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Zero to Integration in Eight Months, The Dawn Ground Data System Engineering Challenge

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The Dawn Project has presented the Ground Data System (GDS) with technical challenges driven by cost and schedule constraints commonly associated with National Aeronautics and Space Administration (NASA) Discovery Projects. The Dawn mission consists of a new and exciting Deep Space partnership among: the Jet Propulsion Laboratory (JPL), manages the project and is responsible for flight operation; Orbital Sciences Corporation (OSC), is the spacecraft builder and is responsible for flight system test and integration; and the University of California, at Los Angeles (UCLA), is responsible for science planning and operations. As a cost-capped mission, one of Dawn's implementation strategies is to leverage from both flight and ground heritage. OSC's ground data system is used for flight system test and integration as part of the flight heritage strategy. Mission operations, however, are to be conducted with JPL's ground system. The system engineering challenge of dealing with two heterogeneous ground systems emerged immediately. During the first technical interchange meeting between the JPL's GDS Team and OSC's Flight Software Team, August 2003, the need to integrate the ground system with the flight software was brought to the table. This need was driven by the project's commitment to enable instrument engineering model integration in a spacecraft simulator environment, for both demonstration and risk mitigation purposes, by April 2004. This paper will describe the system engineering approach that was undertaken by JPL's GDS Team in order to meet the technical challenge within a non-negotiable eight-month schedule. Key to the success was adherence to fundamental systems engineering practices: decomposition of the project request into manageable requirements; integration of multiple ground disciplines and experts into a focused team effort; definition of a structured yet flexible development process; definition of an in-process risk reduction plan; and aggregation of the intermediate products to an integrated final product. In addition, this paper will highlight the role of lessons learned from the integration experience. The lessons learned from an early GDS deployment have served as the foundation for the design and implementation of the Dawn Ground Data System.

I. Introduction

The NASA Discovery Program funds innovative science investigations designed to push the limits of solar system exploration through low-cost, schedule-challenged projects such as Dawn[4]. Dawn is the ninth Discovery project. Its mission is to travel to the two oldest and most massive asteroids in the solar system, Vesta and Ceres, study their geophysical properties, and thus increase our understanding of the conditions and processes behind the creation of the solar system[1]. To accomplish the mission, the Dawn spacecraft relies on ion propulsion technology to orbit both asteroids. This feat is unique to Dawn. The Dawn implementing organizations are: the Jet Propulsion Laboratory (JPL); Orbital Sciences Corporation (OSC); the German Aerospace Center, Deutsches Zentrum Fuer Luft-und Raumfart (DLR), and the Max Planck Institute for Solar System Research (MPS); and the Italian Space Agency, Agenzia Spaziale Italiana (ASI). Dawn's payload consists of 2 Framing Cameras provided by DLR and MPS; a Mapping Spectrometer provided by ASI; and a Gamma Ray and Neutron Detector provided by Los Alamos National Laboratory (LANL). Dawn's Principal Investigator is Dr. Christopher T. Russell (UCLA). The Dawn spacecraft is expected to launch June 2007.

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Strategic partnerships are key to achieving low-cost, innovative scientific missions. The above participating organizations formed a new strategic partnership. DLR and ASI are instrument donors. OSC builds the spacecraft, and is responsible for flight system test and integration and for launch operations. The Dawn Science Center (DSC) at UCLA is responsible for science planning and science operations. JPL is responsible for project management and post-launch operations. In addition, JPL provides the ion engines and the Ground Data System (GDS) to conduct deep space mission operations.

Strategic partnerships also had to be formed at the team level in order to meet project risk-mitigating milestones. One such partnership involves the JPL GDS team and the OSC FSW team. During the first Technical Information Meeting, August 2003, the GDS team was briefed of the project commitment to provide the instrument teams with a spacecraft simulator environment for early instrument engineering model test and integration, by April 2004. The spacecraft simulator (S/C Sim) environment provided by OSC should include flight-like GDS interface components provided by JPL. This requirement emerged in response to concerns regarding the use of two different ground systems: OSC's for flight system test and integration and JPL's for flight operations. The lack of an existing interface between these two systems heightened the concerns.

