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Decreasing the Cost of Spacecraft Processing

A Primer for Smart Launch Site Processing Planning for New Designers

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Introduction

Lowering the cost of access to space is one of the largest issues currently facing satellite and launch vehicle manufacturers. The proliferation of commercial space activity has made the economics of space a central issue in the boardrooms of payload and booster design companies around the world. Clearly, the days of large space projects with huge overheads are gone. The "cheaper, better, faster" scheme has arrived and the previously prescribed ways of building and launching spacecraft must be replaced with more efficient and streamlined practices. The new spacecraft design engineer must become familiar with techniques for smart, affordable satellite program engineering and development.

This paper focuses on spacecraft and payload design for efficient and low-cost launch site processing. An important assumption here is the use of a modern processing facility, one that is optimized for satellites designed for low-cost operations at the launch site. A typical spacecraft processing flow includes operations in three different areas: non-hazardous, hazardous, and on-pad checkout activities. Smart design practices in each of these areas can reduce the time span for payload processing and thus lower costs throughout the operation. A state-of-the-art processing facility requires a large expenditure of funds up front, but will recoup those dollars over the useful life of the facility and the satellites processing through it. It is the purpose of this paper to propose a series of design requirements for any satellite application, be it a series intended as part of a constellation (e.g. GPS) or a one-time mission (e.g. Cassini). New spacecraft designers must be able to think past the boundaries of the satellite bus and its payload and determine how the system will be readied for launch at the launch base. This requires a systems approach to design, one based on a rigorous requirements definition process and regular interaction with the engineers who will perform the processing operations prior to launch. Most engineers are not schooled in designing for ease of processing - they are taught how to create a satellite to perform a certain mission. This paper aims to highlight efficient and simple launch site processing activities. While not serving as an all-inclusive checklist for smart processing, this paper tries to get the new spacecraft engineer to start thinking about streamlining launch base activities.

Why stress launch site processing as one means to lower the overall cost of spacecraft design and access to space? In a satellite program involving the launch of a number of platforms (e.g. a communications constellation), the launch base processing crew becomes essentially a permanent party, requiring housing, transportation, and living expenses over a long period. Reducing the processing time of a commercial communications satellite from three to one month can save millions over the life of the program. In addition, simplifying the processing activities reduces the risk of hardware damage. Removing and replacing components at the launch base is not only expensive because of the need for the new component, but also due to the extra time required for the replacement operation. Depending on the type of subsystem involved, certain operations may have to be redone to verify their integration with the new component. The more times the satellite has to be touched, the more likely something will be broken, requiring costly repairs and schedule delays. This remains true even for "one shot" satellites like astronomical observatories and planetary probes.

A Typical Flow - Off-Pad Processing

Launch processing begins with shipment of the spacecraft to the launch site. This is usually by aircraft, a C-141 or C-5 transport plane for large payloads. The spacecraft is boxed in a special transfer container at the factory. It may be partially disassembled for ease of movement. A GN2 purge is normally initialized inside the container to ensure a continuously dry atmosphere free from moisture and particulate. An impactograph is installed on the box for analysis at the launch site to determine whether or not the spacecraft endured any unreasonable shocks during the transport process. Temperature probes and humidity sensors are also installed for atmospheric measurements inside the box. It is necessary for the spacecraft design team to remain cognizant of the interior dimensions of the transport aircraft. The shipping container must fit inside the aircraft with a minimum of extra effort required by the load crew during the transport operation. The team should attempt to keep the spacecraft design such that disassembly for transport is not required. This is not always feasible, but if possible, does eliminate a series of operations at the launch site to reassemble and test the completed satellite.

Prior to shipment of the spacecraft to the launch site, a processing facility certification is completed. This procedure reviews all facility systems and ensures readiness for receiving the payload when it arrives. This also includes set-up and calibration of all Electronic Aerospace Ground Equipment (EAGE) and Mechanical Aerospace Ground Equipment (MAGE) required in the processing cycles. For facilities used at Air Force installations (e.g. Cape Canaveral and Vandenberg AFB), the appropriate Range Safety directorate will be required to review and concur with this facility certification.

Once the shipment arrives at the launch site processing facility, the spacecraft is unpacked and checked thoroughly for damage. This procedure is known as “receive and inspect”. Environmental data from inside the box is reviewed for any out-of-spec instances and analyzed as necessary. The next phase is nonhazardous processing, which involves a complete spacecraft systems checkout and communications tests between the payload and the orbital operations center. A leak test of the spacecraft propulsion system and fluid lines is also completed during this time. The systems checkout is devised to exercise all subsystems in an integrated manner and operate them just as they will be used on-orbit. The typical spacecraft subsystems include communications, propulsion, electrical, guidance/navigation & control, thermal control, deploy mechanisms, and the mission-unique payload. Various EAGE validations are also accomplished in preparation for use at the launch pad during integrated checkouts with the booster.

Once these tests are completed, the spacecraft undergoes the hazardous portion of the processing operations. This includes lifting and mating the spacecraft to the payload adapter, mating the spacecraft to the upper stage (if there is one), fueling and pressurization procedures, and installing separation ordnance. When these are completed, the spacecraft is encapsulated in the payload fairing and secured to the ground transport vehicle for movement to the launch pad.

