Standardization of XML Database Exchanges and the James Webb Space Telescope Experience[1][2]

Jonathan Gal-Edd
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
301-286-2378
Jonathan.S.Gal-Edd@nasa.gov

Ryan Detter
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
301-286-2378
Ryan.D.Detter@nasa.gov

Ron Jones
ARTS Corporation
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
301-286-2378
ronald.jones@asrcrts.com

Curtis C. Fatig
SAIC
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
301-286-0693
curtis.fatig@gsfc.nasa.gov

Abstract—Personnel from the National Aeronautics and Space Administration (NASA) James Webb Space Telescope (JWST) Project have been working with various standard communities such the Object Management Group (OMG) and the Consultative Committee for Space Data Systems (CCSDS) to assist in the definition of a common eXtensible Markup Language (XML) for database exchange format. The CCSDS and OMG standards are intended for the exchange of core command and telemetry information, not for all database information needed to exercise a NASA space mission. The mission-specific database, containing all the information needed for a space mission, is translated from/to the standard using a translator. The standard is meant to provide a system that encompasses 90% of the information needed for command and telemetry processing.

This paper will discuss standardization of the XML database exchange format, tools used, and the JWST experience, as well as future work with XML standard groups both commercial and government.

TABLE OF CONTENTS

1. INTRODUCTION

The JWST is a large 6-meter aperture infrared space telescope with a 5-year mission (with a design goal of 10 years of operations). The JWST will continue advancing breakthroughs in the understanding of the origins of the earliest stars by detecting the first starlight and answering other questions about the early universe[1]. The launch date for JWST is currently planned for no earlier than June 2013, and the JWST will be placed in orbit at the second Lagrange point (L2) shown in Figure 1. The JWST team, shown in Figure 2, includes several partners in multiple locations:

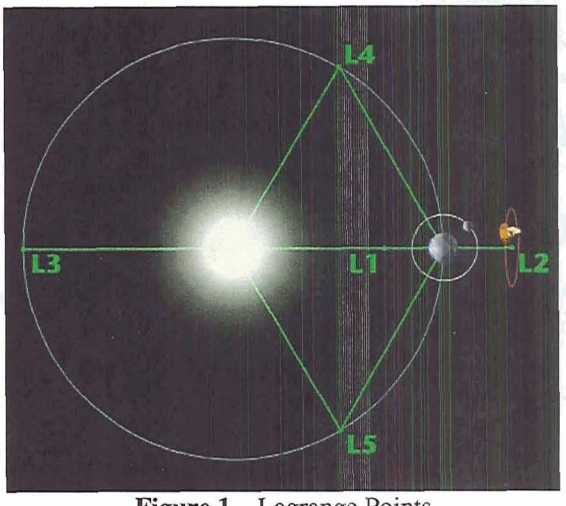

Figure 1 – Lagrange Points

- Project management is located at the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland.
- Observatory prime contactor, Northrop-Grumman Space Technologies (NGST), located in Redondo Beach, California.
- Integrated Science Instrument Module (ISIM) is the responsibility of GSFC.
- Near Infrared Camera (NIRCam) instrument is being built by the University of Arizona and Lockheed Martin, located in Palo Alto, California.
- Near Infrared Spectrograph (NIRSpec) instrument is being provided by the European Space Agency (ESA).
- Mid Infrared Instrument (MIRI) is an international collaboration between NASA JPL in California and the European Consortium (EC).

[2] IEEEAC paper #1170, Version 3, Updated 11/16/2006

- Flight Guidance Sensor (FGS) is the responsibility of the Canadian Space Agency (CSA) and will be built in Canada.

- NASA's Deep Space Network (DSN) located at JPL, Madrid, Goldstone and Canberra will provide the command, telemetry, and tracking services from launch to normal operations at L2.

- Science and Operations Center (S&OC) will be located at the Space Telescope Science Institute (STScI) in Baltimore, MD.

Figure 2 – JWST Team with Observatory Mockup

Personnel from NASA's JWST Project started designing and developing XML databases in 2002. Since JWST was one of the earliest NASA missions to use XML for a mission database, there was little historical knowledge or standards to pull from as resources in the design. As the XML database design in 2004 through 2005, the project team consulted with personnel at the Applied Physics Laboratory (APL), Johnson Space Center (JSC), European Space Agency (ESA), and the Jet Propulsion Laboratory (JPL) about XML database implementations on other space missions. The JPL and JWST teams were at the definition and implementation stages and were interested in the upcoming CCSDS and OMG standards. JPL and JWST personnel met several times to compare the two organizations' mission XML structures and content and proposed XML exchange standards.

