A MULTI-MISSION APPROACH TO SPACECRAFT ANALYSIS

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ABSTRACT

This paper describes the design of the JPL institutional Multi- Mission Spacecraft Analysis System (MSAS) and its initial adaptation to the Cassini mission.

Fundamental to the MSAS design is the concept of a spacecraft state and the ability to define, track and manipulate spacecraft state information with a variety of analysis tools. The processing of this state information in a consistent manner from application to application is central to automating the spacecraft analysis tasks.

The paper concludes with a discussion of possible adaptations strategies for MSAS and identifies future missions targeted for MSAS adaptation

Introduction

The new era of space exploration with it's emphasis on multiple missions of reduced size and cost present unique challenges for spacecraft analysis. Mission sets such as Discovery, Mars Surveyor Program, and New Millennium carry with them the need to develop a cost effective, reusable spacecraft analysis system that can be easily adapted from mission to mission.

In an effort to support this new frontier of spacecraft analysis JPL has developed an institutional Multi-mission Spacecraft Analysis System (MSAS).

A fundamental goal of MSAS is to provide a "systems" view and analysis capability to support Mission Operations. This requires an integrated analysis system that supports both the uplink planning/prediction and command generation and the downlink performance analysis that can be used to support both these uplink and downlink activities in a consistent manner.

This systems view embodies

1. A spacecraft state tracking capability
2. The ability to monitor the spacecraft as a system
3. Commonality of uplink and downlink functions
4. Process automation to support analysis procedures in operation

This type of design and capability then makes it possible to evolve a complete operations analysis system including the people and processes that are also consistent and compatible. Adaptation to different spacecraft design, mission objectives, and mission operations approaches now becomes a reality.

MSAS Development Process

The first customer for MSAS is the Cassini project, scheduled for launch in October of 1997. Since the requirements for many of the uplink analysis functions on Cassini would not be available until late in the development cycle a Rapid Development Methodology approach was adopted. Figure 1 captures the essence of this development approach.

RDM is characterized by the development of a set of final desired capabilities, or Final Operational Capabilities (FOCs) (not requirements). These desired capabilities are then refined into a set of requirements phased over time that can then be developed and delivered in a set of planed builds. Each build then becomes a complete software development life cycle. The FOC acts as a guide for the development of MSAS in that it represents the final evolution of the system, an ultimate goal that may well be never achieved, yet serves to focus the development.

This development methodology allows the for a system architecture and design to be developed based on the desired capabilities while allowing time for the detailed requirements to be developed. RDM is particularly well suited for the development of spacecraft ground systems where many of the requirements depend on the actual spacecraft design and are not available until late in the development cycle.

