reconfiguration of the SCU to represent either SCU string A, SCU string B, or the Impactor SCU. This SCU configuration can be altered easily using dipswitches to change the SCU string or spacecraft identification. For the EPOXI mission the SWTB can be configured as the back-up SCU within the SSTB when dual string testing is necessary. The SWTB is also a hardware-in-the-loop simulation that provides closed loop testing. It provides a software simulation of all its peripherals, celestial mechanics and science instruments. The SWTB, like the SSTB, is set up in conjunction with the DSS to run both the OASIS and AMMOS ground system as the test console for the UUT.

D. Logistics of Test Benches

Since the Deep Impact encounter, the JPL test benches were moved into a temporary facility until word was given on the extended mission. The facility that was used for the Deep Impact test bed was given to a higher priority project. The facility that was used for Deep Impact already had the infrastructure in place that was necessary for flight operations and testing. So it was ideal for missions to re-use it, since it provides a cost savings in facility infrastructure setup. Once the test benches were moved, only the SSTB was on-line for use on Deep Impact during its health checks while in hibernation mode. The temporary test bench facility mainly resembled a large warehouse that was not as secure and did not have the network infrastructure to support testing of flight related files. Like the Deep Impact Spacecraft, the test beds were put in hibernation mode, since it was not known whether an extended mission was in the near future. Once its extended mission was announced the test benches and flight operations were moved to a selected facility for the EPOXI mission. However, the facilities selected for both the test benches and flight operations needed modifications. The extended mission budget did not account for any facility modifications. The facility that was allocated as the EPOXI test area did not have adequate power necessary to operate the test bench equipment. There were also no flight operations network connections available to easily access test articles. The network infrastructure was later installed by the EPOXI project. This network infrastructure also provides a cost savings avenue for future flight projects that will use the facility. The necessary clean room support, including humidification control, temperature control and grounding, was also not provided in this facility. All of these additional costs to the extended mission could have been avoided if the project allocated facility for the prime mission was not given up until the fate of the Flyby Spacecraft was known. Moving the test benches at JPL and BATC several times caused certifications to lapse and stress to the components, making additional work for the EPOXI Test Team.

Movement of test equipment included a host of cables and parts, which is risky, increasing the probability of stressed components, cabling, and connectors. This was the case with all three test benches that were selected for the EPOXI mission. During the movement of the JPL benches both experienced hardware failures. This will be covered in further detail in the following section. It was also a challenge to move the test benches between buildings since the overall dimensions exceeded some building entrances and elevator space. In order to move to and from buildings, doors had to be removed and the benches had to be dismantled. One lesson learned is that test equipment should be built with dimensions that will allow it to be transported to and from its facility without it being completely dismantled. The Deep Impact test bench rack dimensions were too wide to fit through a door and too long to be transported in a freight elevator. The rack had to be dismantled so that it could be relocated.

Since no integration procedures were provided for tearing the test bed down and re-cabling, one was put together on a best effort with the allocated work force during Deep Impacts Hibernation mode. The procedure was developed by JPL without the test bench developer's help or review. Most of the developers of the test bench had been transferred or acquired new jobs and were not available to help with the movement of the test bench. Nor did a test bench maintenance plan exist since it was never planned that Deep Impact would be granted an extended mission. All focus during the Deep Impact mission was on the success of the Encounter instead of documentation of the test benches. The only documentation that was developed was initialization of the test benches for testing of the encounter activities. Emphasis should be placed on documentation even if there is only a remote possibility of an extended mission. This would provide a smooth transition between project phases.

