System Testbed Use on a Mature Deep Space Mission: Cassini

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Abstract—The Cassini-Huygens Program is a joint effort between the European Space Agency (ESA), which delivered the Huygens probe, and the National Aeronautics and Space Administration (NASA), which delivered the Cassini spacecraft. The Jet Propulsion Laboratory (JPL) manages the Cassini spacecraft for NASA. Cassini's primary mission is to survey the complex Saturnian system and release the ESA-Huygens probe at Titan. The Cassini Integrated Test Lab (ITL) at JPL is a high-fidelity hardware-in-the-loop testbed. It uses Attitude and Articulation Control Subsystem (AACS) and Command and Data Subsystem (CDS) flight hardware (H/W), as well as high-fidelity simulations of the other spacecraft subsystems and signals. System Testbeds like the Cassini ITL are often considered to be primarily used in the Final Design and Fabrication Phase and the System Assembly, Integration & Test and Launch Phase of a Mission, but the Cassini ITL has proven to be an essential component of an extremely successful Operations and Sustainment Phase. This paper discusses the role of the Cassini ITL since Cassini's launch, through cruise, orbit insertion at Saturn, probe release at Titan and throughout its tour as Cassini enters the final year of its primary mission. [1] [2].

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1. INTRODUCTION

The objectives of the Cassini Mission to Saturn include studying Saturn, its rings, and several of its satellites, particularly Titan, Enceladus, Iapetus, Mimas, Tethys, and Dione [1]. Other objectives include the study of phenomena of the Saturnian system, including the magnetosphere and its interaction with the solar wind, plasma waves, and radio emissions. Cassini also seeks to detect gravitational waves [2].

To accomplish these objectives, the Cassini Spacecraft (Figure 1) was designed and built for the National Aeronautics and Space Administration (NASA) by the Jet Propulsion Laboratory (JPL). It carried the Huygens probe, designed and built by the European Space Agency (ESA), which it released on December 24, 2004. The probe arrived at Titan on January 14, 2005 and broadcast data to the Cassini spacecraft that was later relayed to Earth.

Cassini was launched on October 15, 1997. To save propellant, Cassini made several gravity-assist flybys: two at Venus and one each at Earth and Jupiter. After an inter-planetary cruise that lasted almost seven years, the Cassini spacecraft arrived at Saturn on June 30, 2004. Cassini fired one of its two rocket engines for about 96 minutes in order to slow the spacecraft's velocity (by about 626 m/sec) and allow it to be captured by the gravity field of Saturn. Onboard science instruments were used to study the structure and composition of the rings during both the ascending and descending ring-plane crossings that happened before and after the Saturn Orbit Insertion (SOI).

The spacecraft has been described as being about the size and weight of a school bus: it is 6.8m long; its maximum diameter in launch configuration was 4m, and its total mass at launch was approximately 5800kg, which included about 2700kg of dry mass and 3100kg of propellants. Cassini carries twelve scientific instruments, with each instrument performing its own internal control and data handling. Three instruments have actuators that permit them to rotate individually about one axis, otherwise the instruments are in fixed positions, requiring that the entire spacecraft be turned

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[2] IEEEAC paper #1554, Version 3, Updated October 9, 2007

to point an instrument in a desired direction. The spacecraft also carries seven redundant engineering subsystems, as all elements whose failure could cause loss of the mission or loss of data from more than one scientific instrument are redundant. The Cassini Integrated Test Lab (ITL) focuses its attention on two of these: the Attitude and Articulation Control Subsystem (AACS) and the Command and Data Subsystem (CDS).

The AACS contains redundant MIL-STD-1750A flight computers. The AACS receives commands from the CDS via the redundant MIL-STD-1553B CDS data bus and sends commands over its own redundant MIL-STD-1553B data bus to AACS assemblies. AACS provides attitude control of the three-axis stabilized spacecraft either by Reaction Wheel Assembly (RWA) control or by thruster (Reaction Control System (RCS)) control, and the thrusters are also used to unload the momentum of the reaction control wheels. Celestial attitude reference is supplied by a Sun Sensor Assembly (SSA) and a stellar reference unit (SRU), which uses a charge-coupled device sensor. Inertial reference is accomplished using vibrating gyros. Spacecraft pointing accuracy is 2 mrad or better when the spacecraft is not thrusting or rotating. The AACS also controls the spacecraft flight trajectory through command of the main engine and thruster valves. An accelerometer on the central axis aids in controlling the duration of engine burns.

