Packaging Multiple Small Satellites On a Single Launch Vehicle

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Abstract

This paper presents a survey of packaging methods applied to multiple satellites launched on a single launch vehicle. The launch vehicle is a significant expense in most satellite programs and can equal or exceed the payload costs. Efficiency is achieved by fully utilizing launch vehicle payload capacity and by using larger, lower cost per mass to orbit boosters. A single launcher placing several satellites on orbit saves time and money. The economies of scale gained by launching several payloads from a single launch vehicle creates a need for innovative packaging and separation methods which are reliable, adaptable, and lightweight.

A group of small satellites can be packaged on a single launcher in many ways. Packaging methods are influenced by the structure of the satellites (and vice versa), reliability, the number of satellites to be launched, space debris production, and development & manufacturing costs. Several different packaging structures are presented including a variety of stacking methods and holddown structures. The merits and faults of these packaging methods have been compiled using Defense Systems' past satellite design and manufacturing experience as a guide.

Introduction

Multiple satellites can be launched and deployed at once by a single launch vehicle. Large satellites are mounted directly above the last stage on all expendable launch vehicles. Similarly, multiple small satellites are also mounted above the last stage. A packaging method's success depends on proper integration with the external structure of the satellite. Satellites of identical external structure are much more easily packaged than dissimilar satellites.
MULTIPLE SMALL SATELLITES ON A SINGLE LAUNCH VEHICLE

The drawbacks of launching several satellites at once include:

- The mass of the additional structure
- The additional orbit maneuvers to deploy the satellites
- The added complexity of the separation
- The additional test and integration of the entire payload.

The advantages of launching several satellites at once include:

- The rapid deployment of a whole series of satellites
- The lower cost to orbit per satellite.

Launching several satellites on one launcher saves time and money by reducing the number of launch vehicles needed to deliver several satellites on orbit.
Packaging Design Criteria

These design criteria include essential and desirable features in a small satellite packaging method.

Separation Reliability

For a packaging method to be effective, the separation reliability must be high. In this survey only bolt cutter initiated separation is considered. Space qualified bolt cutters are a well developed technology. The number of bolt cuttings or events which must occur for each satellite to separate, without the possibility of a single point failure, is a good measure of reliability.

Separation Sequencing

The order in which the satellites are separated from the bus is the separation sequence. Proper sequencing minimizes the possibility of satellite collisions.

Payload Volume Requirements

With several satellites on a launcher, the limits of the payload dynamic envelope can determine the maximum number of satellites which can be packaged aboard the launch vehicle.

Strength and Stiffness Requirements For the Satellite Structure

Various packaging schemes place a variety of loading conditions on the satellite structure. Some of the loading cases are: bending due to launcher accelerations, and stack preloads which prevent partial separation or gapping under launch loads. All packaging methods must be able to prevent adjacent satellites from gapping. "Gapping" is minute separation of a satellite from whatever is holding it. It occurs at the point where external forces equal preload forces.

The packaging method determines the stiffness of the payload and so influences the frequency response. A stiffer payload has a higher resonant frequency and higher loads on the payload due to vibrational accelerations. Lower stiffness structures, while under less severe loading, will deflect more than a relatively stiff payload.

Satellite Integration

Supplying power, separation signals, and telemetry to the satellites through the launcher electrical interface is desirable and often necessary but is often complicated by the packaging method. A particular design can effect the satellites' internal configuration and structure. The packaging system should not be launcher specific to allow adaptation to different launch vehicles.
Space Debris Production

As debris is becoming a problem in earth orbit we seek to minimize any increase. The Solar Max satellite received up to 6 hits per square foot in 50 months on orbit. The recovery of the Long Duration Exposure Facility should provide additional interesting data and possibly even reactive measures from government agencies. Customer requirements and common sense require that separation mechanism not litter space with needless debris. Elimination of production of random particles and pieces is desired.

Cost

Minimizing cost in both money and time is important. While a radically new concept can lead to high performance gains, the possible high development costs must be avoided when large gains are not possible. Manufacturing costs will also vary with the simplicity or uniqueness of a design.