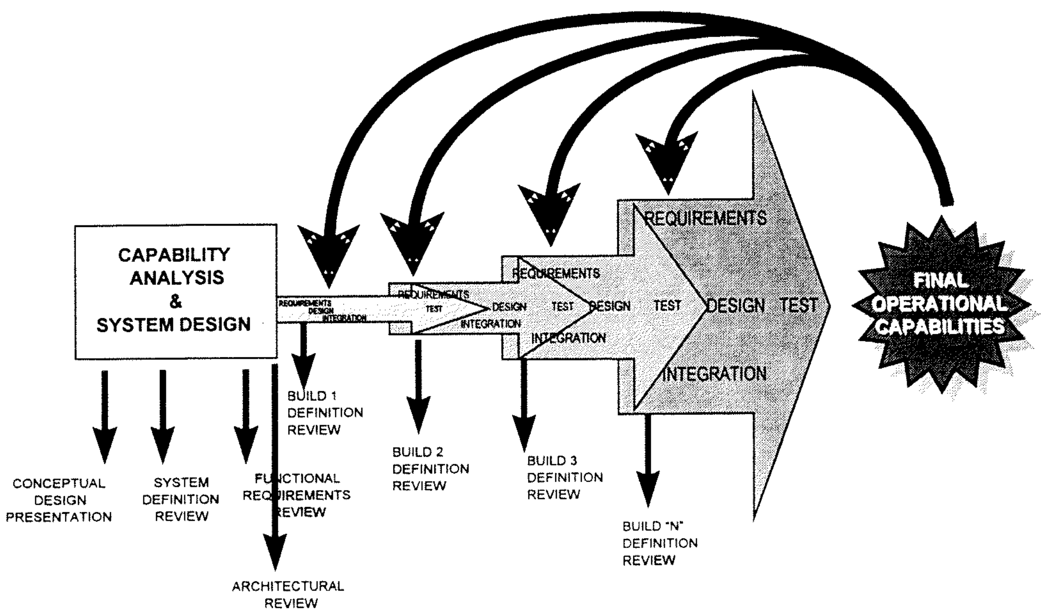

Figure 1 Rapid Development Methodology

MSAS Top Level Design and Key Integrating Elements

As stated above one of the fundamental design objectives of MSAS is to provide an integrated spacecraft analysis system that supports both uplink planning and prediction and downlink performance analysis. The analysis capabilities encompass the classical spacecraft subsystems, namely, Attitude Control, Telecom, Command & Data Handling, Power, Propulsion, Thermal. Bringing these together to operate as a system is the challenge presented to MSAS.

Figure 2 depicts the high level MSAS architectural design. The System Services and Database Services provide a core infrastructure that Uplink Prediction / Command Generation and Engineering Analysis can be built upon or adapted in order to satisfy mission specific needs.

Figure 3 shows how the MSAS architecture makes use of other elements of the JPL Advanced Multi-Mission Operations System (AMMOS). In particular, elements of the Telemetry Command and Data Management System (TC&DM) including data retrieval and the Data Object Management (DOM) system were integrated into MSAS to support the Database Services and Engineering Analysis functions of MSAS. The command generation and constraint checking modeling elements of the Sequencing System were incorporated to support the Uplink Prediction / Command Generation functions of MSAS.

Some of the key integrating elements in the MSAS design include

1. The use of common analysis software reused many times within the system.
2. The use of the State Table as a common communication data type (more on this below)
3. A front panel incorporating the Hewlett Packard Hpvue
4. A common GUI design for all applications
5. A catalogue and catalogue system for storage and retrieval of data
6. A 'Batch Mode" or command line execution capability
7. The use of Application Programming Interfaces (API's) based on abstract data types

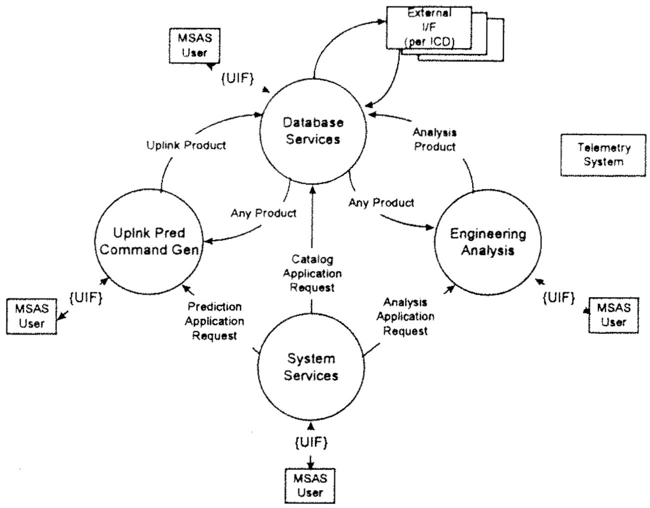

Figure 2

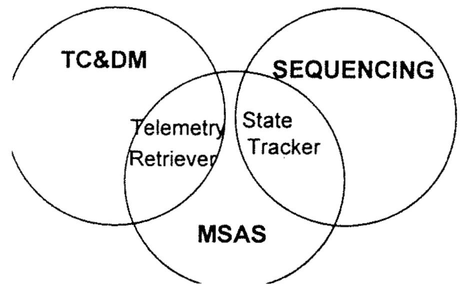

Figure 3

Spacecraft State and State Data

Central to the MSAS design is the concept of spacecraft state data and state tracking. Spacecraft state data in MSAS is represented as a State Table Format (STF) data type. This STF data type is the fundamental unit of communication between all MSAS applications. In simplified terms MSAS is an analysis environment and a set of analysis tools operating in a rich broth of spacecraft state data.