The CDS manages the communication, commanding, and telemetry of the other spacecraft subsystems. The CDS consists of redundant MIL-STD-1750A flight computers and communicates with the other spacecraft subsystems via its data bus. The CDS stores engineering and science data and memory loads in two 1.8-gigabit solid-state recorders (SSRs). The CDS receives ground commands and memory loads from the spacecraft's Radio Frequency Subsystem (RFS), then processes and distributes them to instruments and other subsystems. It receives data from instruments and other subsystems, formats it for telemetry, supplies Reed–Solomon encoding, and delivers the telemetry to the RFS for transmission to Earth. [2]

On Cassini, most commanding is accomplished with nominal command sequences, which are programs

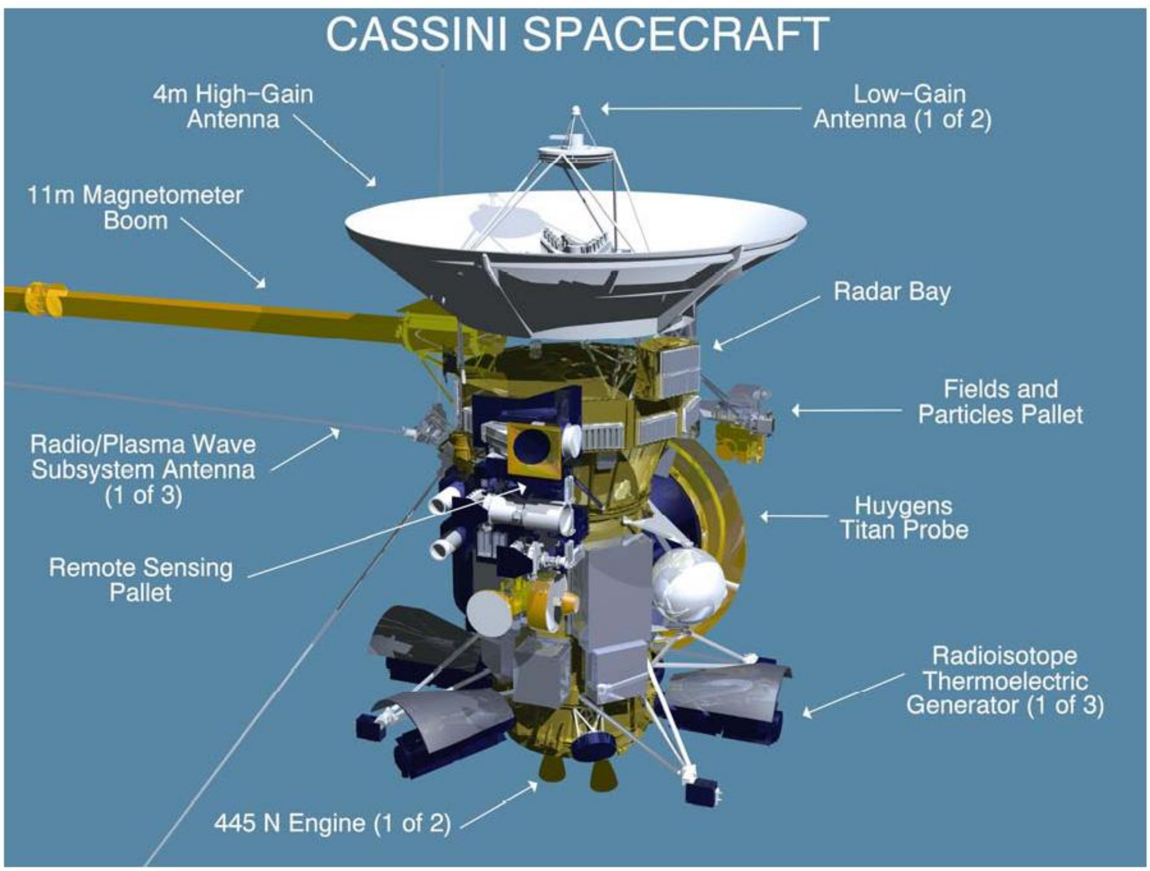

Figure 1 – Cassini Spacecraft

consisting of time-tagged lists of commands and macros. Sequences are stored and executed by the CDS. The commands in sequence programs are executed sequentially, and their time-tags can be relative to the previous command or absolute (i.e., specifying a certain time at which the command is to execute). These sequences specify actions down to the level of detailed hardware commands, whose effects can potentially be felt across spacecraft subsystem boundaries. [3]

