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A NEW APPROACH TO FLIGHT EQUIPMENT: CLEMENTINE & MSTI WORK AT JPL

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ABSTRACT

The Ballistic Missile Defense Office/Air Force's Clementine and Miniature Seeker Technology Insertion (MSTI) programs have set new standards for spacecraft cost/performance. At the Jet Propulsion Laboratory, work on these programs has driven changes in traditional approaches to spacecraft design, fabrication, test and integration.

High-visibility, billion-dollar spacecraft are typically built to a "Class A" standard of quality and reliability. Organizations, including JPL, which receive multiple development contracts for Class A missions have been very successful in creating approaches which do a good job of delivering to these high standards. They have been less successful, however, in modifying these standards for programs of less-stringent requirements. Often, "Class C and "Class D programs are accomplished entirely outside the core of the "Class A organization, resulting in either unnecessary duplication or lack of access to top-notch people and facilities or both.

In this paper we describe how these problems were addressed through the successful "custom tailoring" of JPL's world-class capabilities to the Class D requirements of the Clementine RRELAX experiment and the MSTI-3 data compression subsystem. Hallmarks of this new approach were a very successful use of concurrent engineering practice, a high-level of teamwork, the assembly of a team from across a wider-than-normal cross-section of JPL, the use of a very flat management structure and the willingness of upper-management to support new ideas and new methods.

The MSTI-3 and Clementine RRELAX projects were designed, assembled and tested by the same staff and facilities which are now developing the $1 .6B Cassini spacecraft. The paper also identifies the needed areas of flexibility essential for moving back and forth from Class A to Class C & D projects and how this has improved JPL's ability to move from capability-driven to cost-driven spacecraft projects.

I. INTRODUCTION

It has been difficult to transition organizations used to large space flight programs into smaller, faster projects. A lot of this inertia is due to accumulated wisdom and the perception that to ignore some of this would be to potentially "throw the baby out with the bath water."

In this paper we will discuss the ways we have discovered to do small projects at institutions where large projects are the norm, Some major areas to be explored include teaming, management and documentation.

We will use the Clementine RRELAX experiment as our primary example. Experience gained from the MSTI-3 data compression board will also be included.

II. THE CLEMENTINE RRELAX EXPERIMENT

The Ballistic Missile Defense Office's Clementine spacecraft was a technology demonstration mission which also happened to do excellent science. It was a very aggressive spacecraft program, with design, fabrication, qualification and flight readiness accomplished in less than 22 months. Later we will discuss how this accelerated schedule helped to forge the new JPL approach to small projects.

One of the key Clementine science experiments was the Radiation Reliability and Assurance Experiment (RRELAX). RRELAX was conceived by a JPL principle investigator and was implemented and supported through launch and operation by a JPL science/engineering team.

The RRELAX experiment involved developing space radiation monitors for both the Clementine spacecraft and the launch vehicle's Interstate Adapter. These monitors combined a suite of custom radiation sensors, static RAMs with variable offset voltages, charge-coupled devices (CCDs), and test chips with a radiation-hardened data system to measure total dose and single-event upsets over the course of the Clementine mission, Their primary objective was to characterize the radiation resistance and reliability of advanced microelectronics and gather information about the space radiation environment that other BMDO missions might experience.

Technical challenges included:

- autonomous operation
- error-free operation during peak radiation periods
- mass, power and volume limitations
- simple interface to the spacecraft bus
- variable data storage capabilities

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- support for power cycling

Highlights of the successful RRELAX experiment included the ability to separate secondary electron total dose from proton total dose events during solar flares, proof of dose shielding algorithms from Phillips labs, the ability for the first time to measure micro-solar flares from a space platform, and the contribution of proton-induced nuclear reactions to single-event upset of space-borne microelectronics.

Transition of van Allen belts and a solar flare experienced were measured and correlated to computer failures. This was a very important part of the Clementine spacecraft's mission to characterize microelectronics in a space radiation environment.