State Tables provide a common format for representing spacecraft state information as a function of time. Spacecraft state data is a collection of parameters (not necessarily telemetry) that describes the condition of the spacecraft and relevant aspects of the environment and ground system at a point in time. Included in this are predicted expectations, actual observations, and other qualitative conditions. Sources of spacecraft state data include model based predictions, spacecraft simulation results, and actual spacecraft telemetry.

Each STF produced is the result of a single analysis task, either a single execution of a prediction program or one "session" of engineering analysis operating on real or simulated telemetry. As such a State Table represents a distinct set of data over a specific time period, unique to a particular aspect of spacecraft analysis, whose scope is meaningful to the user.

A shown in Figure 4., MSAS provides a set of State Table Management tools that are part of the core infrastructure. These State Table Management tools can be used to operate consistently on any STF data generated by simulators, predictive models, or the actual spacecraft itself.. Figure 5. Depicts the continuity of spacecraft state data between the prediction, execution and analysis of spacecraft events.

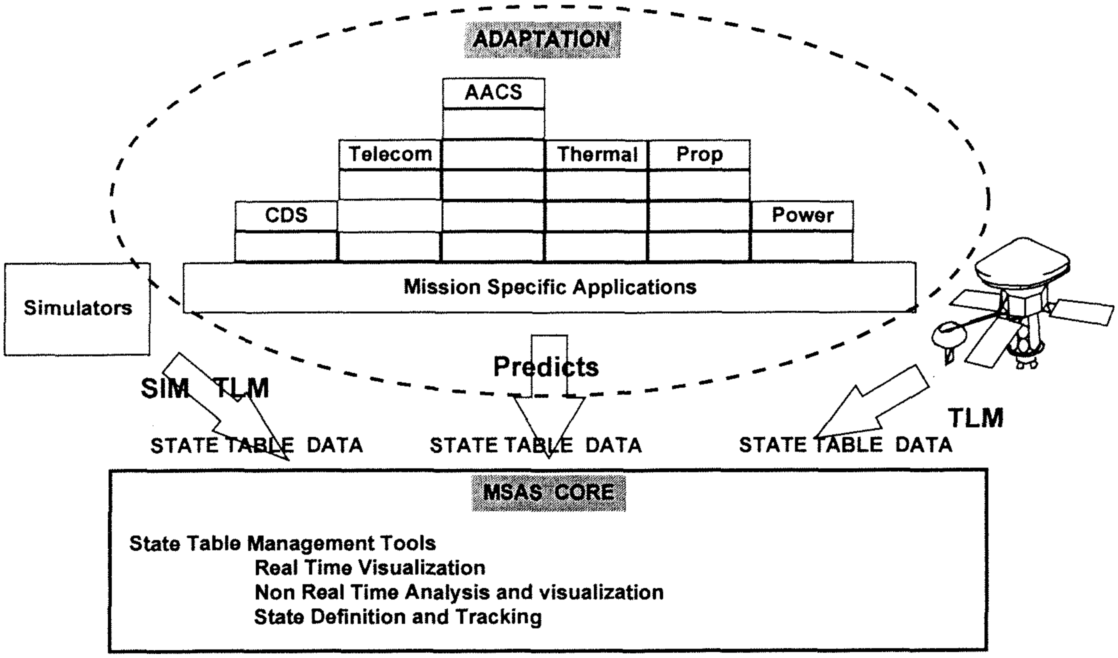

