THE LIGHTBAND AS ENABLING TECHNOLOGY FOR RESPONSIVE SPACE

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ABSTRACT

[1]The Lightband separation system used to separate space vehicles is presented as means to enable responsive space. It does this by simplifying payload integration, lowering cost, delivering rapidly and by the utility of its advanced features. The Lightband can reduce integration time from days to minutes. Low cost is achieved by PSC's focus on the Lightband and all of its associated production tasks including: detailed design, procurement, testing and sales. A by-product of this focus is the upcoming capacity to stock and deliver Lightbands within a day. The advanced features, which resulted from five years and $1.5M yielded a litany of improvements that allows users to save weight, increase payload height, complete inexpensive full-system testing, reduce shock, buy an integrated solution, eliminate temperature dependence and eliminate hazards associated with pyrotechnics and fracture.

LIGHTBAND DESCRIPTION

The Lightband is a payload and missile separation system.

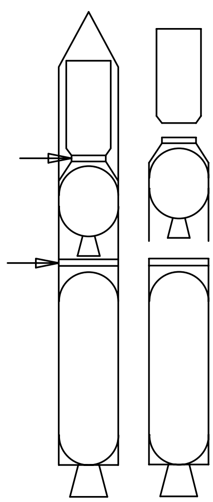

Figure 1 Launch and space vehicles need separation systems

Figure 2 The 38.81 inch diameter Motorized Lightband manufactured by Planetary Systems Corporation (PSC)

Separation systems have two primary functions. The first is to rigidly hold two adjoining vehicles together for shipment and launch. The second is to affect separation of those vehicles upon command from an adjoining vehicle.

The Lightband includes integral subsystems. These are: 1) separation springs to impart a small separation velocity on the two separated vehicles. 2) separation electrical connectors to allow signal and power to be passed between adjoining vehicles while they are joined and 3) separation switches to electrically indicate to adjoining vehicles the state of separation (joined or separated).

The Lightband is deployed and stowed by a snap acting mechanism powered by a set of primary and redundant electric motors. The primary structure and retaining ring (the ring that communicates preload to the leaves) are made of 7075-T7 and 6061-T6 aluminum alloys. Adjoining structures are typically attached to the Lightband with a bolted joint using ¼ inch stainless steel fasteners.

More than 20 missions are using the Lightband for space flight application.

A complete technical description is beyond the scope of this paper but is available at www.planetarysystemscorp.com. The Lightband is covered by the following patents: 6390416, 6343770 and 6227493. Several other US and international patents are pending.

SIMPLE PAYLOAD INTEGRATION

The Lightband allows a much simpler integration process.

Integration is the process of joining two components of an aerospace vehicle. The task of joining two vehicles involves both the physical act of joining and the verification that the joining is as it should be. When joining two vehicles, alignment has to be set with a precision on the order of 0.01 inches to assure reliable operation. The separable electrical connectors must be simultaneously mated without the possibility of pin damage. Clocking (the orientation about the separation vector) must be obvious and failsafe to prevent damage. The separation springs must compress in the mating process. The preload force in the joined system has to be set to narrow limits to assure stiffness and strength. The readiness of the separation initiator must be easily determined.

Traditional Payload Integration A traditional integration process occurs in a building at or near the launch site. Due to the relative fragility of the adjoining vehicles, particularly the separation system, the process of integration is rigidly controlled by a multidisciplinary team, procedures and special equipment. Engineers, technicians, customers and quality assurance personnel are often in attendance. Other members of the launch team typically have to wait for this process to complete before they can resume vehicle verifications. The infrequency of this process leads to atrophy of integration skills, re-enforcing the need use large, and slow teams.

Figure 3 A traditional integration process. Starshine-3 on Athena.

Ideal Payload Integration The process to join aerospace vehicles on the deck of aircraft carrier represents an ideal with respect to time and cost. The joining of an air-to-air missile to the pylon of an F-18 is completed from carrier to aircraft by a team of five in two minutes. Avionics and robust motorized pylon design enable rapid and verified joining.

Figure 4 integrating an air-to-air missile to an F-18 aircraft

Integration With the Lightband Joining space vehicles with the Motorized Lightband is, by design and demonstration, a rapid and easily verified separation system. The process shown in the figures below took 3 people 45 seconds to complete. The satellites were built by the University of Texas at Austin. They will be separated and released 80 times on a KC-135 "Vomit Comet".

