COST-CAPPED AND RISK ADVERSE -- OPPOSITES ATTRACT

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ABSTRACT/RESUME

Currently NASA space missions are either one of the competed cost-capped missions in the Discovery, New Frontier or Scout programs or they are directed missions that have multiple instruments and a greater number of scientific goals. Even directed missions have cost challenges due to higher costs with the same or smaller budgets. However, regardless of the budget, the pressures for missions to be successful are also increasing. Kepler, a Discovery mission, and Mars Science Laboratory, a directed more complex rover mission, have different approaches to the same dilemma of being cost-capped and risk adverse. This paper discusses these two very successful approaches.

1. INTRODUCTION

Generally, NASA space missions fall into one of two categories. They are either one of the competed cost-capped missions in the Discovery, New Frontier or Scout programs or they are directed missions that have multiple instruments, and a greater number of scientific goals that often require substantial new technology and therefore, have a relatively high programmatic and technical risk. In addition, sometimes the Jet Propulsion Laboratory (JPL) level of involvement is also different. The competed missions are cost-capped and that cap is part of the proposal. Typically, these missions use existing proven technology. The directed missions have their budgets set by NASA Headquarters. Those budgets don't reflect today's higher costs. At the same time that funds are effectively shrinking, there remains pressure for missions to be successful. In the end missions have the mantra of being cost efficient and risk adverse. Two JPL missions, Kepler and Mars Science Laboratory, have very different approaches to this attraction of opposites as well as different levels of JPL involvement.

2. KEPLER

The Kepler Mission, a search for terrestrial planets, is a discovery mission. The goal for Kepler is to look for Earth-size planets in the habitable zone. The Kepler Mission will use the transit method to determine the existence of a planet around a distant star. For this discussion a transit is the movement of a planet across its parent star as seen by an observer. As the planet transits its parent star, the star has a dip in brightness. Kepler's photometer, a very precise light meter, measures the dip in brightness. In order to determine if the dip is actually a planet rather than a variable star at least three significant transits are needed. The Kepler Mission will be able to determine the planet's orbital period, its distance from its host star, and its size. The distance from its parent star determines the planet's temperature and the mass determines the planet's atmosphere. If the planet is too big its atmosphere will be like Jupiter's; if it is too small the life-supporting atmosphere will escape to space. Ultimately with all of the above data, scientists will be able to determine if the planet has the possibility of supporting life. In addition, the data will allow scientists to determine what types of stars have planets. Fig. 1 shows the Kepler spacecraft and photometer.

The Kepler spacecraft will stare at 100,000 stars for four years. The spacecraft performs a roll maneuver every ninety days to adjust the solar panels. It maintains an Earth trailing orbit. The Kepler Mission plans to downlink data every four days.

Because Kepler is a discovery mission it is cost-capped and the cost of Discovery Missions is part of the proposal. It is a joint mission with Ames Research Center, Ball Aerospace and Engineering Corp. and Jet Propulsion Laboratory as the partners. Dr. William Borucki, the Principal Investigator, Dr. David Koch, the Deputy Principal Investigator, and the Ground System are at Ames Research Center. Ball Aerospace and Engineering Corp. is building the spacecraft and the photometer. Jet Propulsion Laboratory is responsible for budget, schedule and coordination pre-launch and during commissioning.

As a Discovery Mission, Kepler is science driven and therefore, the mission tries to use existing systems and proven technology where possible. The challenge is to select the correct approaches that will utilize the appropriate existing systems and proven technology. The Kepler Project has been selective in choosing the approaches that will lend themselves to reducing cost and at the same time reducing risk as well.

