Enhanced Integrated Satellite Factory Test Environment

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Abstract**: Boeing Satellite Systems (BSS) is developing a forward-looking project to resolve issues of proliferation of assets and excessive non-compatible software applications and databases. This project has been in the planning stages for two and one-half years. Funding is now being allocated to procure and implement solutions that fit into the context of the Integrated Satellite Factory (ISF) Test Environment Software. The implications and benefits are far ranging. This paper will discuss the effort to design the architecture and incorporate state-of-the-art test software methodologies and products.**

I. Issues That Cost Us Money

A. Statement of Problem

This project was developed to enhance the production efficiency of the Integrated Satellite Factory (ISF), that are now required due to increasing program complexities and replication of test software solutions required to maintain spacecraft production (refer to Figure 1). Key elements to the problem are characterized below.

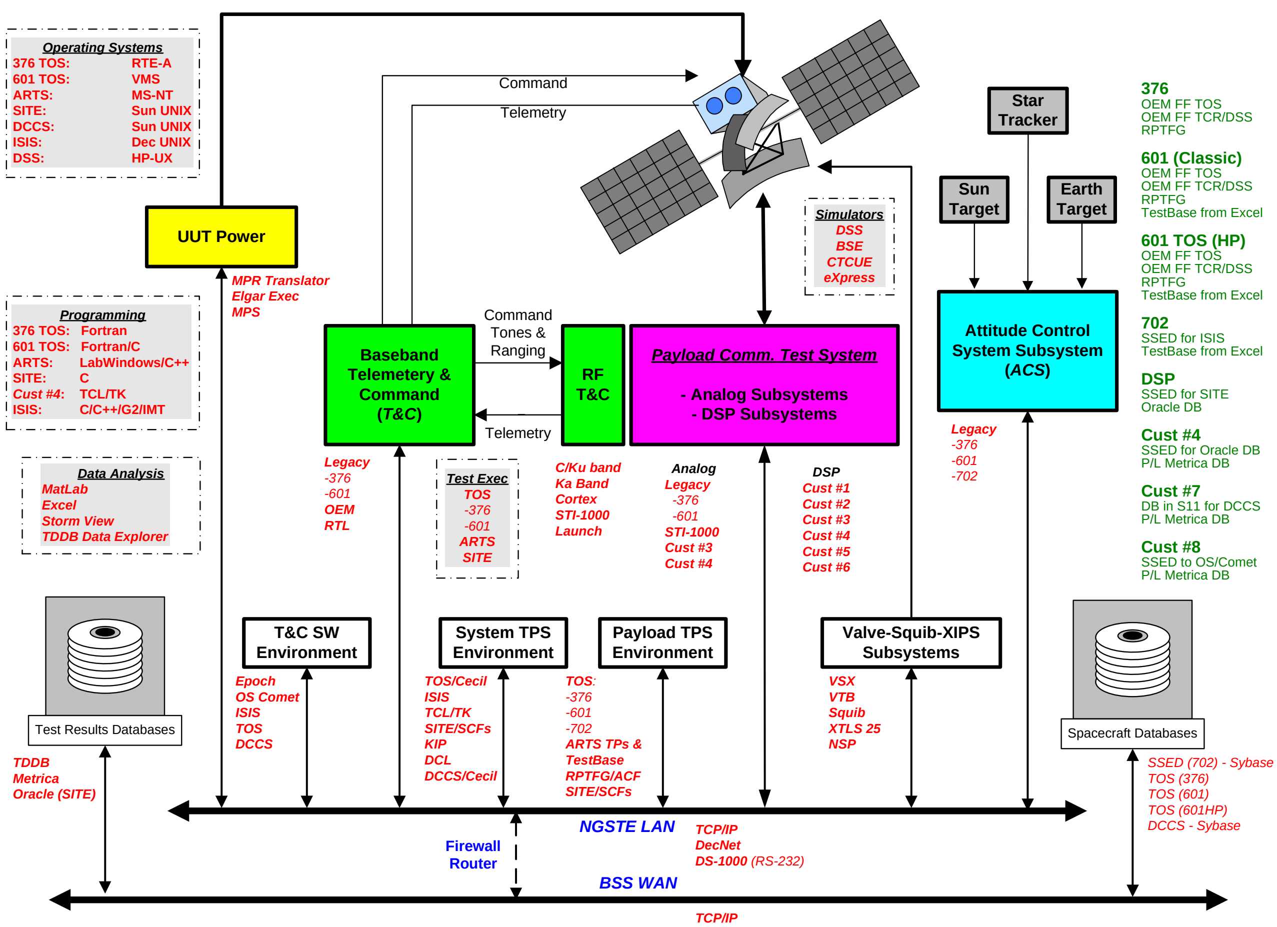

Figure 1 Current ISF Test Environment

Asset Management

The piecemeal evolution of a full-family spacecraft support environment created a large test equipment/systems asset base. The proliferation of software products strongly influenced the amount of equipment required and owned.

People Productivity

Multiple test systems and products impact productivity. Test Engineers, System Engineers and System Administrators must be familiar with many systems, which requires complex training and results in a heavy demand on the use of personnel.

Production Efficiencies

The proliferation of test solutions to support all product lines requires high licensing, operational and maintenance costs and creates a poor utilization of assets. The elevated cost of multiple product line support results from requirements for additional hardware, staffing, skill sets, training, and the impact on test-cycle time. This duplication of system functionality prevents the realization of the advantage of economies-of-scale. Additionally, maintaining older systems also demands an increase in cost. Finally, the environment in the test function is manually intensive, however with today's technology advances, BSS should now be able to transfer engineering information to, or from, the test environment electronically in an efficient manner.

II. Project Objectives

It is important to note that the scope of this project is limited to the ISF. In general, the ISF is defined to be the consolidated manufacturing entities located within Boeing's Satellite Integration and Test Complex in El Segundo, California. This area receives components and units from other BSS production entities, then perform final system assembly, integration and validation testing. This project does not encompass the design of other production and test solutions within the BSS enterprise, however, whenever practicable, it establishes standardized interfacing requirements for other enterprise entities.