II. The Dawn GDS System Engineering Challenge

Dawn GDS system engineering activities started August 2003. These focused on readiness for the Ground Segment (GS) Preliminary Design Review (PDR). The PDR was scheduled for early December 2003, and the first GDS delivery for summer of 2004, per the baseline schedule. A "bare bones" GDS 0.0 was inserted into the schedule to address the S/C Sim commitment to the instrument teams. The Dawn GDS system engineering challenge was to transition from a state of zero design and implementation and zero experience with OSC, to a state of ground integration into OSC's S/C Sim environment, within 8 months. This was to be accomplished within budget and schedule, without jeopardizing PDR readiness and the integrity of the GDS design. The objective of this paper is to describe the GDS systems engineering approach and processes, which enabled the GDS team to successfully meet the integration challenge, and the resulting lessons learned.[2]

III. The Dawn GDS System Engineering Approach

The Dawn Ground Data System inherits JPL's multi-mission ground system, which is known as the Advanced Multi-Mission Operations System (AMMOS). The Dawn GDS is a Software Intensive System (SIS) which requires software system engineering to be integrated into the overall system engineering process. The integration of these two disciplines is a trend in Software Intensive Systems[2]. The flavor of this integration was key to the success of GDS 0.0. The GDS Systems Engineering approach provided a structured development framework which was used to guide, monitor and control the Agile software systems engineering efforts that were adopted to develop critical GDS 0.0 software components. Three medium-scale critical software engineering tasks were identified as candidates for agile methods: implementation of a new Dawn command generation toolkit; implementation of the command and telemetry database translation suite which translates OSC's command and telemetry database specifications into corresponding AMMOS command and telemetry database products; and implementation of a new tool referred to as Test Conductor Assistant with the initial purpose of flight and ground software integration and test. Agile methods are best known for their use by projects with uncertain requirements[3]. In the GDS 0.0 case, the adherence to fundamental systems engineering practices mitigated the uncertainty of requirements. The Agile emphasis was on the skill level of the development teams and on their interactions, rather than on the rigor of their processes and documentation. This proved to be a successful approach by emphasizing the discipline of process at the GDS System Engineering level and using it to guide the engineering design and development. Figure 1 depicts the over-arching GDS System Engineering process, which successfully met the challenge. Furthermore, this is the same process that was in place as part of the roadmap to the Dawn Ground Segment PDR. It was important that the PDR not be jeopardized and that the GDS 0.0 approach be aligned with the overall GDS design effort.

[2] It should be noted that other Systems Engineering domains such as Payload System Engineering and Mission Operations System Engineering are key contributors to the overall success of the project. The intent of this paper, however, is to focus on the GDS domain.