2. Description of ITL

Cassini's hardware-in-the-loop system testbed is the ITL. The ITL consists of CDS Hardware (H/W) and Support Equipment (SE) and AACS H/W and SE. Either the CDS SE or the AACS SE simulates the other spacecraft subsystems. Occasionally, the Power and Pyrotechnics Subsystem (PPS) H/W, RFS H/W, or science instruments are connected via the spacecraft bus (in which case their simulators are not used). [3]

The Cassini Integrated Test Lab has dual redundant AACS and CDS flight computers running software identical to that used in flight. Most of the primary AACS H/W (Engineering Model (EM), or flight spare) is connected and tested in the loop and the Remote Engineering Units (REUs) and the Solid State Recorders are used as well. A sophisticated real time simulation of the optical and physical environment is provided to the AACS sensors in real time to simulate bright bodies and stars based on orientation, and linear and angular accelerations and velocities stemming from the internal and external forces on the spacecraft (S/C). In this way the actual command sequences can be run and the CDS, SSRs, REUs, and AACS interact while the appropriate sensors in the AACS are being stimulated with an environment equivalent to that expected in flight. In addition, science instruments can be connected as needed. This H/W in the loop design yields the highest fidelity representation of the Cassini S/C on the ground.

Since the CDS and the AACS H/W are designed to operate in flight, their SE is designed to generate all of the signals and stimuli necessary to simulate the flight environment. The Testbed can run in subsystem mode (tests using only CDS H/W or only AACS H/W with all other subsystems simulated) or system mode (using both CDS and AACS H/W). The itl_startup script is used to initialize whatever H/W is being used, and runs with a configuration file that specifies variables for a given test.

The ITL is typically initialized to a default time, generally day 1 of the current year, if a test is not dependent upon a specific time. Many tests, however, must be executed at a specific time, and so this time is specified in the configuration file. The CDS keeps the time, called the spacecraft event time (SCET), and propagates it to the other subsystems, keeping them in synchronization with a periodic time broadcast. Hence the CDS can be initialized to any desired time. Once the SCET is set, it can also be changed (without fault protection activity), although when the AACS FSW is running, a special procedure must be used and due to limitations of the simulation software, the time can only be moved forward for a period of about a month or less.

In the case of a system mode test, when the itl_startup script is complete, the CDS is running in RAM with a prime and backup string, both SSRs are loaded with the CDS, AACS, and instrument FSW, and the SCET is set. The AACS is running in RAM with a prime and backup string, the prime AACS string is in home base, and Inertial Vector Propagation (IVP) is initialized (either with specified or default vectors). These states are consistent with the nominal states in flight.

The ITL's primary hardware-in-the-loop testbed is illustrated in Figure 2.

3. Deferred Development

Cassini launched without the FSW capability to perform significant portions of its primary mission, including SOI, the relay of probe data, and some of its planned tour capability. This was all according to plan, since launch occurred nearly 7 years before orbit insertion, and much of the needed FSW development was planned for the interim.

Deferred AACS FSW Development

Cassini was launched without reaction wheel attitude control capability, the main-engine burn algorithm necessary for SOI, [4] and Fault Protection Algorithms to support the Probe Relay activity. [5] These capabilities were developed and added incrementally.

Deferred CDS FSW Development

The bulk of the deferred development in the CDS FSW had to do with SSR management. SSR enhancements included partitioning, priority playback, switching to the other SSR when the first one was full, and duplicate recording of critical data. Another deferred enhancement was data policing: rejecting data from an instrument after it had exceeded a ground-specified limit. At launch, 2 FSW loads for each engineering subsystem and instrument were stored and these loads were collectively treated as identical or different; another planned enhancement that was implemented was the ability to label these loads identical or different independently. The final group of deferred capabilities included SSR error checking algorithms, System Fault Protection (SFP) enhancements, and an SFP response to swap to the High Gain antenna and go to a high telemetry mode if certain conditions exist after a safing event (safing occurs when the FSW detects a severe fault: all non critical devices are powered off and the S/C is put into a "safe" configuration).