In developing a project of this scope it is important to understand that a test/validation approach must align with the enterprise mission and objectives and must also take advantage of "lessons learned" from similar projects. To be relevant, new business forecasts and financial constraints must support the test environment objectives. It is critical that the implementation strategy aligns with the direction taken by BSS's business. A concise and comprehensive vision of all test-related functions is defined in the project's mission as reflected in Figure 2.

To make the project more manageable, it is focused on final production test. The following elements are critical for that goal to be achieved:

- BSS must only develop in-house solutions according to its core competencies (e.g., spacecraft testing, payload test software development, T&C communications, etc.).
- The architecture must be optimized to emphasize modularity and flexibility.
- The project must advocate the use of accepted industry standards and COTS solutions whenever possible.
- To ensure a successful implementation, BSS will strengthen strategic partnerships with key internal and external suppliers.
- The architecture must be supportable. Therefore, internal and external solution providers will be required to include sufficient support implementation and technology insertion plans to minimize impact on test teams.

III. Project Goals

During project analysis and planning stages, four focal areas were identified as being necessary to successfully complete the project in a reasonable time period. Those are standardizing telemetry and commanding (T&C) for the ISF, enhancing productivity, leveraging enterprise resources and controlling the project implementation. These are summarized in Figure 2, and the following paragraphs reference that figure as well.

A. Standardizing T&C for the ISF

To make more efficient the use of T&C in the ISF, several initiatives are being enacted. The project is focusing on solving the T&C solution first because its business case analysis showed that it would result in a rapid and significant return-on-investment (ROI). Following are brief descriptions of each part of that phase:

Standardized/Compatible Database Implementation

As shown in Figure 1 above, many database system formats are used in the ISF. A consistent, standardized database system structure is a key element required for the implementation of this project. To implement this goal, database systems will be extensible to all product lines. In general, there are several types of database systems are required for spacecraft testing in the ISF.

An important goal of the project is to ensure that there is as much standardization as possible in the design and implementation of database systems regardless of the host application. To affect this improvement, applications that require an extensive use of data need to evolve into a "database-driven" methodology, whereby data is retrieved from a standardized database system, minimizing the need for repeated modifications to test programs.