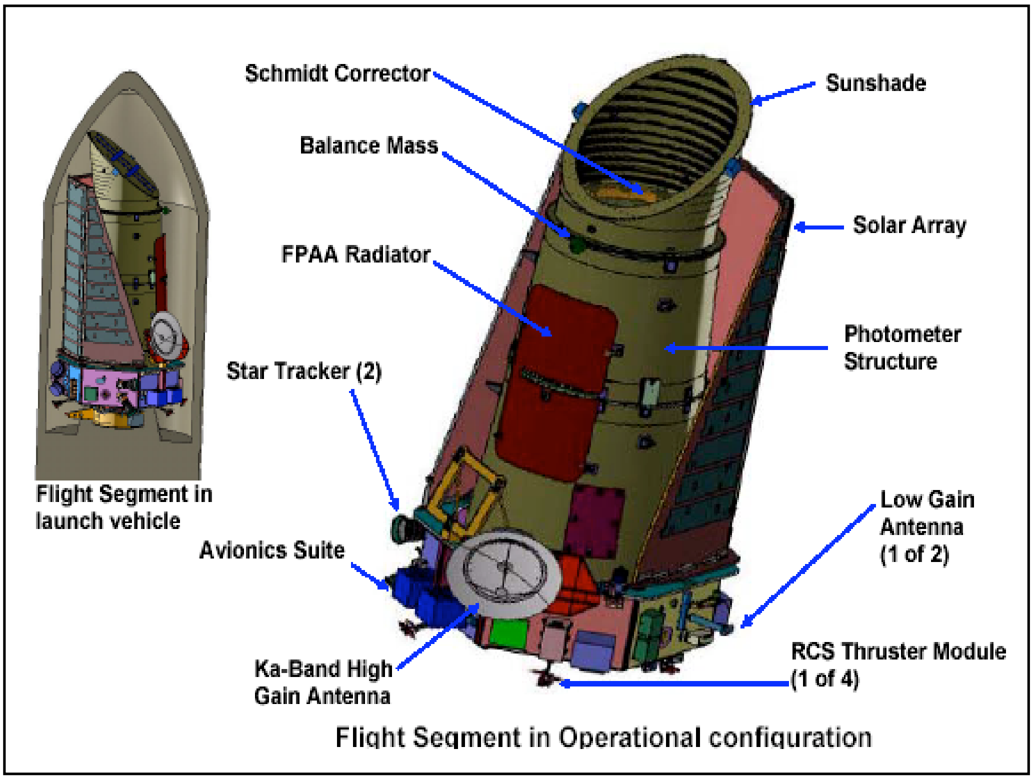

Figure 1. The Kepler Spacecraft and Photometer (Drawing courtesy of Eric Bachtell Ball Aerospace and Engineering Corp.)

The first approach is to simplify the mission. Kepler has only one instrument, the photometer as is typical with observatories. It continually stares at a specified star field. There is no competition for spacecraft consumables including the spacecraft position and orientation. There are no flight rules that need to be checked due to interference among multiple instruments. There is a single maneuver that occurs every 90 days to realign the solar panels reducing the required sun constraint checking. Then the spacecraft returns to staring at the same star field. The spacecraft only transmits its data to Earth every four days. Each downlink pass has more than enough time to receive all of the data. If the downlink period is missed or the spacecraft goes into safing, by extending the mission the same number of lost days the data can be retrieved. This approach simplifies the software that needs to be built and used. Reducing the amount of development reduces cost and reduces development risk. The simplification also allows for smaller operations teams because command loads tend to be reused.

Kepler has many organizations working within the flight and ground system. The following diagram shows the various organizations. The other two approaches deal with utilizing existing systems and standards of these organizations.

The second of these approaches involves using the standards and practices of the various organizations (shown in Fig. 2) developing the spacecraft and the flight and ground software. Ames Research Center uses NASA standards. Jet Propulsion Laboratory uses standards developed at JPL, but based on NASA standards. Ball Aerospace and Technology Corp. uses their Quality Business System as the guideline for their standards and practices. However, all three organizations are working toward being Capability Maturity Model Integration (CMMI) compliant. Ames and JPL are working toward level-2 compliance and by the time this paper is presented Ball should have passed their level-3 compliance. These standards ensure that the number and kind of documents, reviews and inspections is similar at all of the organizations. The similarity reduces the risks that have happened when different organizations with dissimilar standards work together. In addition, allowing each group to stay within their own standards reduces the amount of training required to produce the documents and hold the reviews. One of the additional documents that Kepler has produced is a Glossary Document that defines words specific to the Kepler project. This document helps reduce the amount of translation required on the project and aids communication.