Critical Sequence Testing

Ordinarily, sequences are aborted in the event of safing, but some sequences govern activities that are vital to mission success and so continue even in the event of safing. Such sequences are called critical sequences. Cassini has executed 3 critical sequences: Launch, SOI, and Probe Relay. Obviously, Launch Sequence testing was completed prior to launch, but the SOI and Probe Relay Sequences were not even developed until after launch. There were several iterations of extensive testing of each sequence in the ITL.

4. Unplanned FSW Development

In at least one case, the planned deferred development was revisited and altered: the burn algorithm, "Energy Burn", that was ultimately used for SOI was developed about 2 years prior to SOI. [6]

In addition to the deferred FSW capabilities, other desired capabilities were implemented. One notable case is the SSR Library Region. As the spacecraft neared its destination and instrument activity began in earnest, it became apparent that expanded blocks of software for the instruments would provide expanded capabilities. The Immediate Execution Blocks (IEBs) required storage space on the SSRs, and space was found above and below the region where the CDS FSW load was stored. This space was called the Library Region. [7] The library region was implemented along with the last group of deferred CDS capabilities.

Then in 2007, it was decided to uplink a new version of the CDS FSW. This was not in the original plan, but became desirable because of the potential for a certain type of failure in the SSRs. With previous versions of FSW, the failure could have resulted in an unrecoverable fault in the event of a CDS reset. The failure may still occur, but with