E. Test Bench Hardware Spares

During the Deep Impact Mission there were a limited amount of hardware spares for the test benches. This was always a concern for the Deep Impact Test Team that it generated a lesson learn which the EPOXI team had to address. Unfortunately, by the time the EPOXI Mission started the Deep Impact Mission spares had been used up. In order to repair any failures to any test bench, each test bench was given a priority to which one was to be used for spares. In planning for potential repairs, each test bench was given a priority based on fidelity, which in turn determined which bench would be cannibalized first to repair the others. This process was used when the high fidelity bench located at JPL (SSTB) failed during its recertification for EPOXI. The other JPL bench, SWTB was cannibalized for the needed parts to get SSTB fixed. It was very fortunate that most of the parts that failed were COTS items which meant easy acquisition, however most were obsolete. It was a real challenge to find the correct replacements for these COTS items; in one case the part was sent back to the manufacturer for repair. Even though some of the items were fixed or replaced there was no information to help in reconfiguration of these items for the test benches. The only information available on the test benches was the User Manual that only documented operational use. What was needed was a repair manual that gives steps on how to fix and configure the hardware in case of a failure or upgrade. Fixing the benches involved a lot of time and required help from BATC for guidance and hints on how it should be debugged, repaired and reconfigured.

Most of the items that have failed so far have been COTS products, however the test benches do have a fair amount of custom hardware. In case of a failure it will have to be debugged and its failed component will have to be replaced. During the writing of this paper the project has chosen to target comet 103P/Hartley 2, which extends the mission till 2010. These components have been used since the start of the Deep Impact Mission and create a risk the due to aging components for the EPOXI test benches. On previous long duration JPL missions test equipment is gradually upgraded to avoid failures of aging components. This was done on the Galileo mission to Jupiter and the Cassini mission to Saturn, two of JPL's long duration projects. The test environment computers and some of the obsolete hardware were upgraded so as to minimize test failures due to aging.

F. Ground Data System

The Advanced Multi-Mission Operations System (AMMOS) is JPL's legacy software that is used in mission operations to monitor and command spacecraft. This software is integrated into the test bench architecture so that spacecraft operations are mimicked accordingly and that key in-flight activities are correctly executed prior to flight. Using the actual spacecraft operations monitoring system in the test bench allows for verification of new software releases of AMMOS and also serves as a training environment for future flight directors. The AMMOS software is often upgraded due to enhancements or bug fixes; even though it is multi-mission, it still requires some alteration due to mission specifics. The changes that are mission specific in the AMMOS software need to be tested prior to use in flight operations.

When the Deep Impact spacecraft was put into hibernation so were all the aspects of the mission. There were no AMMOS software upgrades scheduled for the Deep Impact prime mission. As a result, the AMMOS version used by Deep Impact was no longer being supported by the Deep Space Network Operations by the time its extended mission started. It was necessary to upgrade to the latest version of AMMOS to support EPOXI operations. The upgraded interface had trouble interfacing with the test bench. It was assumed that no problems would arise during the upgrade since the GDS system is used throughout JPL and its interface to test platforms is well understood. However, the test EPOXI bench was not a JPL in-house product and source code is not easily obtainable. Therefore members that composed, the GDS team on Deep Impact were brought back to train the EPOXI GDS members on how to configure and setup the software. It was found that the reason the software needed to be altered was because the test bench had been moved to a different location, causing the IP addresses to change.

This type of problem could have been avoided if the test benches had been located on a private network that is unique to the setup. However, a JPL network security rule required Deep Impact to disconnect its private development LAN. The Deep Impact test benches were initially placed on a development LAN within the flight operations network to allow for communications across a dedicated network. After the prime mission, the development network was removed from the flight operations network causing a disconnection from the revision management system (CVS) and other data storage warehouses. However, for the EPOXI mission it was decided to reinstate the benches behind the flight operations firewall to allow access to the dedicated network between JPL and BATC. This network change caused additional changes, to the network scheme between AMMOS and the test benches. Network issues, such as IP address changes require the Ground Data System (AMMOS) and Test Teams to work closely together to understand where changes needed to be implemented. A good network diagram on how the Deep Impact Test Facility was constructed would have made the job at lot easier.

The EPOXI mission leveraged lessons learned from previous JPL missions including Deep Impact in validating any changes to the AMMOS software prior to deployment of a new version for use in spacecraft flight operations. Before it was deployed it was first installed for use on the test benches. The new version of AMMOS software would then run in parallel with the delivered one. In running both in parallel, the new version was validated through comparison. Once the new functions or bug fixes were verified it was then ready for delivery to spacecraft operations. This approach resulted from several lessons learned from previous and existing flight projects where the ground system was updated and did not work for spacecraft operations. In these cases the previous version was available so that no ill effects resulted during spacecraft operations.