Figure 5 The satellites are removed from their crates, the Lightband halves have previously been integrated to adjoining vehicles

Figure 6 One satellite is place on the other

Figure 7 The satellites are joined using integral clocking and alignment features

Figure 8 Push of a button on the controller sets Lightband

Figure 9 Ready for Flight

LOW COST

PSC's focus on a single product, the Lightband, enabled low cost. All the production tasks are similar.

<u>Design</u> The cross-sections of the Lightband are identical. Using modern computer assisted design (CAD), new diameter Lightbands are made by changing the sweep path circle diameters, a variable in the CAD models.

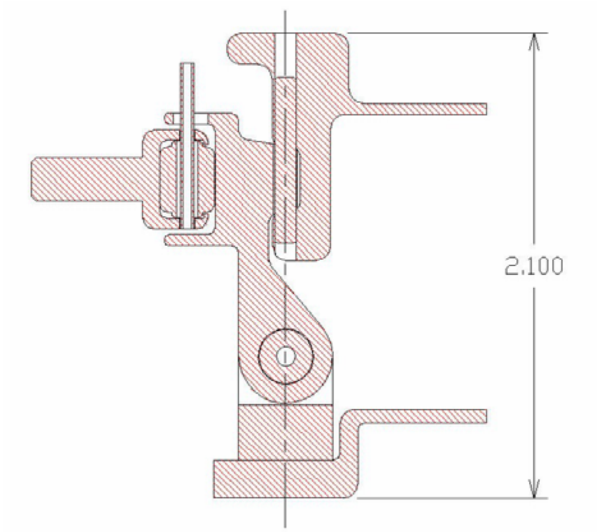

Figure 10 Cross-section of Motorized Lightband. Dimensions are in inches.

Because all the subsystems are identical, completing new assembly drawings only require changing subsystem quantities. Instead of spending six months on all custom parts, a new Lightband can be designed in a few man-weeks.

Procurement Several qualified vendors are used to manufacture all of the Lightband subsystems. Because PSC is constantly re-ordering or ordering simple variations of the same part, the vendors maintain proficiency in their programs and tooling allowing them to distribute fixed costs over many orders.

Test Fixtures All of the Lightband tests are similar. The only variable is the magnitude of test level and Lightband diameter. For every Lightband diameter there is a specific set of tooling to allow rapid integration to the test fixtures. As a consequence the test plans become nearly identical, allowing documentation efficiency.

Sales All nine standard variations of the Lightband have been cataloged and placed into a technical brochure. The brochure allows systems engineers to rapidly down-select. Once a buy decision is made, customers can order without the encumbrance of statements of work or complex procurement vehicles. The Lightband is listed on the GSA allowing them to streamline acquisition. While sales may seem unimportant to engineers steeped in system design, program managers appreciate the potential to cut a month off the procurement effort.

Technical Development The technical development of the Lightband took five years, \$1.5M and a series of five major iterations of the design before the production efficiency was possible. PSC's self-serving need to posses a broadly applicable, high performance product that was not only easy to manufacture, but easy to test, did not come easily. This was due to the inability of present analytical techniques to thoroughly predict performance of mechanisms. Unlike structural design, which generally benefits from isotropic and continuous material properties, mechanisms are intentionally (to let them operate) loaded with a series of difficult to analyze discontinuities. So to come up with a good design, many prototypes had to be made, tested and improved. In the course of development, many promising technical solutions were abandoned because their recurring cost proved to be too high. Over time the trend in the Lightband development has been to increase specific stiffness, specific strength while reducing total production, test and integration cost. The motorized Lightband was the final product of the development effort. The actual use of Lightband on many small satellite missions proved effective in giving PSC engineers feedback on areas for improvement.

Figure 11 Five Lightbands sequentially developed from 1998 to 2002

Custom test Equipment Test equipment that allowed rapid testing was designed and built concurrently with the development of the Lightband. To envelope the environments the Lightband has to perform in, four test items were built.

The Strength test fixture uses a stiff steel frame and hydraulic rams to apply flight-like loading. Additional tooling approximates the local stiffness and flatness of real space vehicles.