Figure 4

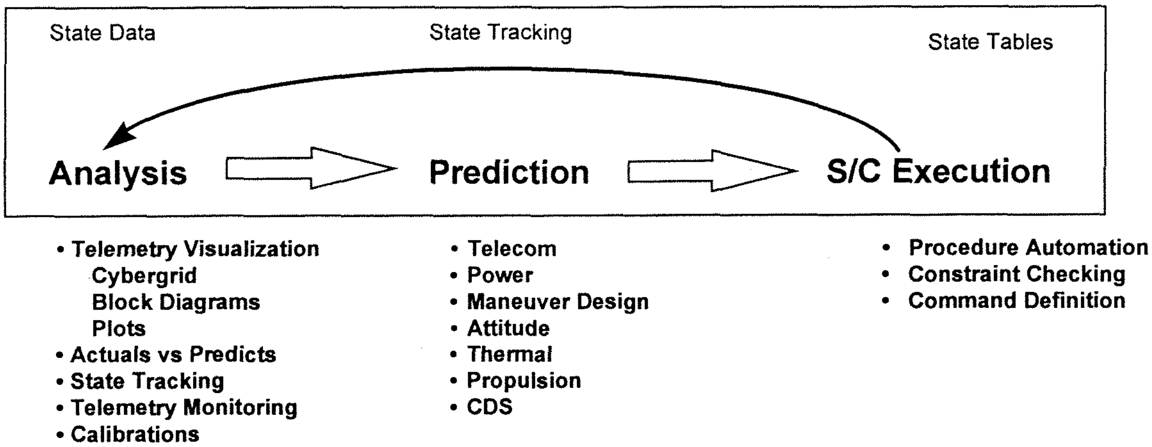

Figure 5

MSAS Core Design

As mentioned above the MSAS core provides the fundamental capability to retrieve, manipulate, and view state date and make it available to the rest of the MSAS system. Figure 6 depicts the MSAS core data management design.

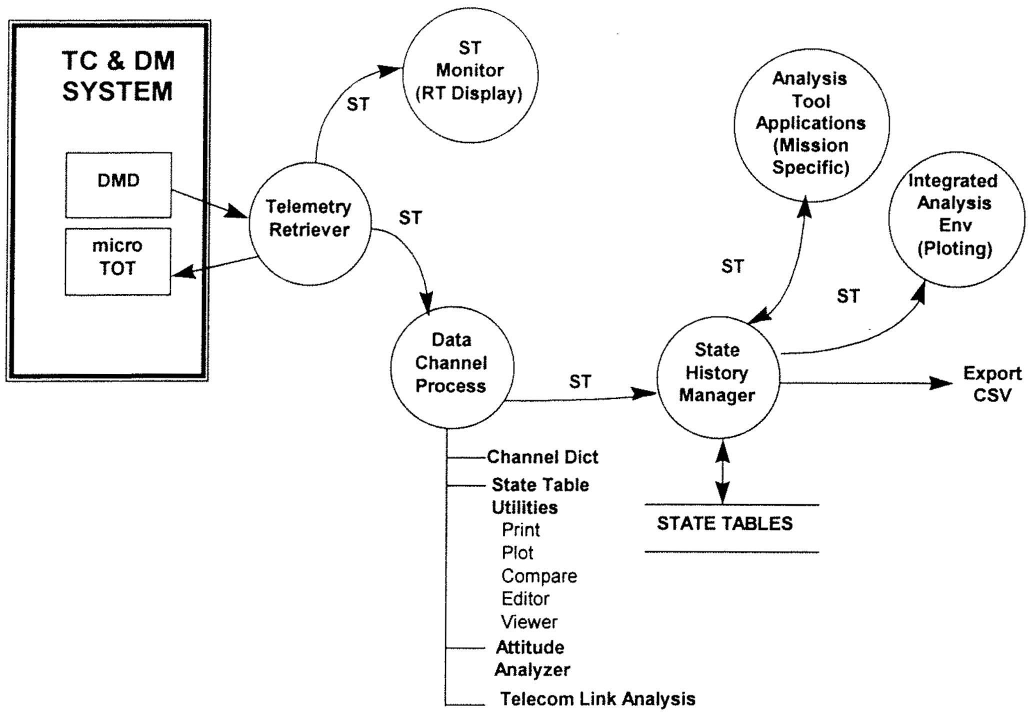

Figure 6 - MSAS Core Data Management & Display Architecture

The fundamental capabilities of the infrastructure data management and display architecture include:

Telemetry Retriever - Provides the capability to easily define and retrieve the set of telemetry data necessary to perform a particular analysis. The data is returned in State Table Format. The telemetry Retriever builds on the JPL institutional data delivery capability provided by the Telemetry, Command & Data Management System (TC&DM) and is thus directly compatible with any project using the JPL TC&DM system to deliver telemetry data.

State Table Monitor - Provides the capability to monitor State Table data in real time or to play it back through the monitor in a pseudo real time mode. This capability is rich with display types such as, plots, tabular display, block diagrams, hierarchical alarming, local and global alarm settings and a 3-D like sub-system grid to support analysis at a system level.