Another goal is to ensure that industry-standards are utilized whenever possible to encourage consistency and to make database development and test solution procurements cost-effective. Additionally, data file formats used for satellite testing need to be able to support compatible data exchange wherever necessary. [16]

That database system used for the T&C function is the T&C Database (TCDB). BSS is designing the TCDB to take advantage of industry-standard file transfer formats, such as created by the XML language. That way, BSS can take advantage of tools and utilities now in use in the test industry and across Boeing. The standard TCDB will be able to support both the System Test and the Ground/Mission phases. Therefore, any T&C engine specified by BSS would be able to take advantage of economies-of-scale that derives from database-driven T&C engine applications.

Standard T&C Engine

In the past, several T&C engines and methodologies were developed to test various spacecraft during the System Test phase. Most of these approaches were not compatible with one another, and could not utilize a common database system format for both System Test and Ground/Mission phases of spacecraft validation necessary for customer acceptance. This project permits the test T&C engine to be used on a variety of programs, with differences simply conveyed via the TCDB.

Update and Create Standardized T&C Test Procedures

The initial phase of T&C sub-environment implementation requires that test procedures (procs) for all bus testing (commercial, DSP and government programs) be migrated and upgraded to be consistent with the optimized, standard T&C engine and the TCDB. Additionally, all interfacing will follow the guidelines established in the Application Programming Interface (API) Interface Control Document (ICD) that will be created by BSS.

Standardize T&C Test Equipment/System Interfacing

Whenever interfacing to the Bus test equipment/systems or to the standard T&C engine is required, modifications must be made to the infrastructure to accommodate that interfacing. All interfacing will follow the guidelines established in the API ICD.