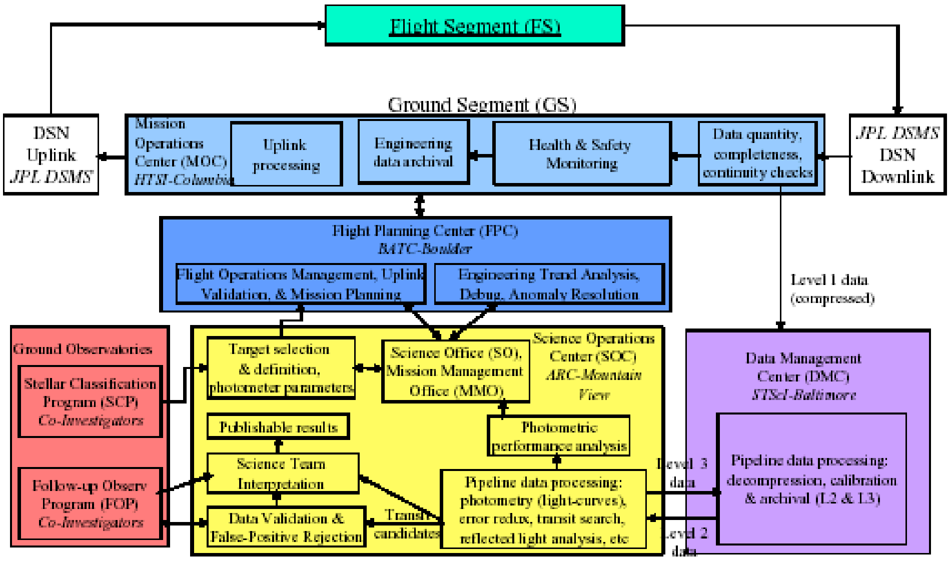

Figure 2. This diagram shows the different companies involved in the Kepler Project and their functions. The companies include Ball Aerospace and Technology Corp, Ames Research Center, Space Telescope Science Institute, and the Laboratory for Atmospheric Space Physics at the University of Colorado (part of the Flight Planner Center).

Kepler also has developed a strong communications link to help the organizations to stay in sync. Once a week the JPL Project System Engineer has a meeting with the Project Systems Engineers from Ames and Ball. Each month there are three monthly manager reviews (MMRs) and the participants present their current status. In most cases the MMRs are held at Ball in Boulder and at Ames at Mountain View, CA. If the attendees can't be there in person then they phone in. All participants use the same document-sharing software and the requirements for all the groups are kept in Doors, a requirements tracing database facility. All members of the project have access to the current document set.

The final approach deals with software reuse. There are many definitions of software reuse. At Ames and JPL the NASA 7150.2 definition is used:

- Reuse Software: Inherited software or third party software that can be reused as is without any modification.
- Re-engineer Software: Inherited software or third party software that must be modified before use. This includes any changes to requirements, design or code.
- New Software: Software that must be fully developed by the software development organization. Requirements, design, code and testing must be developed with little or no baseline.