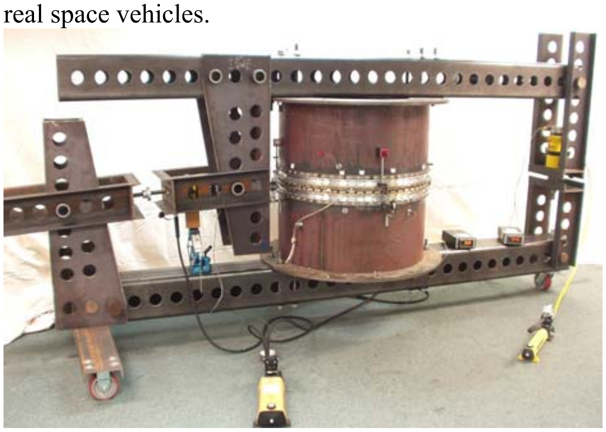

Figure 12 Strength test fixture

The Vibration test fixture is designed to emulate the mass properties of adjoined structures

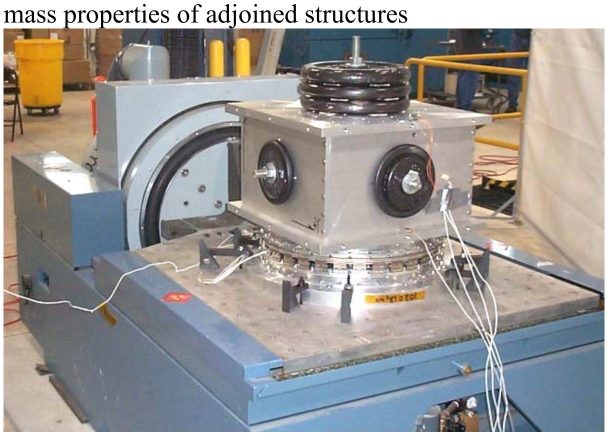

Figure 13 Vibration test fixture, Lightband and electro-dynamic exciter

The Separation reliability test fixture frictionlessly off-loads gravity torques, allowing the Lightband to separate as it will in orbit. A spherical air-bearing allows pitch, roll and yaw; a planar air bearing allows translation. The separating half (supported by the air bearing) is instrumented with an inertial measurement unit, which coupled with measurement of the separating half's mass properties, allows accurate verification of tip-off rates and delta V. Additional instruments record time, current and voltage to separate. The reset-ability of the Lightband allows engineers to execute statistically significant number of tests (at least 10) yielding maximum, minimum, average and standard deviation of all of the readings.

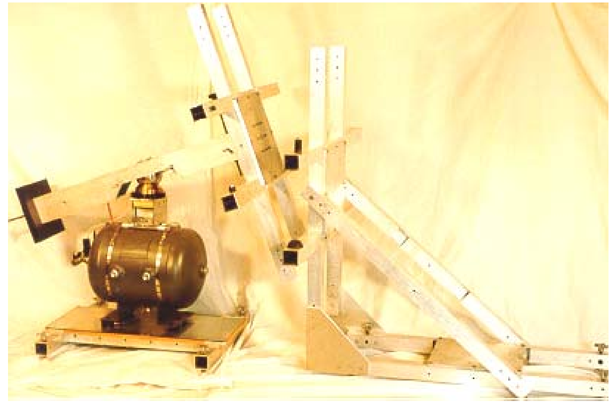

Figure 14 Separation Reliability Fixture

A thermal vacuum test chamber was made to test the Lightband in the vacuum and temperature extremes of space. The Lightband is typically cycled eight times between temperature extremes, at 10-6 torr. During the ninth cycle, separation is initiated. With the motorized Lightband, the Lightband can be reset, to repeat the test without breaking vacuum.

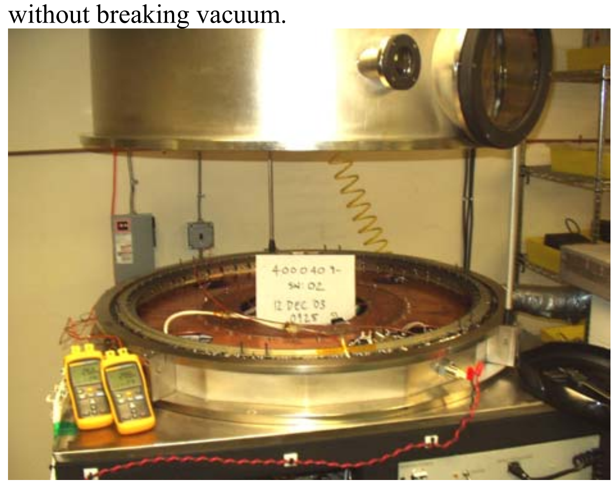

Figure 15 Thermal Vacuum chamber with 38 inch Lightband

RAPID DELIVERY

The aforementioned production efficiencies have allowed PSC to begin stocking the most popular diameters (15 and 23 inch diameter) By the fall of 2004 PSC will be able ship these fully tested Lightbands from inventory. For diameters other than 15 and 23 inches, the typical delivery is seven months. Delivery can be accelerated to three months. Non-catalog Lightbands are usually delivered in 8 months.