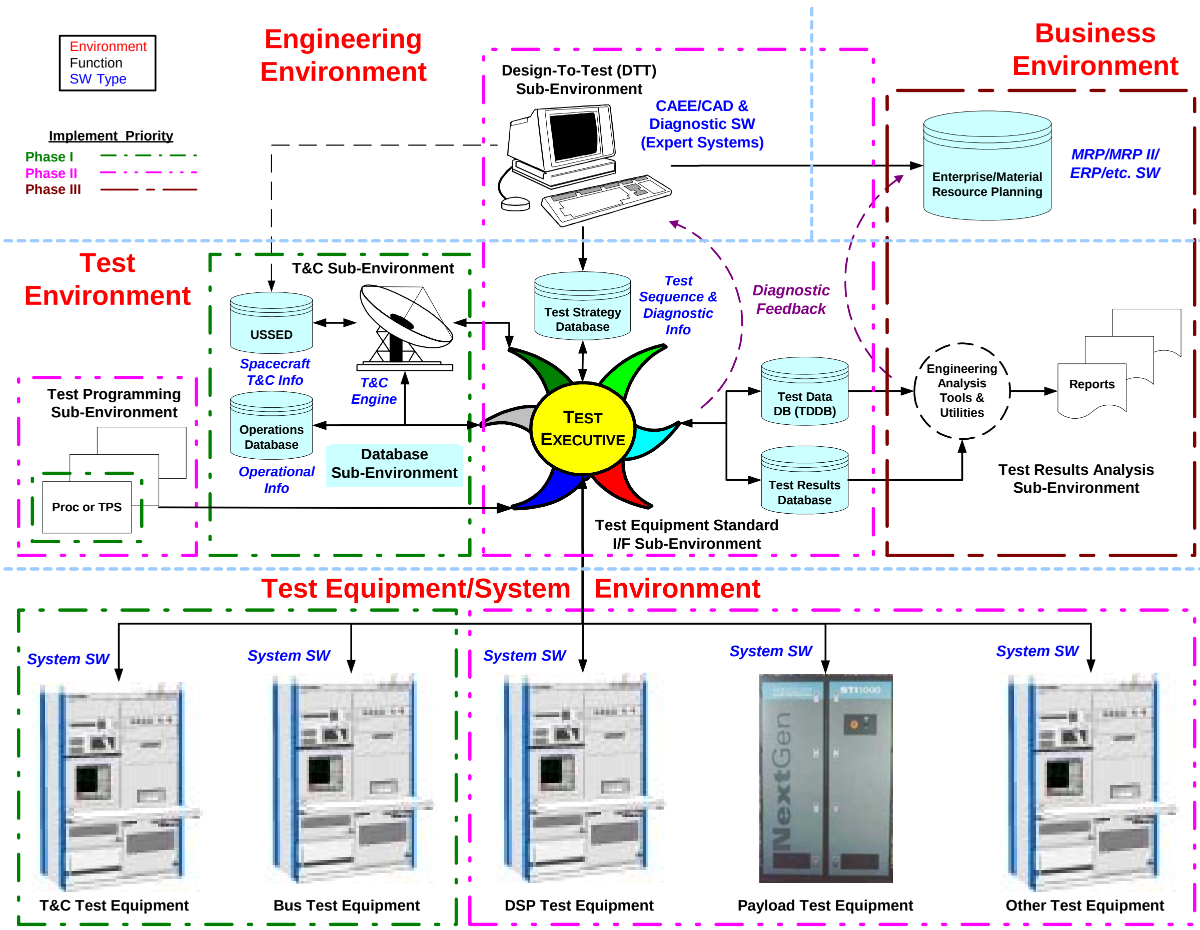

Figure 2 New ISF Test Environment Software Vision

B. *Enhance Productivity*

In an effort to enhance productivity in the ISF, several initiatives have been defined. Following are brief descriptions of each:

Test Programming Standardization

As noted earlier, there are often many versions of the same test programs used to perform the same or similar functions in the ISF. Typically, unique iterations of a test system require unique versions of a test program. This is a very inefficient programming environment and overloads the configuration management function.

A key objective of this project is to minimize the costs of test program implementation and management by using Test Program Set (TPS) methodology. [13][14][18][19] The expected result is that economic efficiencies will accrue due to reduced Test Program (TP) development, maintenance and training times. The direct benefit is a reduction in test-cycle time.

The first phase of the project focused on the development of procs for the T&C environment. The enhancement phase will develop a standardized approach for all programming used for Bus, Payload or T&C testing. Whenever possible, test programming will be developed in a standard format to take advantage of database-driven functionality.

Standardized/Compatible Test Executive Strategy

To accomplish the very challenging tasks noted above, a world-class Test Executive strategy will be implemented. The industry has struggled to define such a product, and no universal solution has yet to be defined. BSS's expects its solution to be a combination of COTS and the development of custom software. It will have the characteristics noted below.

Of primary importance, the solution must be flexible. A custom solution can be flexible, but support is often costly. The best solution is to use COTS for standard functions with provisions for customization. The solution must take advantage of "open standards". That permits products from a wide range of sources to be easily interfaced, to be modular and to be upgradeable. Test Executive systems must be able to coexist on multiple platforms to enable replacement of the legacy systems.

To elaborate further, think of *Microsoft Office*. It contains COTS components (e.g., Word, Excel, Access, PowerPoint, etc.), but unique customization can be provided via "middleware" (e.g., macros, Visual Studio.NET, etc.). For that reason, consultation with other BSS support entities is part of the pre-implementation planning.

The Test Executive(s) must be able to support the holistic vision portrayed in Figure 2. A Test Executive system is the key to enabling the various sub-environment subsystems to interconnect and work in a unified manner. To do that, the Test Executive systems must have a comprehensive toolkit. Moreover, the Test Executive(s) must be able to (1) work in various test phases, (2) communicate using BSS's communication and database protocols, (3) be able to be upgraded as test requirements change, and (4) be easily supportable.