III. THE MSTI-3 DATA COMPRESSION BOARD

The Miniature Seeker Technology Insertion (MSTI) spacecraft are a series of missions intended to demonstrate low mass/low volume/high throughput technologies for the Strategic Defense Initiative Office (now the Ballistic Missile Defense Office, BMDO). The data compression board for the MSTI-3 spacecraft was conceived as a way to increase the data-link bandwidth over an existing telecommunications channel by compressing data on the spacecraft during data acquisition and storage onto the flight recorder.

The data compression board was designed, < implemented and tested by JPL in conjunction with Spectrum Astro (the data system contractor) and the BMDO Kinetic kill vehicle Hardware In-the Loop Simulator (KHILS) facility. It is based on a chip which implements the Rice lossless data compression algorithm in hardware [1, 2], originally designed and used for the JPL Cassini spacecraft.

Technical challenges included:

- radiation hardening to 20 K-rad total dose
- high-speed data compression (100K pixels/second)
- mass, power and volume limitations
- simple interface to the spacecraft bus

To date the board has been successfully tested at the KHILS facility and delivered to the project in flight form. It is awaiting integration into the MSTI-3 spacecraft whose launch date, at present, is TBD.

IV. FORMING AND RUNNING THE TEAM

Beginning

The RRELAX task (like many others at JPL) originated in the R&D community which developed the radiation sensors, Quite frequently, JPL researchers deliver sensor technology to their sponsors in a "proof-of-concept" form and, in-turn, an entirely separate group of spacecraft developers integrate them. The RRELAX effort was not such a task.

RRELAX was budgeted in such as fashion as to require the originating R&D group to also deliver flight-ready systems to a JPL Class D level [3]. Because of this requirement and lack of flight hardware development experience, they asked a major JPL flight engineering section for assistance. However, members of the usual staff were not available for this project. The people who make up this staff are highly trained in Class A [3] flight project methodologies and at the time of the RRELAX work were heavily committed to the Cassini and Mars Pathfinder projects.

In hind-sight, it is clear that this was a vital part of the RRELAX project's success. Several times in the past these groups have been unable and unwilling to attempt projects away from the familiar Class A institutional structure. There is no indication that RRELAX would have been driven in any different direction and the highly accelerated Clementine program would have likely been forced to launch without RRELAX.

Forming a team

A task manager was appointed by the JPL flight engineering management, This was another watershed point for the RRELAX program. If the task manager had not been aggressive, willing to fight the system and buffer his team from the subsequent upset, the project would also not have flown (literally). Almost immediately after the task manager was appointed, he selected a flight hardware cognizant engineer.

Together they quickly realized how aggressive the project was going to be. Not only was the schedule aggressive (five months from the task manager/cognizant engineer selection to flight delivery), but essential objectives, requirements and the operating environment had not yet been determined.

As was mentioned earlier, Cassini and Mars Pathfinder had absorbed most of the flight hardware, software, test and integration people so the usual project approach of securing engineering work from among the JPL specialists had to be modified.

The new approach began by identifying eight key positions. These included system engineer, flight software, ground support, task procurement, etc. While these positions were not new to JPL, the idea that they could be filled by people without specific flight experience was. The individuals were hand-selected from all over JPL, based on their past performance in a specific area of expertise. Not only were they expected to have broad technical knowledge but they were also selected on their ability to learn new things fast, to communicate well and to work hard.

Individuals were told they formed the RRELAX team, not a group, a section or any of the other JPL organizational structures. This was done to eliminate deeply ingrained preconceptions about how to work together in a JPL environment.

A key part of this was to tell people what their roles were and to make it clear that they had both responsibility and authority for their areas, For example:

- the software person was responsible for software womb to tomb
- the hardware person was responsible for hardware womb to tomb
- and so on for the other core positions

As part of this responsibility, team members were encouraged to obtain resources needed to get the job done from any part of JPL. At the same time, these resources were to be brought to bear only when needed. It is interesting to note over 60 people were involved in the RRELAX project at JPL at one time or another but the eight core positions remained constant.