G. Test Bench Implementation of Deep Impact Mission Lesson Learned[5]

The Deep Impact Mission lesson learned published in the reference journel[5] dealt with perceived excessive time required to initialize the test bench. It was assigned to the EPOXI Test Team to resolve. Efforts were made to resolve the problem found with test bench initialization during Deep Impact Mission. However, the funding that was allocated for EPOXI was less than Deep Impact Mission, so innovations were limited due to the shortage of staff. The allocated Test Team for EPOXI contains only one full-time engineer where Deep Impact Mission had up to thirteen. So, it was important for the selected EPOXI Test Team at JPL and BATC to decrease test bench initialization time without any risk to the fidelity. The BATC team came up with a method to initialize the flight software that is done during an uplink of a new build in-flight. This new procedure, adapted from one created and tested during the Deep Impact Mission and developed to help initialize the test bench within 30 minutes, has yet to be used. After including the time required to validate the initial conditions, the new procedure far exceeds the approximately two hours which the current procedure requires to get to a known initial condition. It was decided by the JPL Test Team not to incorporate this new innovation since it involved a larger amount of work in verifying the initialization. Therefore the Test Team has decided to continue to perform a full-simulated launch of the spacecraft during configuration when the system has been power-cycled. The EPOXI test schedule workload leaves no margin for the labor that would be required to fine-tune the new approach to a workable option. Without further development, project management cannot be convinced that the new shortened method introduces no fidelity issues in initialization of the simulation. The current proven procedure was thought a safer choice. The Test Team is overburdened in the current environment and therefore unable to take advantage of innovations even though designed to help them catch up. The current procedure in place is one that had been used throughout the Deep Impact Mission and its pedigree is well known.

III. Training

After the Deep Impact encounter only a handful of previous Deep Impact members were kept on board to monitor the overall health of the spacecraft which kept them current on any configuration changes that the spacecraft may have gone through. So, for the returning members the test benches aided in reacquainting themselves with spacecraft operations, command and monitoring. The test benches were also used as a training platform for new EPOXI members. The new members consisted of previous experienced and non-experienced flight operations personnel. As learned on other missions at JPL, it is best to train new members on a test environment instead of on the actual spacecraft since it may impact the overall mission activities that have been scheduled.

Training sessions are necessary on any flight project; these are also planned on other flight projects that are managed and run by JPL. Such training sessions are needed to make sure the team is ready for a critical operation, encounter and anomaly response. There were some training sessions planned for EPOXI using realistic scenarios and anomalous situations, but these were canceled. These cancellations were mainly due to the late start of the mission, making spacecraft operations a priority. Not having adequate training sessions caused a lot of tests to fail since basic mistakes were being made in the running of tests. However, it was better to lose time on the test bench due to mistakes than to make them on the spacecraft.

IV. Conclusion

The success of the Deep Impact Mission and the cost constraints placed on the EPOXI Mission made it appealing and necessary to reuse the Deep Impact spacecraft and flight operations infrastructure for the EPOXI Mission. This paper has addressed some of the challenges that the Test Team had to overcome in order to tailor the Deep Impact test infrastructure for the EPOXI Mission. There were high expectations placed on the Test Team by management to improve the overall test program based on lessons learned from the Deep Impact Mission. Although these lessons made sense on paper, no EPOXI resources were available to study whether these lessons could be implemented or would benefit the EPOXI mission. Even though EPOXI inherited a proven spacecraft and flight operations infrastructure, it also inherited its problems. The problems that the EPOXI Test Team had to deal with would have been avoided if adequate funding and resources were allocated during the development of the Deep Impact Mission or during the ramp up of the EPOXI mission. Efforts were made by the EPOXI Test Team to correct these problems but like Deep Impact, the EPOXI Mission was heavily cost and schedule constrained.

Acknowledgments

The authors wish to gratefully acknowledge the Deep Impact Team members from University of Maryland, JPL and BATC for their contributions in to the overall success of the encounter. We also wish to acknowledge the EPOXI team for their contributions in keeping the spacecraft healthy and alive. The work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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