Integrated Analysis Environment - Provides the capability to view and manipulate State Table data in a non-real time environment through the use of standardized data analysis displays. This capability uses MATLAB as a an analysis engine and also provides the user with direct access to MATLAB for ad-hoc analysis purposes. This graphical display engine is also called directly by many of the mission specific applications

State History Manager - Provides the capability to collect, concatenate, organize, identify and otherwise manage the set or sets of state table information required for analysis purposes. The State History Manager accepts inputs from either predict applications, simulators or actual telemetry This application is built on top of an Oracle database.

Data Channel Processor - A collection of tools to analyze and manipulate telemetry data for output to the State History Manager. As a specific example the Attitude Analyzer operates on S/C attitude data (in quaternion form) and determines a best set of data over the time period of interest and then outputs it to X the State History Manager (attitude state) for use by other MSAS applications

MSAS Adaptation Approaches
The ability to adapt MSAS to different missions is achieved through the development of a set of Mission Specific Applications (MSA's), as shown in Figure 4 and again in Figure 6. These MSA's are subsystem specific and represent the analysis needs required to support the desired mission. A particular mission may develop as many or as few MSA's as requirements and resources dictate. The MSAS core provides a stable set of fundamental data management and state tracking capabilities that can be provided at a very minimal cost to even the smallest of projects. The MSA's interface with each other as well as the MSAS core via the use of State Table data.

This design of a core infrastructure, MSA's, and a common State Table data type enables a couple of different adaptation strategies.

1. Projects can contract directly with the MSAS development organization to adapt the core and develop the MSA's to a set of subsystem analysis requirements

2. Projects can accept the MSAS adapted core and use their own resources to develop the set of required MSA's. The MSA's need only adhere to the defined set of Application Programming Interfaces (API) and use of the State Table data type. This adaptation strategy should prove attractive to many of the smaller missions being proposed

Cassini Development Adaptation
The development of MSAS to support Cassini and provide the basic Multi-mission capability was accomplished over a period of four years, implemented with three builds using the RDM development approach discussed earlier.

The first build concentrated on the development of the MSAS core data management and display architecture, described above, in preparation to support the suite of mission specific subsystem applications that were to be specified later. Build 2 and Build 3 concentrated on the development of the Cassini Mission Specific Applications necessary to support the Launch and early cruise phases of the mission. Table 1 delineates the Mission Specific Applications developed for Cassini.

Table 1 - Cassini Mission Specific Applications

BUILD 2 June 1996	**BUILD 3 May 1997**
AACS	**SYSTEM**
MAIN ENGINE PREAIM	FLIGHT RULE CHECKING
MANEUVER DESIGN TOOL	FLIGHT S/W STATE TRACKING
ATTITUDE HISTORY / FORECASTER	SUBSYSTEM STATES TO BE TRACKED
INERTIAL VECTOR PROPAGATION	TRENDS / TREND ANALYSIS ALGORITHMS
BASEBODY POINTING	STATE HISTORY MANAGER
ATTITUDE CONSTRAINT CHECK	SYSTEM STATE TRACKER
SYSTEM	**AACS**
FLIGHT RULE CHECKING	CELESTIAL SPHERE DISPLAY
TELECOM	KINEMATIC POINTING PREDICTION
LINK FORECASTER / PREDICTOR	AACS PREDICT GENERATION (SIMULATOR)
LINK ANALYSIS	**THERMAL**
PROPULSION	PREDICTION MODELS
MONO & BI-PROPELLANT PERFORMANCE MODEL	
TANK PRESSURE MODEL	
MASS PROPERTIES MODEL	
THERMAL	
INTERFACE TO TRASIS / SINDA	
CDS	
SOLID STATE RECORDER MODEL	
POWER	
POWER MARGIN PREDICTION	

In total their were 72 applications (counted at the functional level) developed for Cassini consisting of about 900,000 lines of code.

Adapatation to Small Projects – DS1

Within the original development guidelines, the MSAS development was to provide a tool suite which would meet the needs of the Cassini project while providing a infrastructure which would have benefit to all missions of the future. Because of the critical relationship of the MSAS to the success of the Cassini project, heavy emphasis has been placed upon the Cassini deliverables.

The Deep Space 1 project provided a fertile proving ground for the adaptation of MSAS to a small mission. Preparing to launch in June of 98 DS1 had a definite need for a limited set of MSAS capabilities that needed to be adapted in a short period of time , less than three months. The modular design of MSAS with its core capabilities augmented by a suite of Mission Specific Applications allowed MSAS to meet the DS1 challenge.