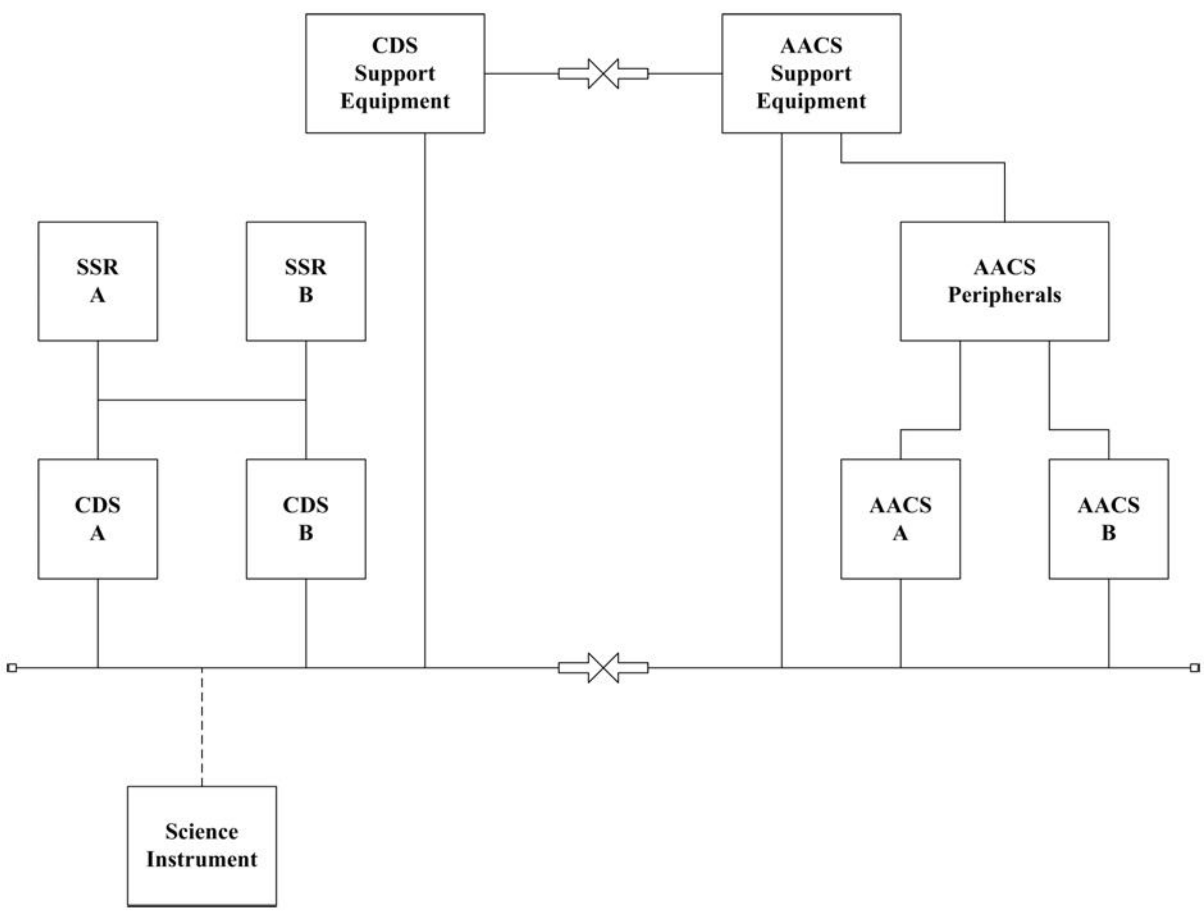

Figure 2 – ITL Block Diagram

the new CDS FSW version it can be absorbed with little impact. Of course, once the decision was made to develop a new FSW version, many issues that had arisen over the years but were accepted because of insufficient impact became possibilities for inclusion in the new build, and some were indeed addressed with the new FSW.

5. AACS FSW UPDATES

The orbital inclination of the Cassini spacecraft changes gradually as the mission progresses. Additionally, the effective thrust of the RCS system decreases as propellant is used and the pressure in the propellant tank decreases. Default safing profile and thruster values are necessary in the unlikely event of an AACS computer reset and reload of FSW, so such values are updated periodically. The ITL is used to test these updates, and to regression test the patched FSW to ensure its integrity.

6. GROUND SYSTEM TESTING

The Multi-Mission Ground Data System (MGDS) is comprised of the hardware and software used on the ground to receive and process telemetry from the spacecraft. Ground system software is updated for a variety of reasons, including the correction of problems, the addition of new capabilities and tools, and the implementation of changes to support new telemetry standards (which occur with FSW updates). The ITL is the first stop for most ground system updates, since they are generally released in the ITL about 2 months prior to being released to the flight team. Additionally, many of the ground system tools are tested in the ITL: tools to generate commands, IEBs, and sequences; tools to process and display telemetry; tools to query telemetered data, etc.

Ground System development and testing is also done indirectly in the ITL, essentially as a component of other work performed there, chiefly FSW development and testing.

It bears mention that in the ITL, telemetered data is not broadcast but is delivered directly to the ground system, and so requires different processing (at least as it enters the system) than does flight data. Thus the ITL has some unique ground system components for this purpose.

7. FLIGHT ACTIVITY TESTING

The ITL has had a continuing role in the Verification and Validation of many flight activities, such as background sequences, modules, maneuvers, Radio Science Subsystem (RSS) experiments, flybys, uplink procedures, contingencies, and analyses. This testing is described in more detail below.

Background Sequence Testing

Most of Cassini's activities are controlled by sequences that are designed to run for several weeks, called background sequences. In the early days of Cassini's flight, many aspects of these sequences were tested. At this stage of the mission, we still test portions of background sequences that are first time events or have some other associated risk.

Modules

Cassini uses on-board programs to generate AACS commands for typical observation scenarios. These programs are called modules. Several deliveries of the modules have occurred over the life of the program. All have been thoroughly tested in ITL.

Maneuvers

Trajectory Correction Maneuvers (TCMs) and Orbit Trim Maneuvers (OTMs) are necessary to adjust the path of the spacecraft. Maneuvers are built from established templates called blocks. The blocks undergo thorough testing in ITL before they are used to generate flight maneuvers. Early in the mission, every maneuver was tested in ITL. At this point in the mission, only maneuvers that have some unusual risk are tested.

RSS Experiments

The RSS makes regular use of the ITL to test Atmospheric Occultations and Bistatic Experiments. In the case of an atmospheric occultation, the spacecraft sends a signal to earth as it emerges from occultation by a body with an atmosphere. The signal transmitted by the S/C is refracted by the atmosphere, and the High Gain Antenna (HGA) is pointed in such a way as to account for this refraction so that the signal still reaches earth. In the case of a Bistatic Experiment, the signal from the HGA is actually directed toward a body in such a way that the reflection is received at earth. In both cases, proper pointing is essential. The RSS team specifies the desired pointing in an Inertial Vector Definition (IVD) file. ITL tests verify the implementation of the IVD. These ITL simulations have proven to be remarkably accurate. This testing has occasionally uncovered errors in implementation, and has frequently resulted in modifications to the IVD file.