At Ball a slightly different definition is used. It is based on the Cocomo Estimation Model that defines reused software by stating that 40% design, 30% code and 10% test is reusable. In both cases reused software is tested as if it is new. Ball has flight software that was built for the Orbital Express Mission and then modified for use on the Ball/JPL Deep Impact Mission. This software will be the basis for the Kepler flight software. It is well understood that both Orbital Express and Deep Impact have needed greater flexibility in the flight software than Kepler, but it is cheaper and less risky to reuse this software using the Cocomo model (40-30-10 reuse) than to build it from scratch. For the ground software, software reuse is also part of the design. The Data Management Center (DMC) at Space Telescope Science Institute collects and houses the data for the ground system. They will be using software that has performed these functions in the past as a basis for their Kepler software. The Laboratory for Atmospheric Space Physics at the University of Colorado in Boulder, Colorado is the Mission Operations Center (MOC) for the Ground System. They have software called Oasis CC that has been used on a number of previous missions. Oasis CC can be adapted to new missions via scripts that are built specifically for the new mission. Both the MOC and the Flight Planning Center (FPC) team, the flight team, will use the Oasis CC software. The FPC will also use software that has been used to test the flight software. Kepler has taken advantage of software re-use in both the flight and ground systems.

Kepler has so far been successful with these established approaches. Dr. Borucki and Dr. Koch have been instrumental in making and keeping the mission simple. Each organization has standard procedures and practices that allow those in charge of the Project to be comfortable that the development of operations and the operations software will proceed smoothly. All organizations have stressed communications and have worked to define and overcome differences. Finally, the Project is developing a balance between new and reusable software. This approach is Kepler's approach to the mantra of being cost capped, but risk adverse.

3. MARS SCIENCE LABORATORY (MSL)

Mars Science Laboratory (MSL) is almost the opposite of Kepler. First of all, JPL is responsible for all aspects of MSL instead of being responsible for coordination, budget and schedule as is the case for Kepler. MSL is a Mars Rover Mission. This rover will have a prime mission of two Earth years (one Martian year) and it is scheduled to launch in 2009. It will have ten instruments and it will be larger than the Mars Exploration Rovers, Spirit and Opportunity. Because it is significantly bigger in size and mass, MSL cannot use the airbag system used by previous rovers and will look at alternative approaches. At this time MSL will relay data to Mars Telecom Orbiter (MTO) or Mars Reconnaissance Orbiter (MRO), but it will not have the capability of sending information directly to Earth. However, the launch date and having direct to earth functionality are both under discussion. Resolution of these two issues plus others is expected in the summer of 2005.

There are four groups of instruments on MSL, the Analytic Laboratory, the Mast Remote Sensing, the Contact instruments, and the Environmental instruments. The Analytic Laboratory consists of the SAM and CheMin. The SAM instrument analyzes the elemental, isotopic and organic chemistry of rock and soil samples, while the CheMin instrument studies the mineralogy of samples. The Mast Remote Sensing instruments include the MastCam, and the ChemCam. The MastCam provides stereo panoramic images and measures atmospheric opacity. ChemCam measures elemental abundance remotely using a laser spectrometer. The third group contains the Contact instruments, the APXS and the MAHLI. The APXS instrument also detects elemental abundance and the MAHLI provides microscopic imaging. Both of these instruments are on the arm attached to the rover. They provide the up-close and personal views. The final group consists of the Environmental instruments, the DAN, the REMS, the RAD and the MARDI. The DAN instrument performs experiments to measure subsurface Hydrogen. The REMS instrument performs meteorological and UV radiation experiments. The RAD instrument looks for high-energy radiation, and the MARDI performs landing site descent imaging. Fig. 3 is a depiction of the MSL rover and the locations of the instruments. This rover also carries a sophisticated sample acquisition, processing and handling system. The mission has more than 100 investigators and collaborators with significant international participation including participation from Spain, Russia, Germany, Canada, France and Finland.

In addition to being significantly more complicated than the Kepler Project, MSL has several additional drivers for operations. Mars Exploration Rovers (MER) operations consisted of three shifts of operations teams that covered twenty-four hours, seven days per week and worked on Mars time for each rover during the prime mission. A Mars day is 40 minutes longer than an Earth day. Therefore the operations teams had a constantly shifting schedule. Keeping this type of schedule is very difficult for people. They would often forget what time it is on Earth including their Earth commitments like picking up children from school. MSL will work toward having one shift, five days per week that operates on Earth time. Accomplishing this type of change requires improvements in the MER process. As Spirit and Opportunity, the MER rovers, continue to operate, great strides have been made in reducing the time required to perform the MER uplink process including a return to working on Earth time. MSL wants to take advantage of the MER process improvements and add to them.