MSAS was able to adapt to DS1 and provided the project with the capability to:

1. Define, Manage, Track, and analyze S/C states
2. Acquire S/C attitude data and generate attitude "C" kernels.

The total adaptation cost was less than $200,000 proving MSAS to be cost effective in supporting the smaller projects that make up a large portion of JPL future mission sets.

Figure 7 shows the capabilities adapted for DS1.

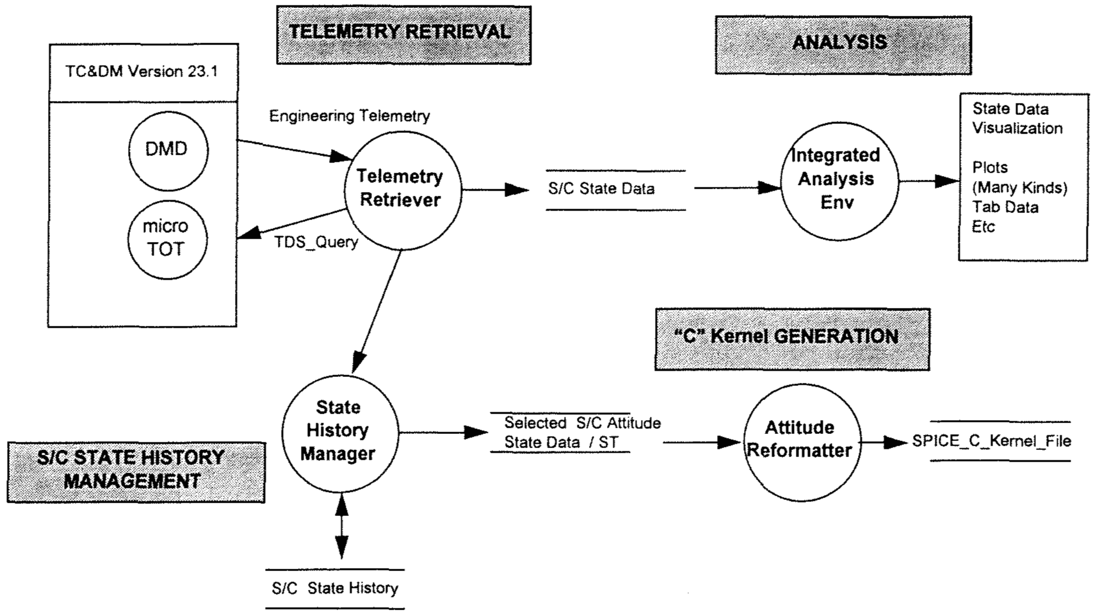

Figure 7: MSAS Adaptation for DS1

Other MSAS Adaptations

Late in 1996, a decision was made to utilize the MSAS Telecom Tool to support the telecom prediction needs of the DSN as part of the NCP Project. Other project adaptations of the Telecom tool have been initiated with the Mars Program's Mars Global Surveyor project being the first user, Lockheed Martin's Stardust mission, JPL's GEM (Galileo Extended Mission) mission, as well as New Millennium's Deep Space1 (DS-1) mission. Additional proposals are being evaluated for use of an expanded set of MSAS capabilities by SIRTF, New Millenniums' DS-1, X2000's Europa mission, and the Genesis Discovery mission.

Spacecraft analysis is not the only usage for MSAS. SIRTF is considering usage of the

MSAS for both spacecraft analysis as well as science instrument health and safety. Consideration has been made concerning its use in monitoring the DSN.

MSAS's modular approach and common data structure provides a project with the maximum flexibility to solving its spacecraft analysis needs. MSAS's modularity as well as its use of the commercial packages, MATLAB, allows a project to pick and choose and to mix and match to the maximum extent possible.

CONCLUSIONS:

JPL's Multi-mission Ground Data System has evolved since its inception in 1985 to include extensive uplink and downlink capabilities. MSAS provides that final piece in the multi-mission ground data system puzzle called AMMOS. Every indication is that the basic structure and design of the AMMOS now including MSAS continues to be available to assist missions of the future in meeting their ground data system requirements within budget and schedule constraints.

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