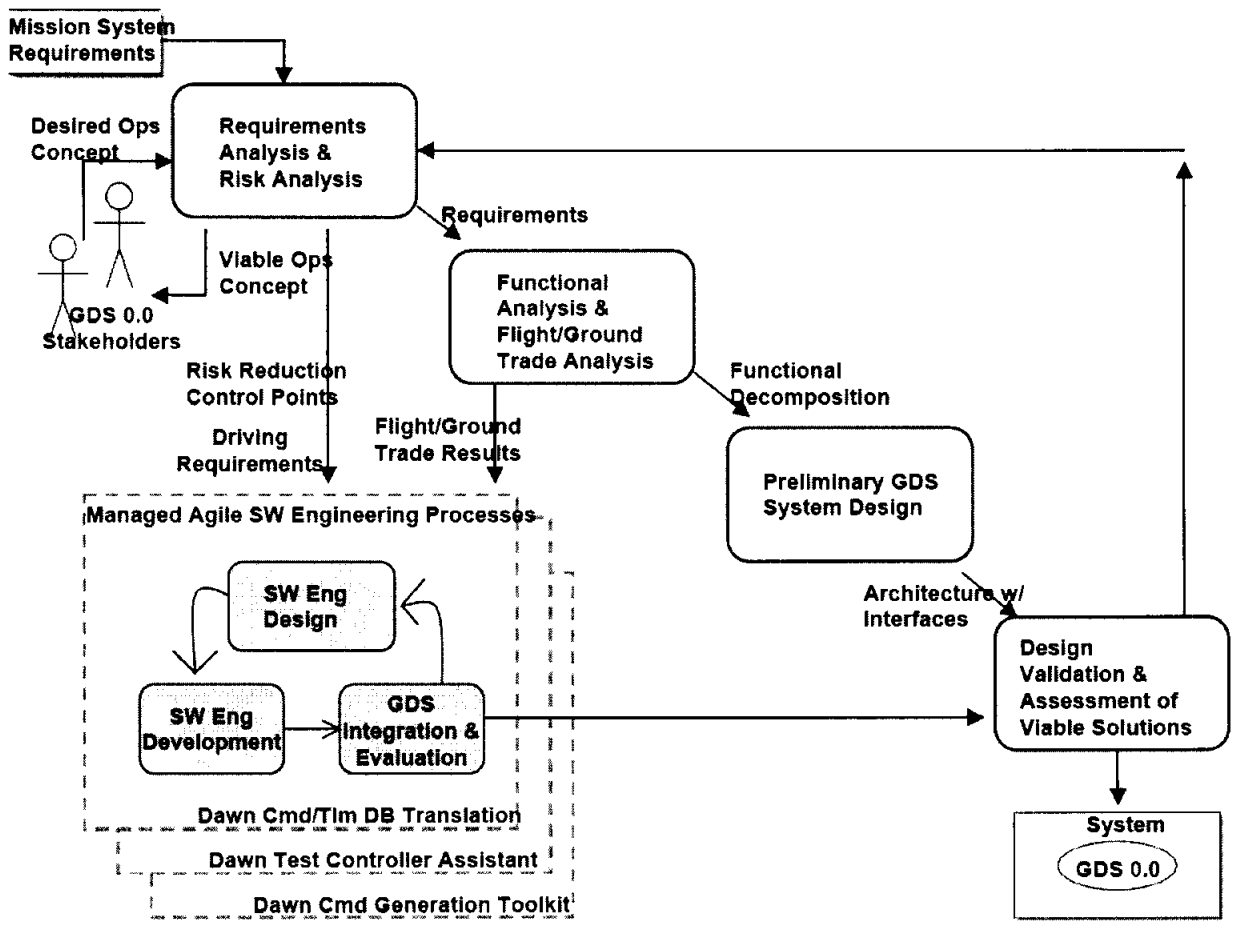

Figure 1. Dawn GDS System Engineering Process

A. The Structured System Engineering Development Approach

An important component of the over-arching systems engineering process is the set of practices which, at the aggregate system level, provided an overall structured development approach. This paper demonstrates that this was the right approach in response to a non-negotiable schedule and no room for failure. The key practices were: integration of multiple disciplines and experts into an Agile team effort; decomposition of the S/C Sim integration project requirement into a manageable set of key functional requirements aligned with GDS system key driving requirements; and in-process risk reduction planning and control.

1. Integration of Multiple Disciplines and Experts into a GDS Team Effort

True to the Agile claim, the focus on highly skilled individuals and their team interactions led to the successful development of the three critical software tasks. Two JPL domain experts were recruited: the authority on the AMMOS multi-mission telemetry standard; and the authority on the AMMOS Command Definition Language (CDL). In addition, the Mars Exploration Rover dictionary software architect was enlisted to develop the Dawn Telemetry and Command Database Translation and Management software. These three experts worked side-by-side for approximately six months in the quest to automate the translation of the OSC command and telemetry databases into their AMMOS counterparts, which were then integrated into the Dawn GDS. As an example of the Agile nature of the teams and work, initially, the CDL expert manually generated a Dawn CDL which was needed as input to the Dawn Command Generation software development effort. The lead for this effort, in turn, worked closely with the OSC FSW Team to test the commands built by the AMMOS software by feeding them into the S/C Sim.

The CDL expert analyzed the OSC command specification and database Interface Control Document and defined algorithms that led to full automation of the command database translation. The structured GDS system engineering process guided these team activities by providing requirements and controlling risk.

2. Decomposition of the Project S/C Sim Integration Request into Functional Requirements Aligned with System Driving Requirements

Early on, a concise set of verifiable uplink and downlink requirements were defined for the Agile teams.
On the uplink side:

- Provide GUI that provides for selection of instrument commands and parameters
- Generate flight-like AMMOS command files containing instrument commands
- Extract Command Link Transmission Units (CLTUs) from command files and sent to S/C Simulator

On the downlink side:

- Process frames from S/C Sim containing instrument packets
- Packetization and instrument telemetry channel extraction
- Display of telemetry channels defined in the instrument telemetry database

GDS System Engineering determined that the above "bare bones" capabilities would meet the S/C Sim integration goal within schedule and cost. At first glance the above requirements appear straightforward. However, the above requirements had to be aligned with the GDS system-level driving requirements (1, 2, 4, 7), which compounded the risk.

1. Advanced Orbiting System (AOS) Frame with Turbo Encoding
2. Translation of OSC Command and Telemetry Dictionaries
3. Delivery of Virtual Machine Language (VML) C structures to FSW
4. Support CCSDS Standards which are part of OSC's heritage architecture
5. Support Instrument and Spacecraft file loads without on-board file system
6. Support Distributed GDS Architecture (JPL, Orbital and UCLA)
7. Support ITAR view of Ground/Mission data for foreign Instrument Teams

Table 1. Dawn GDS Key Driving Requirements

3. Risk Reduction Planning and Control

The Risk Reduction approach consisted of two fundamental practices, which were key to meeting the April '04 S/C Sim Training milestone for the instrument teams: definition of risk reduction control points; and managing expectations in order to control the understanding of the problem to be solved by the Agile teams, and to avoid uncertainty of requirements. Figure 2 depicts the risk reduction approach.