Flybys

Titan flybys are often tested in the ITL. Among other things, this is to verify that control authority is maintained within the required dead-bands despite the predicted external torques, to verify that the prime instrument pointing is maintained, and to confirm control authority despite the predicted atmospheric density. Tests have also been performed to determine the atmospheric density at which tumbling would occur.

Uplink Procedures

The ITL is used to provide the most realistic environment possible to test flight procedures such as FSW updates. FSW updates occur fairly frequently, considering that there are 13 engineering subsystems and instruments that use them. Many files are not approved for uplink in flight until they have been tested in ITL.

Contingencies

The ITL has also been used to test contingency files. Once contingencies are identified, probable recovery paths are developed and tested, including uplink files that can be used in flight. This has enabled the project to set aside tested and approved files to be used if necessary.

Analysis

The ITL has also been used for various analyses. For example: the AACS FSW maintains a log of all Fault Protection related actions (these actions may be initiated by Fault Protection processes or by other processes in FSW, but they are logged if they are relevant to AACS Fault Protection). The actions are recorded with a time stamp, and this time stamp has a format unique to the AACS FSW. In 2006, the FSW team realized that this time stamp format would rollover at a certain time prior to the end of the mission. ITL testing demonstrated that this rollover would be isolated to the fault protection log and would therefore be benign.

8. Flight Instrument Testing

There are 3 instruments resident at JPL: the Imaging Science Subsystem (ISS), RADAR, and the Visual and Infrared Mapping Spectrometer (VIMS). The ISS, RADAR, and VIMS are operated in a special instrument testbed, usually in stand-alone mode, but the instruments can be (and frequently are) connected to the ITL via a spacecraft bus extension. The other instrument teams are based at other locations in the United States and abroad.

Instrument testbeds often become more important post-launch rather than prior to launch, and the instrument teams at JPL and elsewhere have made extensive use of the ITL.

Imaging Science Subsystem (ISS)

The ITL is an important resource for the ISS subsystem because the subsystem consists of 2 cameras, a Narrow Angle Camera (NAC) and a Wide Angle Camera (WAC). Because the CDS could not support the bandwidth for simultaneous transmission of images from both cameras over the S/C bus, the cameras share a Remote Terminal address. The ISS testbed does not support this sharing of a Remote Terminal address and so the ITL is the only place on earth to test the cameras in a flight-like configuration. The ISS team has made use of the ITL to support debug analysis, to understand bus data in order to improve the Ground System, to test unique sequences and first time events, and to verify engineering (rather than ground system) generated sequences for in-flight anomaly resolution. In addition to these tests, the ISS team used the ITL for Verification and Validation of its only FSW update since launch.

Another interesting ISS problem that was solved in the ITL occurred when flight data did not jibe with expected performance. The cameras in the testbed have flight-qualified electronics, so it was possible to run timing tests and expect similar performance to the cameras on-board Cassini. These tests demonstrated that the documentation for the cameras was inaccurate.

RADAR

The ITL has become very important to the RADAR team because it provides the capability to maximize RADAR data collection. The maximum data collection rate at which the RADAR does not drop data is dependant on the geometry of a given observation. Testing these observations in the ITL allows a data gain of 10-20%. This may not seem like much, but the data collected is typically used for SAR (Synthetic Aperture RADAR) during Titan close approach flybys. This is essentially the RADAR's main objective for the Cassini Mission and maximizing the data return of these observations provides a large increase in the science quality of the data collected.

Visual and Infrared Mapping Spectrometer (VIMS)

Data policing was one of the deferred development capabilities in CDS FSW, but after it was implemented the VIMS team found that VIMS data was occasionally being policed when VIMS was not transmitting image data. This is possible because as long as the instrument is powered and the CDS is in a telemetry mode that expects data from the instrument, the CDS will collect data. If the instrument does not have data to transmit, it transmits a special packet that does not get recorded on the SSR. Analysis in the ITL revealed that VIMS packet sizes did not always match CDS expectations when certain telemetry mode changes were commanded (a VIMS FSW bug), and when the packets were larger than expected, they were policed (even though they did not contain valid data).