Maintaining the team

The usual aspects of a team were experienced in the RRELAX work. Team spirit was nurtured and proved to be an essential element. Part of the nurturing of team spirit was the reconciling of differing expectations about work style, work load and project goals. However, the biggest contributor to initial team spirit was the willingness of the leadership to remove individuals early on who wouldn't or couldn't contribute. This showed that the team was more important than any one individual, and management was serious about team accomplishment.

Co-location was important to the team for a number of reasons, For example, consensus building was a by-product of co-location as new ideas and problems became almost instantly communicated across the entire team and feedback came just as fast.

Team members were required to wear many hats. For example, when the system engineer had completed the computer design, he became responsible for system thermal and vibration qualification either coordinating or performing the activity himself. In this way the workload was leveled and people were challenged to grow beyond their specialties. By tapping into the large available knowledge base at JPL, each team member broadened their own capabilities, contributed to the forging of this new small-project approach and made themselves more valuable to the team and JPL.

Training and communication were two important team activities. Communication was largely informal, handled largely by co-location. Training, on the other hand, was more deliberate. Because of the team member's varying experiences with space flight-qualified equipment, the cognizant engineer and the task manager were required to train the team in flight procedures as the project proceeded. The need to modify flight procedures from the classic Class A approaches required a significant amount of training in both the spirit as well as the letter of the "laws" of flight procedures.

One important aspect of the team which wasn't completely reconciled was the stress from the accelerated schedule and associated burn-out. l-he RRELAX team experienced many 80 hour weeks and the almost universal adherence to this was testament to the team's spirit. However, it is clear that it is not sustainable for the long-term even though it probably should not be eliminated entirely.

We recommend a two-pronged approach to burn-out. First, trust must be built between project management and the project sponsor in order to "sell" a reasonable budget and schedule. Second, team leadership must closely monitor team members for a falling-off in productivity or other signs of burn-out and make appropriate corrections.

Considerations after the project

Rewarding the team for its strong performance was one area where JPL has fallen short. A significant amount of recognition has been received by the RRELAX core team, but most team members agree that a chance to participate in an on-going series of projects with this kind of team would be the best reward. Opportunities for this continued teaming are being discussed at JPL but have not been delivered as of now.

Another area of compensation that has been proposed but not implemented is to base some, if not all, of an individual's performance review on the performance of the team. Along with this would also come flexibility in compensation for outstanding teams.

New team members are inevitable as a team moves from project to project and members leave for various reasons or new skills are required. It is important to recognize the need to both allow the new team member to prove themselves and to protect the team spirit during the transition. The team leadership's ability, discussed above, to identify and remove members who cannot team play is perhaps the most important aspect in the integration of new members.

V. MANAGEMENT

Management Motivation/Buv-in

A lot of credit was due to JPL management's willingness to allow the RRELAX team to form. There were four major aspects of the project which motivated JPL management to allow this .

First, the RRELAX project wasn't a clear fit for the principle investigator's (Pi's) organization. At the same time, the PI wanted to champion his technology into an important application. Teaming allowed for this.

Second, the RRELAX project also didn't fit into the selected doing organization's structure. It was too small to motivate the doing organization to grow its traditional organization to fit the project. Additionally, the unusually heavy load placed on the doing organization by large flight projects minimized the conventional personnel available to the RRELAX project. Therefore, an innovative solution was needed.

Third, at the time the RRELAX team formed, a follow-on project, known as Clementine II, was a lure to JPL management. Therefore, they needed Clementine 1 (RRELAX) to succeed.

Finally, the aggressive schedule for the RRELAX project and the overall Clementine program was different from the traditional JPL flight programs. Therefore, new ways of doing business were recognized as clearly legitimate in this case.

Team support

Team leadership (line-level management) acted as an almost impermeable buffer for team members. The high--pressure technical challenge was viewed as enough work for the team, thus, traditional JPL review by all levels of sponsor organization, doing organization management and peers were kept to a minimum and, in some cases, eliminated.

As mentioned earlier, management's willingness to allow the team to co-locate was an important part of building and maintaining the team. Along with this management also supported a controversial JPL tradition, one which allows flight project groups to choose the tools and approaches which, in their best judgment, will get the job done.