The OMG and CCSDS approved the use of a common XML for basic command and telemetry database structures in 2006. The CCSDS standard is the XML Telemetry and Command Exchange (XTCE) and directly relates to the OMG XML database exchange version 1.1. The standard is used not only to exchange information, but also as a means to solicit database information for various spacecraft hardware providers.

The JWST Project's experience with the OMG and CCSDS standard groups has been a benefit not only for the JWST team, but also for other users wanting to learn about the standard, XML mission databases, and associated user tools. The experience of the JWST mission database encompasses the use of 24 diverse users for flight software, flight hardware, simulators, command and control systems, and trending tools. An additional challenge for JWST is the geographic diversity of the user community, with laboratories located in the United States, Europe, and Canada. The JWST project reference database (PRD) not only defines XML for the basic command and telemetry database structures, but also table definitions, pages, scripts, and other items needed for the real-time operations, archive, and planning systems.

2. JWST Database History

It was recognized that JWST database is key to the different systems exchanging information, migration of ground system components, and reducing testing needed for each database release.

At first, the choice of XML was not widely accepted. Many meetings and reviews were held to discuss the advantages and disadvantages of XML. XML was a departure from the traditional use of relational databases such as Microsoft Access or Oracle for spacecraft databases. XML was selected as it was an emerging standard.

The next key decision point was whether to structure the database as one large file or to have each command and telemetry item exist as a separate file. The JWST team chose to have each command and telemetry item exist as a separate file in order to facilitate identification of changes, reduce the regression testing needed on the databases, and to visually separate the various spacecraft PRD elements in to subdirectories as shown in Figure 3. This organization of the XML data will be discussed in later sections since the various XML database groups do it differently.

The JWST database tools allow the various users to locally modify, add and delete database items as part of the JWST flight software and hardware development. The master database is maintained at the S&OC so the users can access a configuration-managed database at any time. Each item in the database has an owner who is responsible for verifying the data item has been tested at various certification levels: by analysis, with simulators, with engineering test units, and with flight hardware units. To date, ten master databases have been created, and at least 100 databases have been created at the local sites.

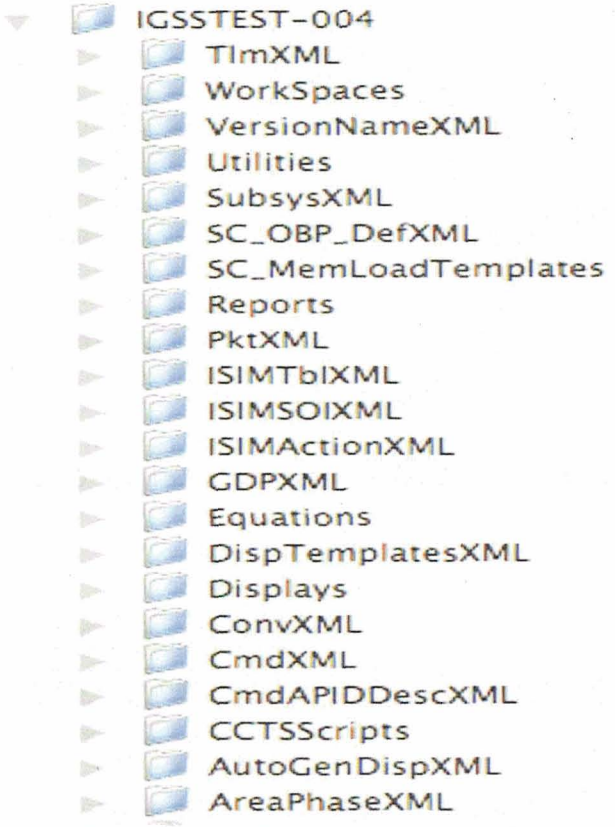

Figure 3 – JWST Database Subdirectories

It was recognized that unless the users have a quick and easy way of modifying the database, they would find alternatives that could cause the loss of configuration management and make tracking of database updates overly complex. The JWST PRD tools can build a database in less than 10 minutes that is ready to use, including verification checks. Also, a user interface (shown in Figure 4) not only allows the user to enter the data in an easy manner, but also performs initial validation checks as the user inputs the data.

