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Paper Session IV-B - Design the Support rather than Support the Design

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DESIGN THE SUPPORT
rather than
SUPPORT THE DESIGN

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ABSTRACT

A major portion (73%) of the life cycle cost of the Space Shuttle is related to operations; this paper presents recommendations for reducing that cost. Operational cost drivers at the launch site are identified, based on an examination of Shuttle operational data collected over the past two and one half years.

For decades, the launch vehicles of the Free World have been designed for performance, with very little attention given to consideration for support and/or maintainability. Examples are: multiple commodities; toxic materials; complexity; ordnance; inaccessibility; unique systems or components (lack of commonality and multiple function); Flight hardware designs drive Launch Site resources for: test operations to demonstrate hardware/software conformance to design parameters; test personnel--numbers and skill mix; ground support equipment; facilities; assembly; and maintenance. A case is made for incorporating support and maintainability criteria in the design process.

INTRODUCTION

Life Cycle Costs (LCC) of space vehicle systems have been significantly influenced by inordinately excessive operations costs, due to the fact that for decades, vehicles have been designed primarily (if not exclusively) for performance, with practically no attention given to operability. The current practice is to perform

operability analyses outside the design process, and usually "after the fact", with little or no input to major design decisions. As a result, after the hardware is shipped to the launch site, the onus is on the personnel there to "make it work". Fortunately, launch site personnel have been very successful in "making it work", but the recurring cost of operations has been excessive.

Boeing Aerospace Operations has conducted a two-and-one-half year study known as "Shuttle Ground Operations Efficiencies/Technologies Study" for the Kennedy Space Center, using the Space Shuttle Program as a source of data. (Final report of the entire study is available from the authors, as well as the library of each of the NASA centers.) Operational cost drivers were identified and recommendations were made to eliminate or reduce those items. The results of the study indicated that although it may be too late to "significantly" change the Shuttle system per se, development of launch site criteria for use by the various design agencies would be beneficial for future programs. The study began with an exhaustive examination of the prelaunch and postlanding process and provides, for the first time, a published set of launch site data prepared to a level of detail sufficiently rigorous and credible for acceptance and use by design organizations. Although it was a generally accepted premise that the Shuttle system is not as efficient as predicted, the actual figures are quite startling. The system costs more than

promised, it is not as productive, and it costs more to fly (e.g. cost per pound of payload in orbit is ten times the projected cost) (see figure 1.). A significant contributor to the greater-than-projected cost is the fact that the launch processing time is more than ten times the original design goal of 160 hours (see figure 2.). Furthermore, due to safety requirements imposed as a result of the Challenger accident, the processing time is becoming longer, rather than shorter.

The next major space vehicle on the horizon is the Advanced Launch System (ALS). The ALS Program has a stated goal of reducing the cost of launching payloads by an order of magnitude. It is a formidable goal, and will require a new way of doing business--starting with the preparation of the requirements (as defined in the Request for Proposals) to the design of the vehicle, to manufacture of the hardware, to the

activities at the launch site, as well as a new philosophy in the management of the Program.

The design of flight hardware drives launch site resources (facilities, consumables, and personnel) for: test operations to demonstrate hardware/software conformance to design parameters; test sequences and schedules; hardware configuration control practices; test personnel - numbers and skill mix; GSE (Ground Support Equipment); and facilities. The first action that must be taken to assure the incorporation of launch operation criteria in the design process is a change in mind-set: designers of future vehicles, beginning with the design concept phase, must put life cycle costs ahead of performance. We are hauling cargo via a freighter--not participating in a yacht race for the America's Cup! The place to start is in the preparation of the RPP (Request For

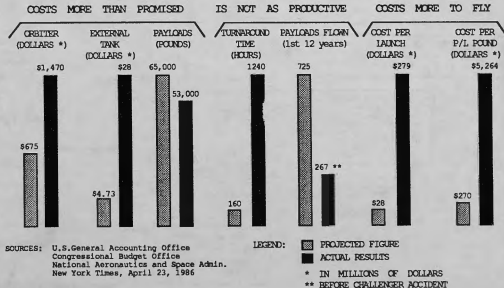


Figure 1
SHUTTLE PROJECTIONS
VS
RESULTS

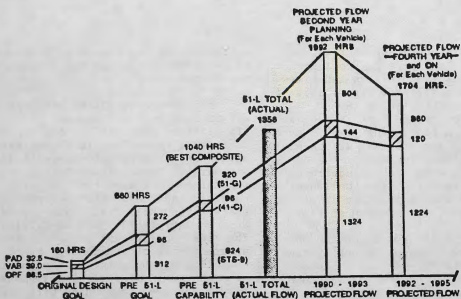


Figure 2

SHUTTLE GROUND OPERATIONS PROCESSING

Proposals), where presently, there are two prevalent practices that contribute to excessive cost (see Figure 3). One is the tendency to prescribe how the job is to be done, rather than describe the required performance of the requested product; and the other is to impose

specifications that are more stringent than required. A prospective supplier's innovative approach is frequently stifled by constraints on size, weight, performance (e.g. specific impulse), test requirements, etc.