VI. DOCUMENTATION

The class D project definition was developed at JPL to allow for lower costs and increased risks. At the same time, Class D programs have not usually been very well-defined or well documented. For the RRELAX project increased risk was somewhat mitigated by the selected use of Class A fabrication, safety and documentation procedures. A lot of Class A material was analyzed for its applicability, and then either bypassed or modified and used. The general rule followed for this filtering was to use what was needed and not just accept the net sum of years of accumulated "wisdom" (rules of thumb, common sense, old wives' tales,' etc.)

The RRELAX team used the rule that every flight project, independent of classification, needs good hardware, software and build documentation and that at every stage of the project the documentation must reflect what is really in a system. A simple method of change control was implemented along with a single point of approval (the cognizant engineer) and strong archiving procedures. Every team member was made familiar with these tasks and their roles relative to them were made explicit.

The authors feel it is useful to now discuss some of the details of the RRELAX project documentation.

The RRELAX project used commercial CAD tools (a mix of workstation- and PC-based tools) for the design and simulation of the system. The schematics, program listings, test sequences/programs, timing diagrams and mechanical drawings generated by the CAD tools were valued as essential documents and archived. JPL Assembly and Inspection data sheets were used as build instructions for flight fabrication technicians. JPL Engineering Change Instruction (ECI) sheets were used for rework. This level of build documentation was not cumbersome or costly and is the minimum, we feel, required to build flight equipment.

Problem Failure Reports (PFRs) area JPL requirement once power is applied to any flight equipment. We used a developmental PFR system which does not require a paper trail and a chain of signatures. PFRs were generated by any team member to flag a problem to the cognizant engineer. In general, when a PFR was generated, the RRELAX project policy was to "retreat" to the last known "safe state".

JPL Inspection Reports were used for quality assurance procedures. Even though class D programs do not require formal quality assurance, some selected QA procedures saved a lot of time and money in the test and qualification phases of the project.

Extensive archives were kept of all the above documentation and will be an excellent source of information with which to refine our class D approach for subsequent projects,

Even through documentation was flexible, once it was assigned to the project, it was used consistently.

VII. MSTI-3 DATA COMPRESSION CONTRIBUTION

The MSTI-3 data compression board was a direct follow-on to the RRELAX project, Most of the RRELAX team participated in the board's design, fabrication and qualification, The most significant aspects of this follow-on exercise was the validation of the RRELAX lessons learned. Additionally, it showed that the team approach was valid even though members change.

VIII. LESSONS LEARNED LIST

- It is possible to do these' projects in a "High-Ret" organization
- It is possible to use custom-tailored Class A fabrication and safety procedures with Class D projects and not throw all "pedigree" procedures away

- It is possible to use a number of non-flight-experienced team members, training them in flight procedures while doing their '(main" tasks on the project

- It is important to remove non-team players early

- Concurrent engineering practice pays off. Experts were there at the beginning, including task manager, cognizant engineer, fabrication, QA, safety, design, layout, and technical support

- A flat management structure was necessary. Only first level management was involved day to day. This kept team running smoothly by minimizing upsets & distractions
- Need upper management working hard to keep bureaucracy overhead to a minimum and support alternatives to Standard Operating Procedures

- An unusually high level of personnel & other resource "sharing" was used, People, equipment, labs & other resources were used for the Clementine and MSTI projects from parts of JPL which normally don't work directly on flight design, fabrication & test. This aspect of the project was key to its success

IX. CONCLUSION

Technically, both the Clementine RRELAX and MSTI-3 data compression boards were successful. The RRELAX experiment was essential for the Clementine spacecraft's need to characterize its microelectronics operation in a space radiation environment. The MSTI-3 data compression board will play a key role in allowing that spacecraft to meet its science data down link goals.

Programmatically, both projects were successful in the ways that they delivered working space-qualified systems to aggressive schedules and bare-bones budgets.

Most importantly, "new" methodologies were forged which allowed the immense spacecraft resources of JPL to be channeled into the kind of projects which will typify the programs of the foreseeable future. It is interesting to note that one of the team members recently returned to a large flight project and is now using the methods learned to accelerate that program.

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