The JWST database has been actively used since January 2002 in simulators and multiple ground systems, and is considered a success, due in large part to the flexibility of the XML technology being independent from any particular application. The complexity of the JWST necessitates a long development lifecycle which, taken together with the goal of ten years of operations, forces the need for a database capable of supporting many years of use. The JWST team quickly came to the conclusion that the data needed to be non-proprietary since companies and products will change over time, and may not even be available over the entire development and operations phases of the JWST mission. With XML, the data can be stored in a manner that allows it to be easily transformed, ingested, and accessible to many other systems. The JWST ground system architecture has gone through three major design additions since the beginning of its development, and with each major change, a translator is provided that updates from one version to another. With these translators, the users have seen very little impact from any of the changes.

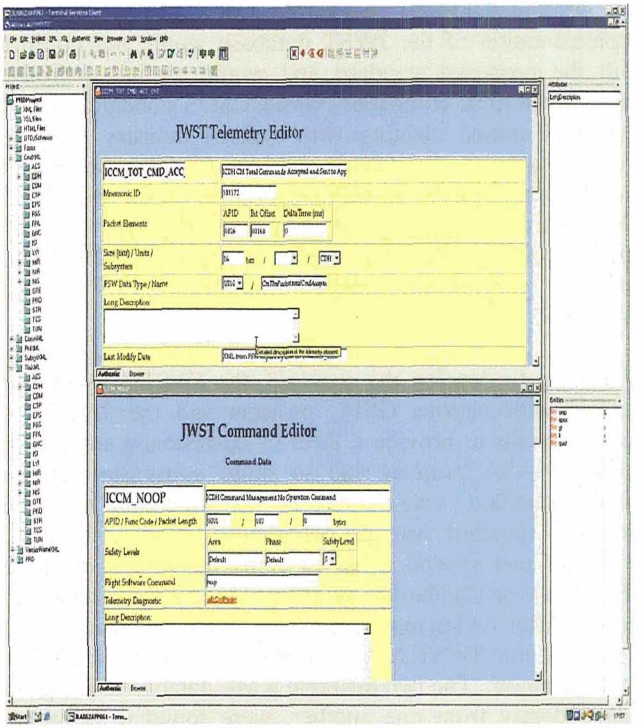

Figure 4 – JWST Database User Interface

As with any system, as the JWST XML database grows and evolves, maintaining compatibility with the tools used, the systems ingesting the data, and with the existing data in the database presents a challenge. An interface control document (ICD) for database users is used to control and manage the impact of the changes that are being implemented. The ICD defines the exchange of information with the prime contractor and other database systems that are dissimilar from the JWST XML database. The JWST Ground Segment and Operations Office implemented a change control board (CCB) for the database that includes user representatives as well as JWST system engineers, who not only evaluate the merits of a change request, but also its impact. The JWST database tools, available to all users, include a cross-referencing tool to allow a user to identify the data items affected by a proposed change prior to submission.

As the JWST database has matured in both its uses and interfaces, the JWST Project began not only to accept the use of the XML for command and telemetry definitions, but started adding XML to other systems, such as spacecraft load files, spacecraft characteristics, display pages, scripts, time correlation formulae, etc.

3. SETTING STANDARD EXPERIENCE

JWST personnel first heard of the CCSDS XML database group at a conference in 2004 when a draft of the standard was presented. JWST personnel had concerns that the implementation of the JWST database would not confirm with the proposed standard and would violate a project requirement to be compatible with CCSDS standard. JWST personnel started meeting with various industry standard groups, such as the OMG and the CCSDS Spacecraft Monitor and Control Working Group, to ensure the JWST XML maintained a level of compatibility with the draft standard and assisted in writing of the CCSDS XML standard. In 2006 the standard was approved by CCSDS and OMG.

In helping to develop the standard, the JWST Project also worked with various GSFC projects and the JPL Mars mission teams to provide a level of consistency among the various NASA projects and to build consensus for the CCSDS standard. One of the common complaints about the proposed standard was its complexity. JWST and JPL personnel met several times to come up with a common XML database standard to propose to the CCSDS standards group. After reviewing all the XML tags and structures, it turned out that JWST XML database is a subset of the JPL XML database. The two different XML databases, designed independently from one another, were found to be about 95% compatible with other on commands and 90% compatible on telemetry without any changes to either database. When some minor additions were made to the JPL XML, the compatibility increased to 100% for commands and 95% for telemetry.