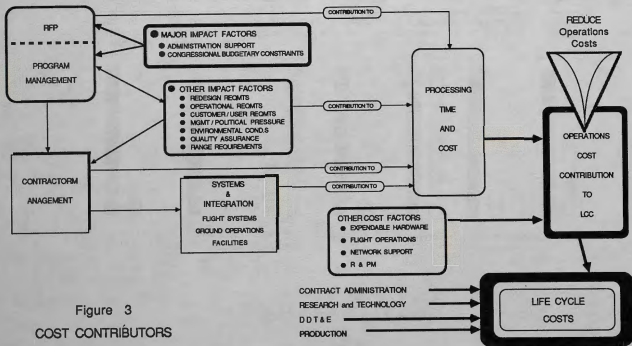


Figure 3

COST CONTRIBUTORS

Government procurement must utilize a contracting mode that establishes prime contractors with sufficient authority for system integration to define not only the operational requirements for the system, but the detailed, specific configuration requirements as well, including hardware and software. This will enable cost-effective management for the total system architecture, including hardware acceptance and sub-contractor control. Contracts that specify GFE (Government Furnished Equipment), such as engines, and dictate detailed specifications rather than the performance of the product severely limit a prime contractor's ability to achieve the optimum design, or manage the job in a cost effective manner. Most detail hardware specifications limit the contractor's capability to be innovative and cost effective. The list of applicable specifications in an RFP is usually based on "What did we do last time?". Many requirements are substantially arbitrary, and conservative requirements never get reevaluated and go away.

Major recurring operational cost drivers are instigated by decisions made in the design process. There often are design solutions that will substantially reduce those operational costs and thus reduce life cycle cost. They can be found in all elements of the vehicle: avionics and software, power, structures and materials, propulsion, as well as facilities and support equipment. A simple, robust propulsion system, for instance, is a prime candidate. Some suggested solutions are:

- 1) An integrated system, that within itself, provides the essential elements of main propulsion, orbit insertion, and attitude control. Such an integration would radically reduce the supporting operations and maintenance.
- 2) Provide Thrust Vector Control or a form of vehicle attitude control by a means other than gimballed engines. The vehicle and ground operations will be simplified by the deletion of

gimballed engines and the associated systems. Most gimbal actuators are driven by hydraulic systems, which are inherently complex and plagued with Operation and Maintenance (O&M) and GSE activities. They require extensive check-out, are subject to leakage, and require a "standing army" of engineers and technical specialists. If gimbaling cannot be eliminated, use an alternate actuation system such as electro-mechanical devices.

3) A vehicle design that uses only one set of commodities (oxidizer and fuel), will simplify propellant procurement, transport, storage, pumping, safety equipment, etc. The Shuttle has five propellant components. Each of the associated ground systems requires its own operational procedures; its little army of engineers, technicians, safety personnel, expensive, hazardous facilities, and specialized GSE.

4) Avoid the use of hypergols for propulsion or APU (Auxiliary Power Unit) systems. A very significant quantity of non-productive manhours is consumed during each Shuttle launch processing flow for "area clear" during hazardous "opening", entry, or operation of these systems. There is also a snowball effect on facilities and O&M requirements for special ventilation, scrubbers and a multitude of safety equipment, including a small army specially trained to do its job in SCAPE (Self-Contained Atmospheric Protective Ensemble) suits.

Another significant conclusion in the study was that the increased application of automation to evaluate systems and conduct operations will provide several means for reducing launch operations costs and will provide benefits such as:

- (1) Increase the speed of the total checkout (reduce time -in-flow requirements).
- (2) Reduce manpower requirements

- (3) Reduce the possibility of human error.
- (4) Minimize documentation changes (test-to-test consistency) and increase the potential for reducing the time required for manual tasks as a result of the "learning curve" process

The area that will benefit most from the incorporation of additional automation techniques is "Test and Checkout". Improvements that should be provided in that area include:

- (1) 100% Computer Connectivity. All computers associated in any manner with operations, flight or ground, must maintain complete connectivity (bridging). The large amount of data required to support and maintain an operational system requires efficiency in its acquisition, processing, and use. Paperwork, including its development, maintenance, use, and control, currently consumes a large portion of the operations budget. A significant reduction in Life Cycle Cost can be achieved by intensive application and use of automation to reduce the amount of paperwork required to process the vehicle.