The ISF test environment software strategy will depend upon the selection of one or more Test Executives that are the focal point of the software architecture. As it strongly impacts the ability to integrate various sub-environments, the selection of the Test Executive solution is an early focus of phase two in the project. [11][20]

Analog/DSP STE Standard Interfacing

A major hurdle in creating an efficient test environment is the proliferation of test equipment/systems. That is because most test equipment/systems have unique requirements for software that matches their operation. Today, the state-of-the-art in the test industry permits BSS to establish a new paradigm for instrumentation programming, control and maintenance. This project takes advantage of the development of standard test equipment/systems interfaces (IEEE- 488, "firewire", IVI, etc.) to the ISF test environment software. [7][13][19]

There are several benefits to the described approach. First, test equipment/systems are developed independently of the test-programming environment. That makes it easier to procure COTS solutions. Second, the ISF environment does not need to be modified to suit each new Test Equipment/System solution. Third, maintenance support of test equipment/systems becomes easier. System software provides online and offline support through use of utilities like System Functional Test (SFT) and Calibration Verification (CalVer). Finally, it becomes possible to streamline support requirements for internal or external entities.

Design-to-Test (DTT)

As a general statement, production test is functional, whereas performance test is parametric. At BSS, unit-level testing is where most parametric testing is performed, and system-level testing is primarily where functional validation is performed. Nevertheless, there are some instances where parametric and functional testing are performed at the opposite organizational level.

In the test industry, production test has two modes—specification validation testing and diagnostic analysis. To validate specifications, at the system level, in the factory, the test process compares the measurand (measurement result) to limits specified by the Test Requirement Document (TRD). The result of this process is a PASS or FAIL. If an analysis of the test results is desired, then a diagnostic mode needs to be implemented. [20]

BSS will be selecting tools or utilities that can export design data and "test vectors" into the integration and test environment. Therefore, this project will bring to fruition the link from System Engineering to Test. Using the Design-to-Test (DTT) function, BSS will be able to maximize the reuse of engineering information across all product lines and business units. To make this happen, a synergy will be developed between BSS's Design Center's test configuration tool, the DTT Functional Design/Diagnostic Modeler, the Test

Strategy Database, the Test Programming sub-environment, the ERP/MRP sub-environment and the ISF Test Executive(s).

Computer-Aided Design (CAD) and Computer-Aided Electronic Engineering (CAEE) tools for electronic or electro-mechanical products offer tremendous benefits to designers. The lack of a standard information model for transporting data between the design tools and the test and diagnostic tools, increases the cost of supporting designs throughout their product life-cycle. In the test industry, integration and test engineers sometimes create custom translators between the tools. Nevertheless, many times engineers must re-create the pertinent design data manually for input into the test and diagnostics tools. Some CAD/CAEE tools allow for the inclusion of test and diagnostics related data for use by other tools, but most of these tools target only other specific tools or include incomplete information sets.

The two basic methods of diagnostics used most often are "failure-based modeling" and "functional-based modeling". Both methods rely on a technique known as a "fault tree" analysis. This is accomplished through a process well known in the electronic test industry. [20]

- First, through a method known as "schematic capture", functional components are captured, usually graphically, to describe the electronic circuit's topology (interrelationship of components).
- Next, parametric information, known as "attributes", is assigned to each component in the topology.
- Finally, a diagnostic engine (i.e., an expert system) analyzes the parametric and topological relationships and creates the diagnostic "fault tree".

Although most diagnostic applications have been "Digital-Functional" (e.g., LASAR, CADAT, etc.), these techniques are equally applicable for analog or digital parametric and functional testing. The fault tree is developed in a diagnostic modeler and tested with the diagnostic simulator. "Functional-Based Modeling" is required for all diagnostics, but if "Failure-Based Modeling" is used then it will later be possible to generate FMECA-type analysis reports. The fault tree, validated by the Diagnostic engine, is then exported to a Test Strategy Database (TSDB) system in a format such as DiagML [5] where a Test Executive can access it. The Test Executive can then provide the diagnostic information to the appropriate payload or bus validation test systems to be used as described in the following paragraph.

The final and most beneficial aspect of the diagnostic process is Runtime Diagnostics. Until recently, diagnostic analysis was done manually. Currently, the technology exists to invoke a diagnostic analysis as soon as a failure is detected.

C. Leveraging Enterprise Resources

The final phase of the project features methodologies and process enhancements to provide better intra-enterprise connectivity.