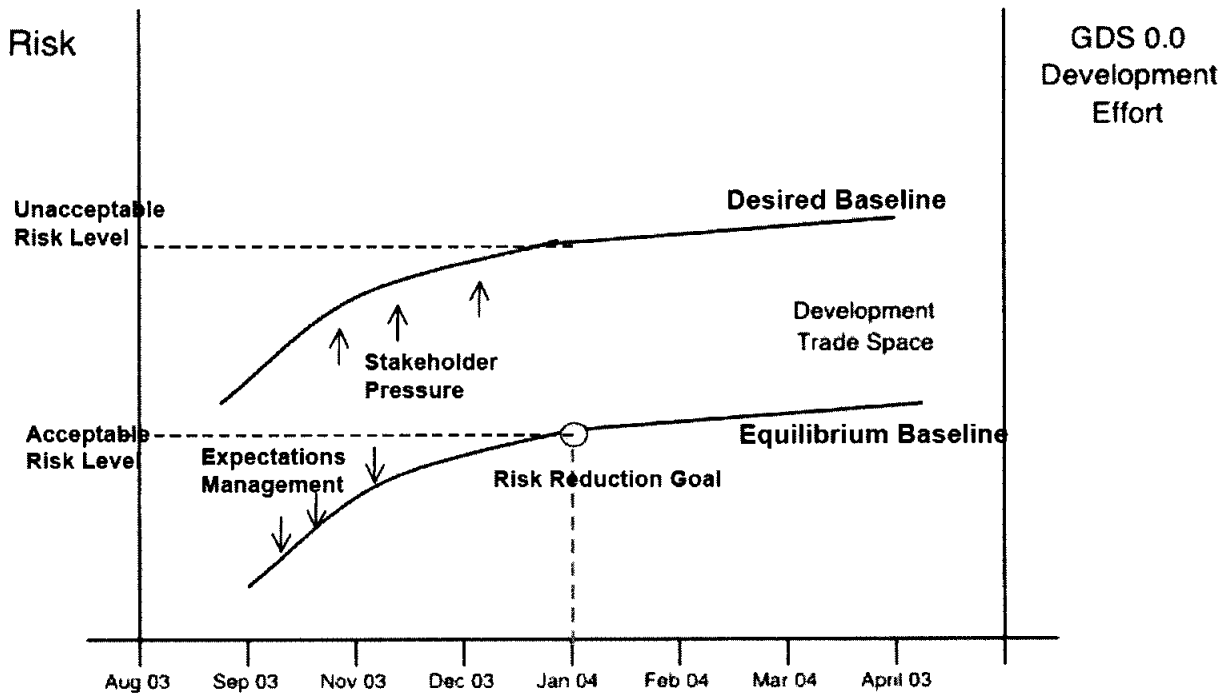

Figure 2. Risk Reduction Approach

Firm management of expectations was necessary to counteract stakeholder pressure for more capabilities within the non-negotiable schedule. The GDS System Engineering team determined that the desired baseline presented an unacceptable level of risk. Analysis of the development trade space concluded at an equilibrium point where critical capabilities should be implemented by Jan '04, and allow GDS 0.0 system level integration and test to begin. The risk reduction control points were used to re-group Agile teams and to assess their intermediate products.
The following risk reduction control points were defined:

- Operational remote socket interface between JPL Dawn Command Generation toolkit development environment and OSC S/C Simulator Environment November 2003.
- Delivery of Dawn Telemetry Input Subsystem by multi-mission AMMOS team December 2003.
- Commanding of S/C Sim using Dawn Command Generation Toolkit January 2004.
- GDS Telemetry processing of S/C Sim downlink data January 2004.
- Test Conductor Assistant able to accept commands and parameters and generate command files dynamically February 2004.
- GDS hardware and software deployment to OSC March 2004.
- On-site GDS training for OSC FSW team March 2004.
- On-site GDS support for Instrument Team S/C Sim Training April 2004.

As each risk reduction control point was reached, comprehensive tests were executed to ensure that any software re-factoring done as a result of the Agile mode the teams were in, did not jeopardize the integrity of the system interfaces and system capabilities.