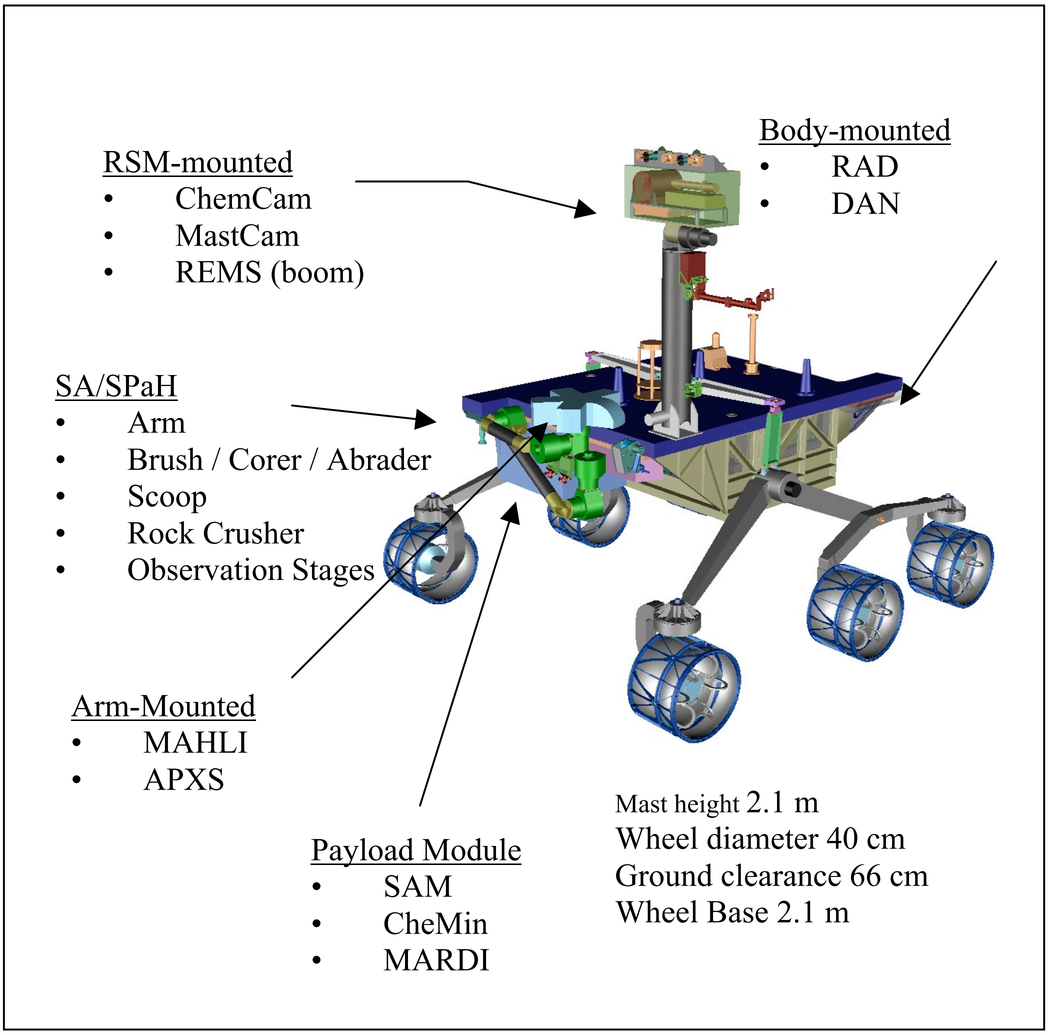

Figure 3. This figure is a depiction of the Mars Science Laboratory (MSL) rover and its instruments.