Packaging Methods

Stacks are a prevalent method of packaging, however other options do exist. Four types of simple stacks and three other methods are discussed below.
Simple Stacks

Description: Stacks are one satellite on another with interconnecting separation mechanism between satellites. Stacks have certain attributes which are independent of separation mechanisms; these attributes are discussed below. Later the considerations for four different separation/retention mechanisms are presented.

Several types of simple stacks and retention/separation mechanisms

Design Considerations: Separation of the individual satellites from the stack begins with separation of the top satellite. Each satellite in turn is separated. If each satellite in the stack carries its own separation mechanism, some initiation signal must be sent to each satellite. To accomplish this without radios or timers, an electrical connection between adjoining satellites' separation sequencing electronics must exist. Battery charging and testing also justify electrical connections between sat in a stack.
The separation mechanism must not interfere with operation of experiments, antennae, instruments or solar panels while transferring loads between satellites. The probability of all satellites in the stack separating decreases as the number of satellites increases. This is because as the number of separation events goes up, the probability of a failure increases.

As stacks get taller, the loading at the base increase rapidly from both increase in mass and moment arm.

![Diagram of forces and stresses in stacks]

- LOWER STIFFNESS
- HIGHER STRESS AT BOTTOM SATELLITE

LARGE & MEDIUM STACKS

The higher loading must be supported by a stronger structure using either more material or higher performance materials. The increase in mass or cost becomes an important consideration in a program where several identical satellite structures are being built because the additional strength in the upper satellites is unused.
V-Band Stacks

*Description:* The V-band stack uses V-bands as the retention and separation mechanism. As the V-band is tightened it compresses the wedges on the upper and lower satellites. The bands are in tension circumferentially and longitudinally while the upper and lower rings are in compression. Commonly the V-band has two bolt cutters mounted 180° apart. Either bolt cutter can open the band allowing adjacent satellites to separate.

*Design Consideration:* The V-band has a long flight heritage and high reliability. Because the V-band takes up significant room between satellites, interference with antenna, experiments and deployables is possible. For a fixed V-band cross-section, larger diameter V-bands are capable of carrying higher loads but are also more massive. Although small satellites do not need large diameter bands, the bands can be integrated into the outer structure of the satellites. This has the advantage of forming the outer edges of a small satellite, which strengthens and simplifies the structure, while providing the largest possible area on the separation interface. Space debris can be prevented if it is possible to retain the V-band to each satellite after separation.
Bolted Stacks

Description: The bolted stack uses bolts or rods and bolt cutters placed between the satellites as the retention and separation mechanism. The rods are preloaded in tension holding a stud (often referred to as a snubber) or ring in compression to prevent gapping.

Design Considerations: Each rod should have two bolt cutters, each in a different plane, to provide redundant separation initiation. As the number of rods increases to support higher loading so do the number of pyrotechnic bolt cutters. Even with the large number of pyrotechnics, reliability is only slightly reduced because of the very high reliability of the bolt cutters (typically 99.9% reliability at a high confidence level\(^2\)). A more restrictive concern is how to provide the power to all the pyrotechnics. This power can come from the satellites or from a separate dedicated pyrotechnic initiation power source.

Rods concentrate loads on discrete areas of the structure. However, they can open up the separation plane of the satellites for use by antenna, instruments, and deployables. Additionally, it is possible to retain the bolts by only firing the second plane of bolt cutters if the first plane did not initiate separation.
Preloaded Stack with an Internal Auxiliary Structure

Description: An entire stack can be preloaded to prevent gapping by a rod or cable which passes through the center of the stack. The compressive preload on the stack will equal the tensile preload on the rod or cable.

Design Considerations: Because the stack is preloaded as a unit, cutting the rod or cable initiates simultaneous separation of the entire stack. Because the separation mechanism is simple the reliability is high and independent of the number of satellites in the stack. The preload creates relatively high stresses in the rod or cable used for preloading the stack. No additional volume outside the satellites is necessary but the auxiliary structure passes through the satellites and interferes with the internal packaging of the satellites. If possible, the cable should be retained to prevent the creation of additional space debris.
Preloaded Stack with an External Auxiliary Structure

*Description*: An entire stack can be preloaded to prevent gapping using a set of rods or cables which surround the stack. To balance the stack a minimum of two cables or rods are necessary. Separation is initiated by cutting the cables or rods at the top of the stack.