IV. The Dawn GDS Solution and Lessons Learned

By managing expectations and requirements through a disciplined GDS System Engineering approach, a simple yet complete GDS 0.0 solution was designed, implemented and deployed to OSC in time for the April '04 instrument team S/C Simulator training. The key lessons learned are: a structured system engineering process is

needed to 1) manage risks and requirements even when localized agile-type development approaches are called for; and 2) simple solutions can be the best solution as long as the interrelated components work together toward the common goal at the system level. Figure 3 below depicts the final GDS 0.0 solution. By targeting a risk reduction equilibrium point, the integrity of the baseline solution was maintained and additional features were added after the acceptable risk level had been reached.

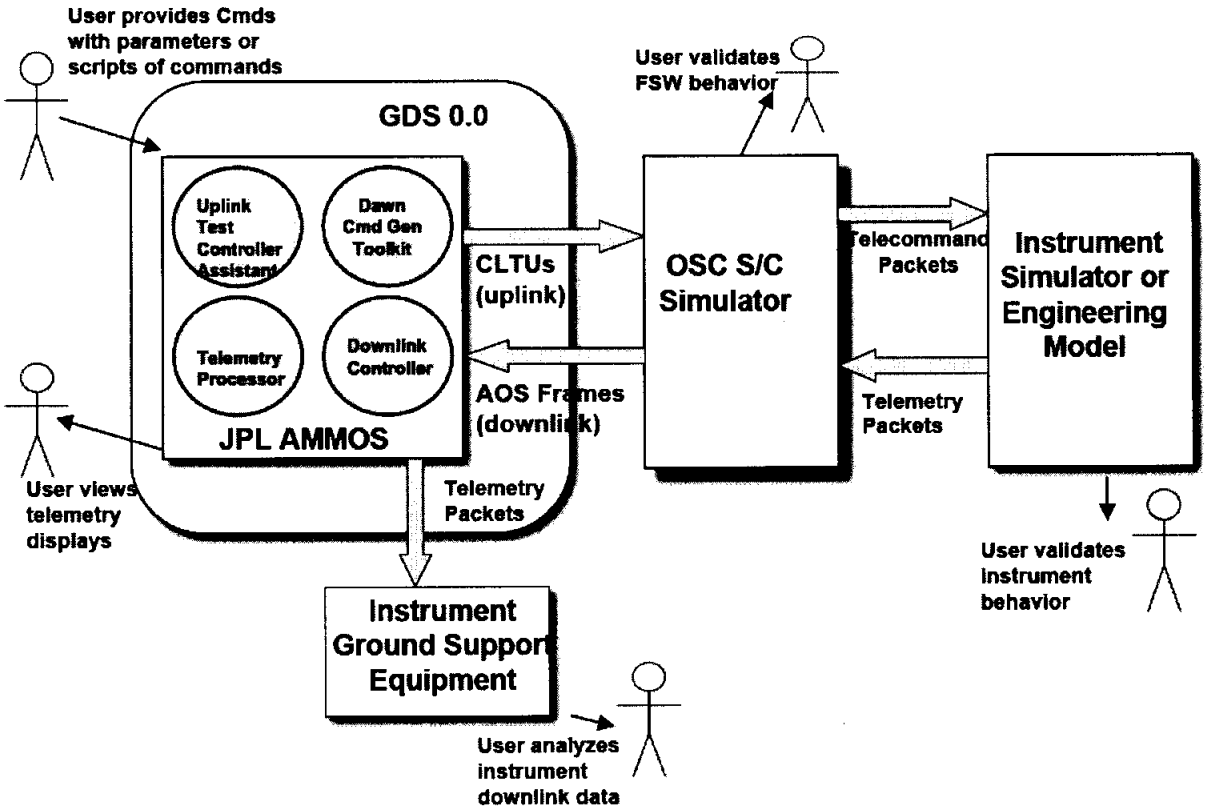

Figure 3. GDS 0.0 Final Solution to the Integration Challenge

GDS 0.0 provided valuable lessons learned which have been fed into the Dawn GDS design and delivery process. The GDS preliminary design was validated with GDS 0.0. Standing review board concerns were addressed by solving command and telemetry interface issues early on. Driving requirements played a key role in GDS 0.0. Four out of the seven key driving requirements were addressed in GDS 0.0. This resulted in a very stable GDS foundation to build upon, which includes a rigorous command and telemetry regression test suite. Early deployment of AMMOS to OSC resulted in a strong technical partnership between the GDS Team and the FSW Team, and in the acceptance of AMMOS by the OSC Team.

V. Conclusion

In conclusion, The Dawn GDS Team met the integration challenge in zero to eight months by using a structured systems engineering approach, which guided and cared for multiple threads of software systems engineering efforts with an emphasis on people, skills and innovations. The over-arching system engineering process was the catalyst for the meaningful aggregation of these threads into a final integrated GDS solution.

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