Transporting the encapsulated spacecraft to the pad is the primary difference between off-pad and on-pad processing. In an on-pad operation, the spacecraft is taken from the transport aircraft directly to a clean room on the launch tower for receive and inspection activities, and nonhazardous and hazardous procedures are then carried out right there at the pad. With an off-pad scheme, the encapsulated spacecraft is lifted to the top of the tower and mated to the launch vehicle. Final communications checks are completed using a T-0 umbilical or a re-radiating antenna. Flight termination systems checks are also performed, in addition to continuity tests between the spacecraft and the launch vehicle. Depending upon the type of launch vehicle used, a practice countdown, including establishing uplink and downlink with the spacecraft, is conducted prior to booster fueling and pressurization activities, leading up to launch day activities.

Design Considerations for Payload Processing - An Overview

The following checklists are meant for Phase 0 studies involving spacecraft design tradeoffs and early mission planning initiatives. The new spacecraft design engineer should view these as minimum processing requirements that must be addressed in designing the satellite for ease of processing. These are not all-inclusive, but general guidelines that can save time and money in a typical payload processing operation when taken into account early in the design cycle.

- Easy spacecraft access and processing
    - - Fueling and pressurization ports, fill and drain valves, etc.
    - - GHe leak check ports
    - - Electrical connections for spacecraft integrated systems checkout
    - - Ordnance installation
    - - GN2 purge ports
        - - - Minimize use of GN2 as much as possible
    - - Power generation trades (solar versus nuclear)
    - - Simple deployables mechanisms (e.g. springs)
    - - Modular components for easy replacement
    - - Use of flight-proven, time-tested components with experience bases
    - - Accessible hoist points
    - - Pre-launch telemetry T-0 disconnect or re-radiating antenna

- Integrated* Processing Facility design considerations
    - - Class 10,000 clean room capability (minimum)
    - - Environmental controls (heating and cooling)
    - - Blast walls compliant with Range Safety requirements
    - - Hazardous commodity handling and storage apparatus (fuel, ox, etc.)
    - - Aspirator systems for cleanup operations
    - - Filter systems for ox and fuel venting
    - - Storage areas for spacecraft, EAGE, MAGE, etc.
    - - Adequate spacecraft grounding system
    - - Control room for payload telemetry evaluation during integrated systems checkout
    - - Airlocks and air showers
    - - Personnel rooms for SCAPE suit-up and storage
    - - Hazardous processing cell(s) compliant with Range Safety requirements
    - - Uninterruptable Power Supply (UPS)
    - - Adequate lifting devices for movement and mate operations (cranes, lift slings, etc.)
    - - Security system for payload protection
    - - Convenient location relative to launch pad

*Integrated - one facility designed for both nonhazardous and hazardous operations

Most payload processing facilities have many (or, in a very few cases, all) of the features listed above. The point here is to design the spacecraft to take advantage of as many of these as possible, especially when considering the number and type of personnel required to process the spacecraft at the launch site. Cost savings at this level can be greatly influenced by keeping the size of the processing crew to a minimum. This is done by providing the payload personnel with the right facility tools and equipment to complete each spacecraft activity efficiently and in the shortest amount of time.

It is not uncommon for a processing procedure to take longer to set up and prepare for than actually performing the activity and recording the results. It is therefore desirable to simplify the procedures as much as possible. This reduces the risk of human error and the possibility of equipment failure. In addition, large dollar savings can be realized by using a processing facility that is designed and certified for both nonhazardous and hazardous operations. This eliminates an entire transport operation from one building to another for hazardous processing. At the completion of integrated systems testing, the spacecraft is simply wheeled from one payload cell to another, in the same facility, for fueling and pressurization activities. The need for lifting, bagging, securing to a ground transport vehicle, establishing and maintaining the environment inside the bag, and moving the spacecraft to another building is thus eliminated totally. A schedule savings of two to three days, not to mention loss of a fairly high risk factor, can be easily gained in this scenario.

On-Pad vs. Off-Pad Processing - A Discussion

Different launch vehicles approach payload processing in different ways. Some boosters allow the satellite payload to be processed “off-pad”, in a dedicated payload processing facility. Conversely, other launch vehicles require “on-pad” processing of the spacecraft. Which is better, or, more to the point for this paper, which is lower in cost? It is impossible to say precisely which method is cheaper based on actual cost comparison, since most payloads don’t release cost figures for such activities. However, from a pure “ease of processing” standpoint, off-pad is more efficient in terms of easier scheduling, relaxed personnel requirements, and more streamlined procedures. Without a booster sitting below the satellite, payload processing can be handled far easier inside a dedicated facility. The impact on payload processing operations is clear: schedules can be made with only spacecraft needs taken into account - booster operations are not a player; personnel are dedicated to the spacecraft and are not required to share the pad with booster personnel; and procedures do not have to take into account booster activities and precautions.