- (2) Automated Electronics. Operational and support procedures should be based and maintained on computers. Automation of the OMI (Operations and Maintenance Instructions) process, including development, maintenance, and use of OMIs, provides improvements in costs, discipline of usage, verification of performance data, and compliance with configuration changes.

- (3) Automatic Verification of Test Requirements. An automated testing system would verify and document the satisfaction of approved test requirements and would automatically correlate the verification with the completion of the associated procedures. A truly paperless, automated OMI would control the sequence execution and scheduling systems that track the completion of each procedure and task. As each task is completed without error, or

after maintenance and retest is accomplished, all associated test requirements would be automatically verified.

- (4) Multiflow Redundant Avionics Suite (MFRAS). To support mandated system availability, avionics systems must provide for higher reliability by providing several levels of fault tolerance through redundancy. Future systems could be designed such that they can be dynamically configured to provide for more than one function. Should an allocated processor or subsystem fail, another processor with a lesser priority function would be assigned to reconfigure and perform the function of the failed processor.

- (5) Returned Vehicle Self-test for Reflight. After flight, the returned vehicle should have sufficient self-test capability to verify its readiness for the next flight or provide problem isolation down to the LRU (Line Replaceable Unit) level. During flight, BIT identifies and records anomalies. After landing, BIT/BITE isolates the problem to the LRU level. After replacement of the faulty component(s), BIT retests the system and verifies flight readiness.

- (6) Autonomous Guidance Navigation and Control (GN&C). Onboard BIT/BITE of GN&C can eliminate, simplify or reduce the requirements for ground support operations. The use of computerized electronics similar to that in the Boeing 757/767 or advanced military aircraft would provide self-test and fault isolation to the LRU level of system elements. The design should include the concern for easy accessibility of components and should provide the capability to replace circuit boards without system shutdown.

- (7) Software Commonality. The vehicle should utilize the same set of software for ground operation test, integration, and flight operations. Current Shuttle ground operations are accomplished with several different programs, depending

on the stage of testing. Consequently, manhours are consumed reloading the main computer memory. For example; it requires 14 hours to accomplish the final prelaunch load.

The avionics should be designed as a distributed system with one or more high speed buses providing communication between subsystems as required. Each subsystem should be capable of autonomous ground operations by commanding the system to a stand-alone mode. In this mode all required external stimuli would be sufficiently simulated by the subsystem to verify its proper operation. This would enable each subsystem to be tested independently of the operational state of the other systems. When all ground testing and vehicle integration is complete, each subsystem would be commanded to the flight mode without additional reloading of the flight computers.

The achievement of the stated goal of reducing the cost of payload to orbit by an order of magnitude will require a change in "mind-set" on the part of each person on the Project Team. It must start at the top with a leader with the imagination and fortitude to "buck the tide". Albert Einstein wrote: "Imagination is more important than knowledge, it is a preview of coming attractions." James Webb, the first Administrator of NASA was such a leader. In the October, 1988 issue of Government Executive, Elmer Staats wrote that when Webb was first approached by Vice President Johnson and President Kennedy about accepting the position of NASA Administrator, he demurred on the grounds that he was not a scientist or engineer. However, after receiving an expression of confidence from President Kennedy, he accepted. Later he (Webb) wrote: "The key executive must be able and willing to adjust his own work and the work of those associated with him to the needs of the totality. He must be able and willing to forego use of his position for 'hobby shopping' in accord

with his own interests and his own individual judgments about what is most important. He must be willing, when necessary, to take actions calculated to get the total job done and to assume responsibility for decisions and judgments of others, even when he would himself have it otherwise."

Fortunately, opportunity exists today to significantly improve the process of considering system supportability requirements while designing a system that meets performance criteria. To make the most of these opportunities requires two major changes in our way of doing business:

(1) Change the "mind set" of all of us in the space program to make (or accept) compromises in performance if they contribute to a reduction in LCC.

(2) Provide more effort (dollars) up front in the early design phase to supportable and maintainable, robust systems.

The objective should be Design the Support along with the rest of the system. Eliminate the need to Support the Design with large groups of people during the recurring prelaunch processing, launch operations, vehicle recovery, and refurbishment activities.

Sufficient data are available from previous programs to help the designers solve many of the operational problems. Use of that data to effectively reduce recurring Operational Costs would require that all levels of Program management (Government and Industry) put in place the organizational mechanisms to place Operational Requirements on an equal or higher level than Performance Requirements in the interest of reducing those costs.

THIS IS A CHALLENGE FOR THE ENTIRE INDUSTRY FOR THE NEXT GENERATION(S) OF SPACE SYSTEMS -- BOOSTERS, UPPER STAGES, AND PAYLOADS.