The VIMS team also benefited from ITL testing in the implementation of IEBs. VIMS has always sought to maximize their IEB space, so it pleased the team when it was discovered through ITL testing that the Ground System was shorting VIMS by one 22 word block of IEB space in the SSR library region. VIMS also swapped IEB space with another instrument (Cassini Plasma Spectrometer (CAPS)) that had a larger allocation; ITL testing smoothed the transition.

Ion and Neutral Mass Spectrometer (INMS)

Perhaps the primary reason that the Ion and Neutral Mass Spectrometer (INMS) was included in Cassini's instrument suite was to analyze the atmosphere at Titan to inform the final decisions that would be made regarding the probe mission. As Cassini neared this phase of the mission, the INMS experienced unexpected resets. The INMS team brought an EM INMS instrument to the ITL (from their facilities at the University of Michigan at Ann Arbor) in order to take advantage of the ITL's CDS H/W and debug the problem. Although the bug was not found, this work enabled the INMS team to develop a strategy to work around the problem and successfully return the valuable data.

Cosmic Dust Analyzer (CDA)

At various times, the Cosmic Dust Analyzer (CDA) team has brought a flight spare and an EM CDA to the ITL from their home base at the Max Planck Institute for Nuclear Physics in Heidelberg, Germany. They have used the ITL to successfully debug anomalous behavior and to validate and verify FSW deliveries.

Post-launch, it was discovered that the in-flight CDA was susceptible to single event latch-ups. The behavior was studied and a workaround was developed and tested in the ITL. The solution involves a signal from the CDA when the condition is detected which triggers a CDS Fault Protection response that is executed by the PPS. The use of the ITL was essential for developing and testing the solution on the ground, as it could not be done in the CDA's stand-alone testbed.

The flight spare CDA was used in the ITL to ensure that changes to internal task scheduling in a new CDA FSW delivery did not affect S/C bus interaction. S/C bus traffic timing analysis and system level tests were needed to demonstrate that proper functioning of the new FSW, and this testing could only have been accomplished in the ITL.

9. Anomaly Resolution

There have been a few in-flight anomalies for Cassini. [7] The ITL has been used in such cases to recreate the anomalous conditions and to test the recovery processes and the uplink products that were used in the recoveries.

In September 2007, there was a Solid State Power Switch (SSPS) [8] trip that resulted in a S/C safing event (Cassini's first safing event during its primary mission). The SSPS was one of a redundant pair powering the prime Telemetry Control Unit (TCU). Since this is a vital device, the trip resulted in safing. The safing event occurred only hours after an Iapetus flyby, and recovery had an increased urgency as the science community anxiously awaited that data. After the flight team confirmed the failure, playback of the Iapetus flyby data was commanded and the process to be followed for recovery was identified. The special files and procedures required for the recovery were tested in the ITL, and the recovery was accomplished successfully in flight.

10. Training

Periodically the Cassini flight team conducts Operational Readiness Tests (ORTs). These are essentially exercises in which a hypothetical problem is presented to the flight team and the team must formulate and execute a recovery. The ITL is used to simulate the problem and the recovery, providing the team with as realistic an experience as possible, as, for the AACS and CDS subsystems at least, telemetry from the ITL is very similar to flight telemetry. Additionally, only a small subset of the flight team is dedicated to preparing the fault scenario; those team members responsible for designing the fault and initializing the testbed then step aside under strict orders to maintain silence while the rest of the team determines and corrects the fault. These ORTs have tremendous value: the TCU SSPS fault that actually occurred in flight (and was discussed in the preceding section) was fortuitously chosen by the Cassini Spacecraft Office Manager, Julie Webster, as the fault scenario for an ORT in 2006, which of course made detection and recovery when the fault actually occurred in flight even more swift and sure.

The Cassini ITL has also been used to train both Cassini personnel and new JPL employees who have been hired for other project assignments. Such training has involved the engineer functioning as a test analyst for 6 months. The ITL benefits from the extra manpower, and the employee benefits from the training and the exposure to a large flight project.