Test Results Analysis

Today, there are methods available to BSS to analyze test results data. Therefore, this phase of the project will focus upon developing better interfaces for retrieving information from applicable database systems for post-test analysis. This may be used to better analyze data from the T&C sub-environment, or to better analyze data collected from the Integration and Test (I&T) phase, or it may mean applying new analysis tools.

MRP/ERP Linkages

Linking MPR/ERP systems into the test environment brings a more holistic solution to the test arena. Currently, it is cumbersome to share test-oriented information among different business units in the enterprise. During the final phase of the project, this area will be addressed in order to improve information exchange throughout the enterprise. [14]

D. Control Project Implementation

Statement of Work (SOW)

BSS will use a standard Statement of Work (SOW) process to control all phases of the project. The SOW will define and describe the various project phases including planning, implementation and deliverables. BSS plans to develop a specific SOW for each focused functional area instead of using one comprehensive SOW.

Phased Implementation

Due to the size and planned expense of this project, BSS is specifying a phased approach to implementation. That scenario was described earlier in this paper.

IV. Business Case Analysis

In previous years, the satellite test organization had a strong engineering emphasis. No one can argue that this mindset can produce some very interesting and sophisticated test solutions. Clearly, the challenging market conditions, the demand for higher quality of its products, and the necessity for longer on-orbit life-cycles heralded a requisite paradigm shift in the satellite manufacturing industry. As a result, BSS was forced to reexamine its test paradigms. This is not unlike the activity that was initiated by the DoD joint services through the ATS R&D IPT (ARI) initiative. [4] Following is an outline of the areas in which BSS analyzed its production and test business needs:

A. Testing operations efficiencies

Major Savings:

- Creation of one T&C database system for System Test and Ground/Mission for all product lines reduces costs for the enterprise.
- Non-Recurring Engineering (NRE) labor reduction is a benefit of software reuse.
- DTT eliminates or reduces the Test Engineer's manual test sequence database entry by at least two to nine man-months per spacecraft.

- Reduced equipment proliferation and less-complex Graphic User Interfaces (GUI) significantly improve the productivity of Test Engineers.

Savings Realized from Asset Reductions

- A direct savings will be realized by the reduction in the types of test equipment/systems required to support test.
- The high diversity of computing hardware and operating systems (e.g., HP RTE-A, Dec UNIX, Sun Solaris, Dec VMS and PC NT) will migrate toward a single compatible system with high connectivity.

Other Key Cost Savings

BSS anticipates that it can reduce its heavy reliance on outsourced tasks and multiple licensing fees once the lean production system is in place. In turn, that will enable BSS to reduce its requirement for overhead administrative support costs.

A. Financial justification

ROI Analysis

Boeing uses a very sophisticated financial tool when justifying any potential new project. That tool examines such factors as the Benefit/Cost ratio, Net Present Value (NPV), Internal Rate of Return (IRR), asset reduction benefits, costs related to upgrading capabilities, support costs and tax implications. This is the very same analysis that is being advocated in today's top business schools and lean manufacturing environments.

Leverages

As described in the business case discussion, there are several benefits that accrue from implementing the project over its duration. The following benefits permit BSS to reduce its upfront capital investment for the project by taking advantage of savings and reductions of risk:

- application software and database license savings
- common maintenance/operations for standard hardware and software systems
- efficient utilization of personnel
- asset reduction due to standard hardware and software systems
- cost-effective "strategic partnerships" with suppliers.

V. SUMMARY

As BSS developed an approach to enhancing its test environment through use software processes and tools, two important justifications became relevant—how would it be done and what would be the benefit to the Boeing enterprise. These questions have been addressed in this paper and are summarized below.

A. Improving the test environment in four ways:

- Enhance and standardize the software and hardware architecture in the factory
- Continue to leverage the use of COTS and industry standards
- Enhance productivity and reduce test cycle-time across BSS disciplines by streamlining current processes and creating new more efficient processes for design, execution and support.
- Reduce continued dependency on obsolete hardware and software

B. What benefit does this approach offer Boeing?

BSS believes that it shares common challenges that are being experienced throughout all of Boeing as well as the rest of the satellite industry. As BSS must solve these challenges to enhance its productivity and grow its business, it can then share its growing experience, expertise and knowledge as a good corporate citizen.

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