One of the process improvement strategies adopted by the Mars Program has been to have a Mars Technology Office. This office has been created to look at and to infuse new technology into the Mars Program as an approach to dealing with cost caps and risk aversion. Part of the Mars Technology Office is the MSL Focused Technology. This group has been established to look at new technologies that can be used specifically by MSL. Two of the tasks in the MSL Focused Technology Program are operations tasks. One of the tasks is called the Next Generation Uplink Planning System and the other one is the Maestro Task.

The Next Generation Uplink Planning System (NGUPS) task is to determine a ground system approach and prototype it for the MSL ground system. Since MSL has decided to model its ground system after the MER ground system, the first task was to talk with people on MER operations teams both past and present. The NGUPS team interviewed approximately twenty people who have participated in MER operations. Basic questions like the following were asked:

- “What was your job?”
- “What worked well in the MER Uplink Process?”
- “What could be improved in the MER Uplink Process?”

In general, the two aspects that most of the interviewees wanted to see improved are:

- The software tools did not work well together.
- There was redundant functionality within the tools.

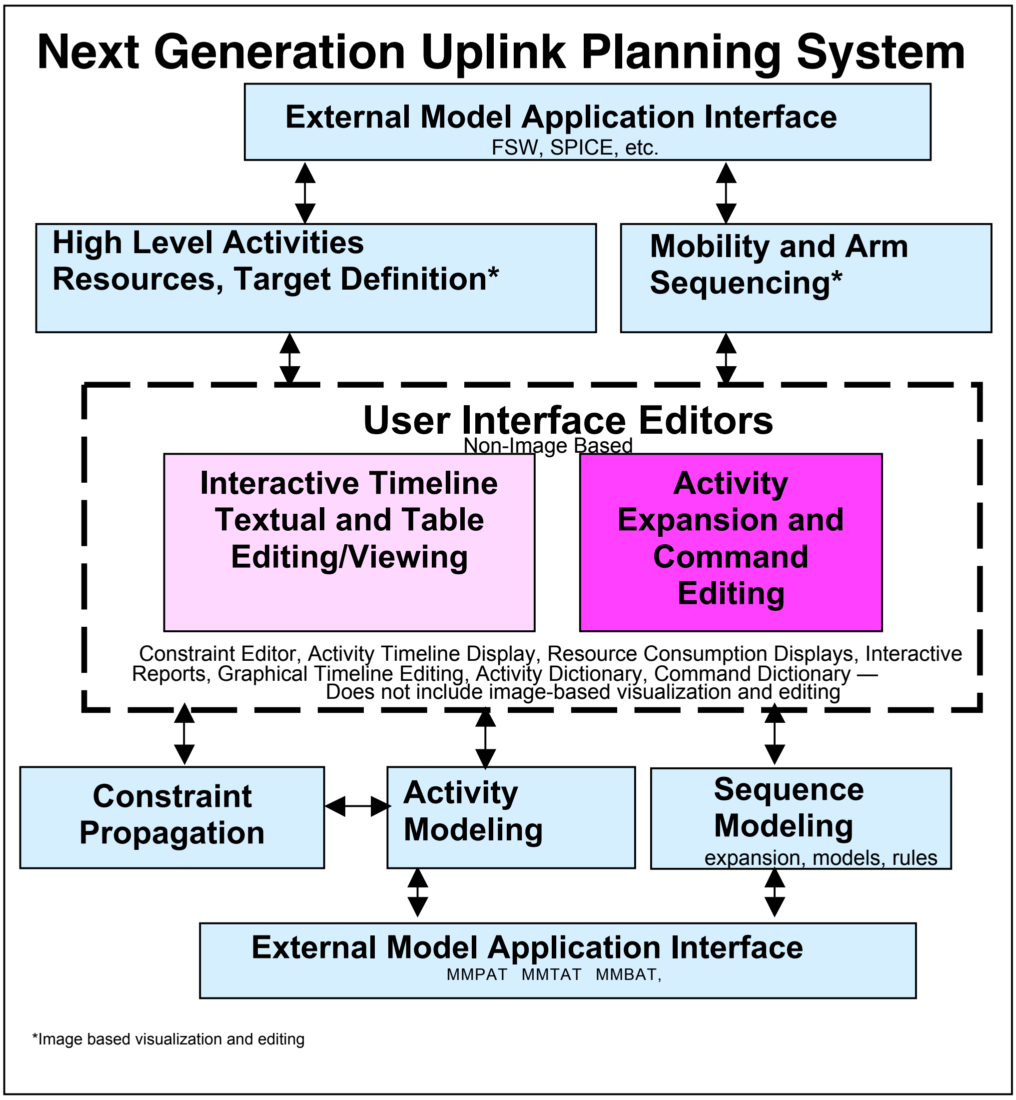

Figure 4. This drawing is of The Next Generation Uplink Planning System for the Mars Science Laboratory (MSL).

In the first category scripts had been built to move the data from one tool to another tool. In all there are over 200 scripts in the MER Uplink Process. There will always be a need for scripts, but the software tools need to have better connections and communications with each other. In addition, because of the lack of direct connectivity, information was lost from one tool to the next tool. The end result is that the process can only go forward making it difficult to reuse command sequences. The NGUPS task decided to improve the software tool to software tool interfaces to erase this concern. In order to improve the software tool interfaces a common framework is being used and a common input source – the Activity Dictionary. The Activity Dictionary is something that MER developed and used.

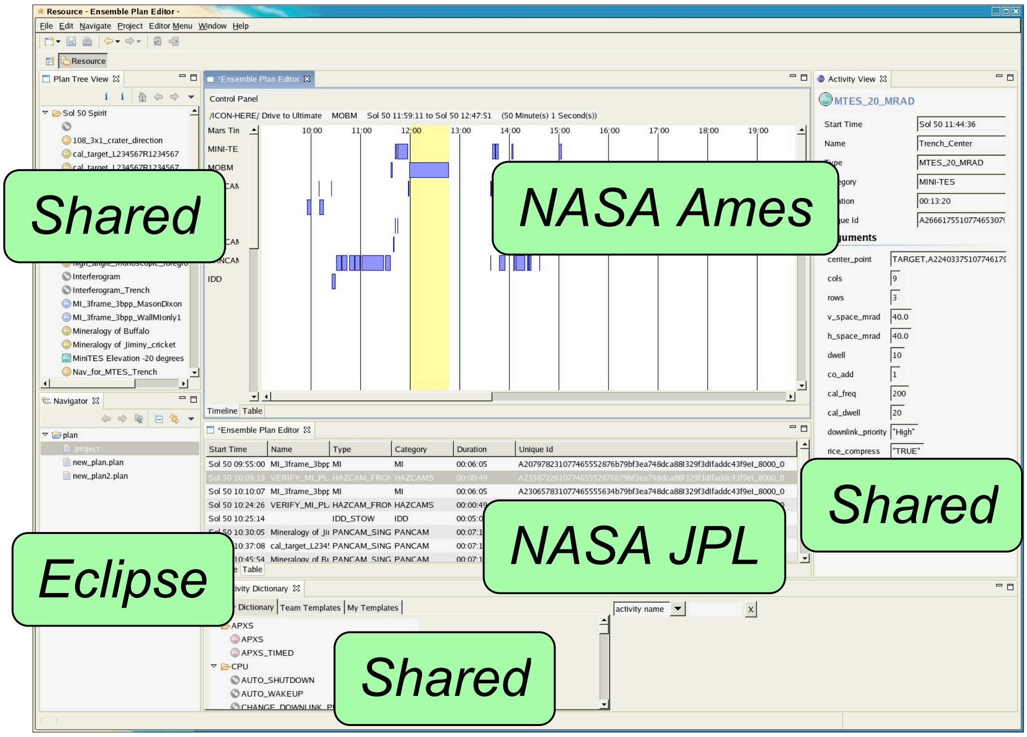

Figure 5. Screen shot of the different elements of the User Interface to be used for MSL. It identifies the sections that have been implemented by JPL; those implemented by Ames Research Center and the ones that are shared by both organizations. (Screen shot by Jeff Norris, Maestro MSL Focused Technology Task)