After working with JPL, JWST personnel began working with OMG and CCSDS members to address the complexity of the CCSDS XML standard. To inform the users of the CCSDS standard and reduce the stress many users were feeling about the adoption of the CCSDS standard, the CCSDS working group developed the 'green book' (Figure 5) as a user's guide for the various managers and users not familiar with XML to understand the purpose and structure of the CCSDS XML database standard. Also, a 'magenta book' (Figure 6) was developed to assist the XML database developers by providing examples, alternative ways of using the CCSDS XML tags, and a means to incorporate database items that are not covered under the CCSDS standard.

From the perspective of the JWST Project, the experience of working with the CCSDS standards group was informative in learning the way standards are developed, provided a greater appreciation for the amount of time and effort it takes to get agreements on a standard, and also provided stimulating interaction with dedicated and intelligent personnel from the various international groups.

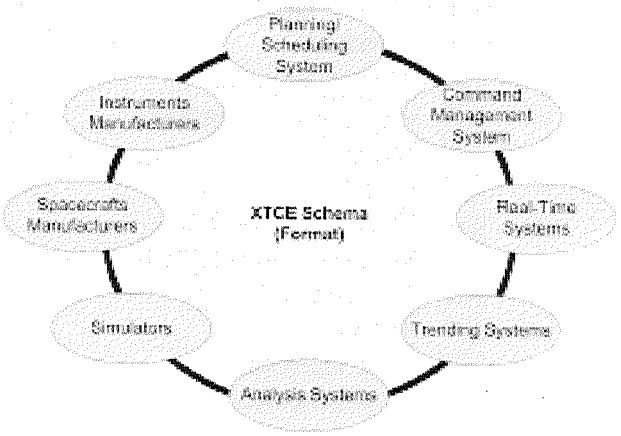

Figure 5 – CCSDS Green Book XTCE Exchange Concept

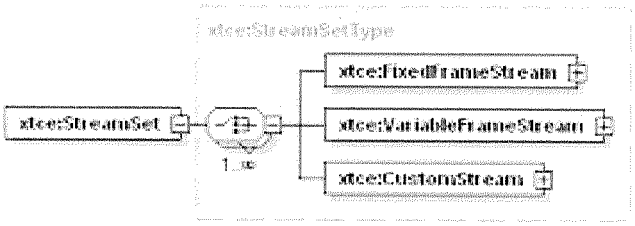

Figure 6 – CCSDS Magenta Book Sample

4. ARE ALL STANDARDS EQUAL?

All standards are not equal. The various space agencies often have guidelines on which standard group to follow and in the case of the JWST Project, there is a Level 2 requirement stating that JWST mission will be compatible with CCSDS standards. Existing ground systems were developed without regard to standards, and retrofitting would need to be addressed. For the CCSDS XML database standard, an effort was made to keep the CCSDS standards group and the OMG standards group in sync with one another. To date, this effort has been successful but challenging as the OMG standards group, funded by private industry, also supports legacy non-CCSDSS formats (such as time-division multiplexing [TDM]) and the standard incorporates more than would be normally needed for a true CCSDS mission. Another issue with standards is that industry often moves faster than the standards groups and purchasing the equipment and programs that support a 'proposed' standard has risk involved, particularly if the standard is not adopted.

The CCSDS standard for space missions has proven itself over the years. The JWST command and telemetry system, following the CCSDS standard, is out-of-the-box compatible with the DSN. Having CCSDS approve a standard for exchanging databases in XML format hopefully will provide the same advantages as the CCSDS standard for the command and telemetry system.

5. ADVANTAGES FOR JWST

The JWST PRD is compatible with the CCSDS XML database standard. The CCSDS XML database standard is a means to exchange telemetry and command databases during the development, integration and test (I&T) and operations phases of a mission. It was designed to be used for exchanging databases between spacecraft manufacturers, instrument manufacturers, various development teams, and different ground system elements. The JWST Project also plans to benefit from vendors' standardization as the JWST operational ground system is developed. The JWST ground system needs additional components such as trending tools and an engineering archive that can be easily integrated if the components utilize XTCE. The JWST Project is hoping to reap the benefits of vendors providing XTCE-compatible tools to NASA's Constellation program.

The use of the CCSDS XML will drastically reduce mission costs for several reasons. There will be no need to neither create proprietary tools to convert and edit the database between systems nor will the onerous task of converting data between the mission phases of I&T and operations need to be performed. Also, telemetry and command databases from legacy systems can be easily converted to the CCSDS XML format; JWST personnel have performed a number of these conversions.