*Design Considerations*: All the stacks are simultaneously separated because of the common preload structure. Separation is possible with the cutting of only one support; however, the release is unbalanced and the satellites could tumble. As the number of cables or rods used in the auxiliary structure increases the stack becomes more stable. This can take up a fair amount of the dynamic envelope. By cutting the cables or rods at the top of the stack, no debris is generated but an initiation signal must pass to the top of the stack.
Tree Holddown

Description: The tree holddown uses a single external structure to preload several adjoining stacks. A single cable or rod running between stacks, connected to the preload distribution beam, distributes a compressive force to hold the satellites in place. The tree holddown can retain many stacks and the preload distribution beam can take any shape. The payload interface for this design is much wider in diameter than for a single stack.

Design Considerations: Tree holddowns offer a way to package large numbers of satellites at the cost of sequenced separation. Tree holddowns are similar to internally and externally preloaded stacks; all three designs are simple but provide no active separation control. Separation of satellites from the launch vehicle can be achieved by proper ejection spring sizing and slight angling of the stacks away from each other. Collisions between neighboring satellites are possible because of their nearly identical orbital injection.

The tree holddown, and the satellites under it, can be reliably released by a two bolt cutters mounted on the launcher side of the payload interface. To provide sequencing to the several stacks additional separation mechanisms, such as in simple stacks, must be provided. This, however, conflicts with the quick and dirty separation that a tree holddown provides.

Tree holddowns are a significant amount of additional structure, and as in preloaded stacks, require a satellite structure which can support longitudinal compression. In the holddown scheme the separation planes of the satellites are unincumbered by separation and retention mechanisms. The separation planes can easily provide for protruding antennae.

Because of the simple separation, satellite integration to the stacks is simple. The payload interface must provide for concentrated loads produced by preloading. The preload distribution beam may become space debris.
Dispensing canister

*Description*: The dispensing canister is an external structure which is a cylinder or prism providing all launch load support. When using the canister as a preload device, the satellites are held in place much like the externally loaded stack. The top cover distributes preload to the stack inside the canister. The canister can also enclose a simple stack and not act as a retention and separation device; for this case refer above to simple stacks.

*Design Considerations*: The probability of the canister opening determines separation reliability. Separation, like preloaded stacks is uncontrolled: all satellites are released simultaneously. The strength and stiffness are high because the loads are supported through the canister. Placing satellites in a canister limits the utility of their outside surfaces. For example, antennas cannot protrude through the canister. The satellites need to be integrated into the canister. This method could be particularly suited to STS based deployment in the GAS or Hitchhiker-G Canister.
Carriage

*Description:* A carriage design is a square, triangular or thin rectangular beam which has satellites mounted to its walls. The carriage is mounted to the launcher. Satellites can be separated from the carriage by the same methods described in simple stacks: V-bands, Rods & Compression springs.

*Design Considerations:* Each satellite requires only the strength needed to support its own weight during flight. The carriage takes up significant volume in the payload envelope. The carriage adds mass and the design effort of an additional structure. Mass is reduced in each satellite since its structure must only support its own weight. However, the carriage will add mass as it must bear the weight of the entire payload. Separation sequencing depends on mission requirements, however if separation direction is to be controlled, the launch vehicle will need three axis stabilized attitude control.

The carriage internal structure provides for centralization of separation control and power, and simple electrical communication paths to all satellites. Carriages do not need to pass information through one satellite to get to another. Post separation debris can easily be retained to the carriage. Separation failure of one satellite does not affect separation of another.
Conclusion
Each of the seven methods discussed above has unique advantages and disadvantages. While not all inclusive, this survey should provide a reference when packaging small satellites on single launch vehicle. Although launching multiple satellites on one launch vehicle adds 8 to 15 percent to the payload mass, the cost savings achieved with the multiple satellite launch more than makes up for the weight penalty.

References