In the second category of redundant functionality each tool has its own user interface. This situation meant that training and cross-training are more difficult because the operations person must learn each user interface for each tool. Often the same information was presented differently in all the tools. In addition, since there were different software models for each tool, sometimes there were just as many answers as there were tools. For this aspect the NGUPS team decided to use a common approach to user presentation. All the tools use the same user interface and communicate with the user interface through a common framework. For the spacecraft models the team is looking at software reuse where the various tools will be able to share a common set of models. This last approach is still in work and it hasn't been determined if it is feasible because of the differences in model fidelity

The NGUPS task is prototyping parts of this new system. Primarily the NGUPS task is working with the sequence elements of the task. The Maestro task is working on the planning aspects of the new system. Fig. 4 shows the results of streamlining the MER ground system into the MSL Ground System. The right side of the drawing including the mobility and arm sequencing, the command expansion and sequence modeling are being prototyped in the NGUPS task. The high level activities, resources, target definitions, the interactive timeline viewing and editing and the constraint propagation are being prototyped by the Maestro task.

Both tasks are using a software component framework called Eclipse to build this new environment. Eclipse has a Rich Client Platform that has been developed by IBM and is now open source. This platform allows the various software tools to build plug-in software elements (components) that can be shared among the tools. By using this approach the Maestro task with support from the Human Computer Interactions Group at Ames Research Center has prototyped a user interface that all the tools are in the process of communicating with. Eclipse has also provided an easier mechanism for directly sharing data among the tools. Another group at Ames, Intelligent Systems, is working on the constraint propagation software. Even though this software is not Eclipse based, it has an Eclipse bridge that allows the other tools to easily communicate with it.

In addition to using Eclipse, the Maestro task is also using some elements of Extreme Programming. Pairs of software developers implement the needed functionality in Extreme Programming. The implementation group divides the functionality up into small sections and schedules only a week at a time. Prior to starting implementation, the pair creates an automatic test. By creating these tests in advance, the implementation pair has a way to know that they have completed the work and that it meets its requirements. The early creation of the tests has been left to the discretion of pairs on the Maestro team and is based on the new functionality. The use of Extreme Programming has worked well for them and their productivity is high. Fig. 5 shows the results of the Maestro work. The screen shots are of the actual user interface being used. The notations on the different screens show the group responsible for the work (JPL, Ames or joint).

Through a combination of study, prototyping and technology infusion, MSL will be able to meet their budget constraints. At the same time the more risky elements will have been proven prior to paying for a full development. In this way MSL has answered the call of being cost capped and risk adverse at the same time.

4. CONCLUSION

Both Kepler and MSL have used strategies that may not be considered new. However, the most important aspect is that both projects have been very successful in their implementation of these approaches. Everyone on Kepler works diligently to hold both cost and risk at a minimum while still producing an exciting mission. On the other hand, MSL has been extremely successful in their approach of try-it before you buy-it. Demonstrations of prototypes have been well received by the MSL Project. The primary reason for success is that each project has developed an environment that fosters communication, coordination and cooperation. Both projects have diverse groups working together to produce a better final product. It takes energy and respect (both are in abundance on Kepler and MSL), but projects can be cost-capped and risk adverse and find a way to satisfy both extremes. Now after all this hard work on the part of many people, it will be terrific to see these two missions launch.

5. ACKNOWLEGEMENTS

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