The JWST Project is working with various suppliers of systems to incorporate XML in a more direct manner, limiting the translations needed between the JWST XML database and the JWST ground system elements, including the Eclipse® command and telemetry system. JWST's goal is to build a complete database within 10 minutes. This goal will eliminate the need for database 'short cuts' found in some I&T environments that do not follow the database configuration management process. If the database is built quickly enough, the users will be less likely to implement the 'short cuts'. Using a direct XML import, such as with the JWST Portable Spacecraft Simulator (PSS), there is no database build time. The current JWST XML database, with about 20,000 telemetry items, 1000 commands, plus equations and limit definitions, completes a build in 13 minutes. A build includes a database for the simulator, ground system, and a load for the spacecraft. The JWST spacecraft accepts a file load of the database to be used onboard for command and telemetry activities.

6. SUMMARY

The OMG and CCSDS approved the use of a common XML for basic command and telemetry database structures in 2006. The CCSDS standard is XTCE, and directly relates to the OMG XML database exchange version 1.1. The XTCE, together with other CCSDS standards, will help to reduce risk for the JWST Project and other space systems and will allow dissimilar systems, such as real-time systems, archives, simulators, and trending tools, to communicate without the need for expensive mission-specific tools. JWST is the first NASA XTCE-compatible mission. New NASA missions such as Constellation and the Landsat Data Continuity Mission (LDCM) will also be using XTCE.

For the JWST Project, the use of a XML database has clearly reduced risk; three different ground systems have been used for flight software development since 2002 and no changes in the JWST XML database were needed. Also, as new telemetry and commands have been added to the JWST XML database, the existing XML database items do not need retesting since each database item is an individual file and cannot affect any other item.

These standards are a great benefit in reducing cost as well as providing tools and products as a starting point in the mission system development. The CCSDS XTCE standard is extensible to accommodate future changes that are expected as technology and systems advance.

The JWST Project is a leader in using XML on large-scale spacecraft databases. Working with various NASA and international standards groups, the JWST Project is spreading the knowledge and experiences gained during the development of the XML database. The JWST XML database has three years of use, and with many more years to go, a lot of history is still to be written.

REFERENCES

[1.] Mather, J., 'JWST Science Goals', http://www.jwst.nasa.gov.

[2.] Mesarch, M., 'NGST Libration Point Introduction, NASA/GSFC, Greenbelt, MD, March 2003

BIOGRAPHIES

Jonathan Gal-Edd has been working at NASA since 1994. His current assignment is the Ground System, System Engineer Lead for the James Webb Space Telescope (JWST) and the Lunar Program. JWST is the follow-on program to the Hubble Space Telescope (HST), and is now entering its design and development phase. Mr. Gal-Edd was also the Ground System Manager for NEXUS, the JWST flight demonstration. Mr. Gal-Edd's previous NASA assignments include working as a member of the GSFC development team for Earth Observing Science (EOS) data and information system (EOSDIS) and serving as the Software Development and Integration Lab (SDIL) Manager for the International Space Station (ISS) program at the Johnson Space Center (JSC).

Curtis Fatig currently works as the James Webb Space Telescope Ground Segment System Engineer. Previously he was the Hubble Space Telescope Servicing Mission Test and Integration Manager. His team of engineers set up remote payload operations centers, tested the entire ground/space software and communication links used for each HST servicing mission, and tested NASA institutional upgrades affecting HST. He also supports long term development of new mission ground systems. Mr. Fatig has received NASA's Spaceflight Awareness Award, Public Service Medal, and many Achievement Awards for these efforts from GSFC, JSC and Kennedy Space Center (KSC).

Ronald A. Jones has been working for NASA/GSFC for nearly twenty years. Mr. Jones currently works for the James Webb Space Telescope (JWST) Project as the Flight System Engineer within the JWST Ground Segment and Operations Office. Mr. Jones brings to JWST his experience with re-engineering the ground systems for the TRMM, UARS and ERBS missions. Mr. Jones has also previously worked on the Earth Observing System (EOS) Aura, EOS Aqua, EOS Terra, GOES-M, GOES-L, GOES-I, EUVE, Landsat-5 and Landsat-4.

Ryan Detter is the XML Database Designer for James Webb Space Telescope Project. Mr. Detter is the author of "XML - James Webb Space Telescope Database Issues, Lessons, and Status", presented at the 2004 IEEE Aerospace Conference and "James Webb Space Telescope-Supporting Multiple Ground System Transitions in One Year", presented at the 2004 SPIE Astronomical Telescopes and Instrumentation Conference, Glasgow. Mr. Detter is a charter member of the NASA XML Working Group.