It can be argued, however, that the cost of a dedicated processing facility, off-pad, is an unnecessary burden when the launch pad can be outfitted with a clean room enclosure to perform the same function. While it is true that such an on-pad facility can be built and successfully utilized, its value and long-range economic advantage may wither under close scrutiny, especially for commercial payloads. In situations where spacecraft components must be replaced prior to encapsulation, due to malfunction or some other calamity, it is infinitely preferable to execute such a “swap-out” away from the booster. Indeed, such was the case with the recent NASA Cassini spacecraft when its Huygens probe had to be demated. This operation was deemed too involved to be completed on the pad, so the entire spacecraft stack was removed from the launch vehicle and returned to its processing facility, off-pad. In this manner, using an area where there is plenty of room for opening access panels, hooking up electrical and mechanical equipment, and positioning new equipment for checkout and installation is far easier than trying to work around equipment and activities solely related to the launch vehicle. It eliminates the many precautions required when working around (and on top of) the launch vehicle, as well as the risk of damage to the booster. In general, the time savings alone from not having to rearrange booster schedules to accommodate payload work make the dedicated, off-pad processing facility a smart investment.

It can be argued, however, that on-pad processing makes economic sense in that a dedicated off-pad processing facility is not required, thus eliminating the overhead required to keep such a building operational. Unless the satellite is a military project, where security requirements are greater than for commercial payloads, the benefits of processing away from the pad are worth the extra investment.

Spacecraft Design Phase Philosophy

It must be a given that, starting from a blank sheet of paper, the satellite will be designed with low-cost, efficient processing operations in mind. History shows that it is enormously cheaper to construct the spacecraft with the required "ease of access" options listed above right from the start, rather than changing the design midstream. This makes the traditional requirements review process more critical than ever, because it sets the stage for program savings down the road. And, in order to develop the requirements so as to support efficient launch site processing, it is imperative to cast a critical eye on current processing procedures and incorporate lessons learned from other projects.

Use of pathfinder operations at the launch site is an extremely valuable method of exercising processing activities without endangering flight hardware. In some cases nothing more than plywood mockups are used to check positioning inside processing cells and entry angles to various access panels. Such testing must be completed prior to the preliminary design review in order to allow changes to be made before the design is frozen. The majority of satellite programs that encounter cost-overruns during design are those that did not properly account for specific mission and processing requirements early in the design phase.

Pathfinders also serve an important role in crew training. A satellite processing program can enjoy a reduction in the number of hours required to complete individual processing operations anywhere from 45 to 60 percent; more if it is an ongoing program, rather than a two or three spacecraft project. Confident crews translate into operations completed on-time with no errors and no rework, which means less money over the life of the project.

In addition, spacecraft designers must not forget that processing crews will be wearing clean room garments and environmental suits when performing certain operations on the satellite. Fueling activities involving the use of such commodities as hydrazine and nitrogen tetroxide are extremely hazardous and require personnel to wear protective suits with self-contained air systems. The designer must keep in mind the special vision and maneuvering constraints imposed by such suits. Fuel ports and transfer apparatus must fit within gloved hands and be within easy reach on the spacecraft. In other words, the satellite must be designed with the processing crews in mind through a thorough understanding of human factors. Easy access means simpler and quicker completion of launch base processing activities.

Another design requirement that will decrease cost over the life of a program is the use of common payload-booster interfaces. The spacecraft must be designed to accommodate either the standard interface used by the launch vehicle or a common interface adaptable to a series of boosters. Changes in spacecraft design requiring interface changes are unacceptable to most programs. This also, more often than not, adds more complexity to the interface mechanism, in addition to pushing up costs. The smart design engineer will keep a constant payload interface over the lifetime of the program.

Finally, it is imperative for the design engineer to develop and solidify launch base test requirements with verifiable results. Each spacecraft readiness test, be it a mechanical boom deployment, an ordnance signal firing exercise, or a communications system checkout, must have clearly defined criteria for pass and fail. Running unplanned tests on subsystems at the launch site is expensive and time-consuming. It also poses extra risk to the vehicle from additional handling and component wear. Redlines for subsystem specifications must be based on appropriate margins and clearly indicate to processing engineers whether or not the satellite is responding properly and ready for the next phase. There is no room for ambiguous data at the launch site.

Conclusion

An often times overlooked and underestimated aspect of satellite design, launch base processing is nonetheless a critical, and expensive, part of putting a spacecraft into orbit. It is not typically stressed in design courses and tends to be rooted in antiquated procedures that are difficult and hazardous to perform. Simplifying these procedures through careful attention during spacecraft early design will yield surprising savings at the launch site. Additionally, making use of off-pad integrated processing facilities lessens the likelihood of schedule delays due to booster activities and provides a “safe haven” for spacecraft activities. The time to start factoring in the processing equation is from day one, from the blank sheet of paper during the initial trade studies. The new spacecraft design engineer must evaluate the satellite design from a processing standpoint in all subsystems, throughout all phases of development. A spacecraft tightly integrated with the launch base operations team will sail through checkout and readiness activities in a minimal amount of time and save precious program dollars in the process.