11. Conclusion

Cassini continues to enjoy a long and successful primary mission. The ITL has been an important component in that success, and continues to provide valuable services to the mission. These services include:

- Deferred FSW Development and Testing
- Unplanned FSW Development and Testing
- FSW Updates
- Ground System Testing

- Flight Activity Testing
- Flight Instrument Testing
- Anomaly Resolution
- Training

The ITL has proven its value to the Cassini Mission to Saturn time and again. Originally created for the integration of flight H/W and the development of FSW, the ITL was maintained to accomplish Cassini's deferred development. Interestingly enough, while that deferred development was taking place, the ITL was becoming an essential component of instrument testing and sequence development as well as maneuver and flight activity testing. So, in Cassini's case, the ITL was necessary for post-launch activities (i.e., deferred development), but as a result of being available during the prime mission, proved to be an invaluable resource for purposes that were not originally anticipated.

The cost of the ITL has varied over the course of the Cassini mission, but typically approaches 10% of the Cassini Spacecraft Office Operations budget (i.e., the engineering operations budget, as distinguished from the science operations budget). At present, the ITL annual budget is approximately $800,000 (during Integration, during Assembly, Test and Launch Operations (ATLO), and during critical sequence testing, the ITL team was larger and so the cost was higher). The annual cost to maintain the testbed (regular cleaning, certifications, instrument calibration, facilities maintenance, etc) is approximately $25,000.

These costs are significant, but not prohibitive, and this paper has shown that the ITL has proven to be a valuable asset to the Cassini Mission and has justified its expense. As Cassini plans its 3-year extended mission, the ITL is included in that plan to continue in its present capacity. That capacity includes engineers with expertise in the AACS and the CDS who function as test operators and analysts, engineers with expertise in SE H/W and S/W who maintain the SE and implement improvements, and a System Administrator (the ITL maintains a web page so that test reports and test data are web-accessible, and the data is also archived). With some overlap in expertise, and some engineers working only part-time on Cassini, the ITL team at the present time is comprised of the equivalent of about 4 full time employees.

Many flight projects use System Testbeds for the purposes of integrating flight H/W and testing critical activities, purposes that are sometimes accomplished by launch and generally by arrival at their destinations. The author recommends that such flight projects seriously consider maintaining System Testbeds throughout the lives of their missions. The use of a System Testbed, the Cassini ITL, has improved science data return, improved instrument activities, removed errors and oversights in flight procedures through testing, credibly tested ground system tools and software, improved maneuvers, and solved problems that have occurred in flight. At less than 10% of the engineering operations budget, System Testbeds provide improved reliability, improved functionality, a significant and positive impact on mission success, and a substantial return on investment.

ACRONYMS

AACS = Attitude and Articulation Control Subsystem
ATLO = Assembly test and Launch Operations
CAPS = Cassini Plasma Spectrometer
CDA = Cosmic Dust Analyzer
CDS = Command and Data Subsystem
EM = Engineering Model
ESA = European Space Agency
FSW = Flight Software
HGA = High Gain Antenna
H/W = Hardware
IEB = Immediate Execution Block
INMS = Ion and Neutral Mass Spectrometer
ISS = Imaging Science Subsystem
ITL = Integrated Test Lab
IVD = Inertial Vector Definition
IVP = Inertial Vector Propagation
JPL = Jet Propulsion Laboratory
MGDS = Multi-mission Ground Data System
NAC = Narrow Angle Camera
NASA = National Aeronautics and Space Administration
ORT = Operational Readiness Test
OTM = Orbit Trim Maneuver
PPS = Power and Pyrotechnics Subsystem
RCS = Reaction Control System
REU = Remote Engineering Unit
RFS = Radio Frequency Subsystem
RSS = Radio Science Subsystem
RWA = Reaction Wheel Assembly
S/C = Spacecraft
SCET = Spacecraft Event Time
SE = Support Equipment
SFP = System Fault Protection
SOI = Saturn Orbit Insertion
SRU = Stellar Reference Unit
SSA = Sun Sensor Assembly
SSPS = Solid State Power Switch
SSR = Solid State Recorder
TCM = Trajectory Correction Maneuver
TCU = Telemetry Control Unit
VIMS = Visual and Infrared Mapping Spectrometer
WAC = Wide Angle Camera

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BIOGRAPHY

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