ADVANCED FEATURES

The advanced features of the Lightband enable responsive space. Here the Lightband is contrasted to a traditional V-band (sometimes called "Clamp Band" or "Marmon Band").

The most useful feature of the Lightband is its weight savings. The Lightband weighs 0.36 lbf per inch of diameter, while a typical Vband weighs 1.10 lbf per inch[1] of diameter. On a 38.81 inch diameter separation system the Lightband is 28.7 lbf lighter than a Vband. This equates to a savings of $430,500 in launch costs assuming $15,000 / lb to orbit. Practically, users don't get this money back; they apply this credit beneficially to the rest of their payload.

The Lightband is 2.1 inches tall while Vbands range in height from 4 to 8 inches. The 1.9 to 5.9 inch height[2] savings can be applied to allow longer or simpler satellite structures and larger stowed solar arrays. In the cramped volume of a payload fairing, several inches of height savings is substantial.

The Lightband's design enables inexpensive full system testing. Performance can be repeatedly measured, especially when the Lightband is integrated into adjoining vehicles. The critical item to measure is the separation indication. Will the space vehicle turn-on after separation? Will the launch vehicle detect separation? Other tests include verifying inhibits and enables related to the separation event. Vbands have not been designed to support repetitive testing. The high tension band usually reaches its fatigue life in ten uses. The need to replenish the pyrotechnic initiators and the bolts they cut each cycle adds to cost and personnel safety burden. For these reasons, program managers and engineers on limited budgets may be tempted to minimize Vband testing. For any mechanism, lack of testing reduces confidence level on reliability[3]. PSC's use of advanced test equipment has allowed it to test were traditional Vband suppliers are unable, simply because they have not developed the test equipment. Specifically the separation reliability fixture used to rigorously verify separation dynamics.

The shock of the Lightband is below 300g while Vband typically produce a shock of 1,000 to 5,000 g at the interface to adjoining vehicles[4]. Some sensors are sensitive to high shock and are intentionally located away form shock sources. With the Lightband, engineers are free to locate shock sensitive equipment next to the Lightband allowing them to make the best use of available volume.

The Lightband integrates all separation subsystems. This unburdens the engineers of the adjoining vehicles. Since the design and negotiation of separation spring, connector and switch location can involve many iterations of the engineering teams on both sides of the interface, the elimination of this time consuming task saves time. The Lightband has been designed to allow many permutations of subsystem placement. Engineers can place separation connectors at optimal location to minimize wiring harness weight. Further, the separation springs can be segregated on one side to induce tip-off. Angled springs can be employed to spin a payload up around the spin axis.

The time to deliver a Lightband can be 3 months (soon 1 day for the most common diameters). The typical delivery is 7 months. This compares favorably to a typical delivery of 12 months for a Vband. In the same vein, the time to integrate a Lightband can be 6 man-hours for a highly motivated team versus 168 man-hours applying traditional aerospace methods and using a Vband.

The Motorized Lightband is fracture proof because the retaining ring is in compression. The retaining ring, which distribute preload to the latching elements, can be completely severed without separation. On a Vband, however, the tensile band wrapped around all the shoes is susceptible to fracture due to its high stress and because it is a mono-filament. Once a crack starts in the tensile band of a Vband, its growth is accelerated with each separation event and thermal cycling. This is why Vbands are typically limited to ten or fewer uses.

The Lightband employs motors to initiate separation while Vbands typically employ pyrotechnics[5]. The use of motors eliminates the possibility of electro-static discharge induced separation while Vband require substantial electronic, range safety and shipment inhibits. The elimination of the need for safety measures reduces cost.

The Lightband's preload does not vary with temperature because all of the load-bearing elements have the same coefficient of thermal (CTE) expansion. Preload is the tension or compression in a fastened structural joint. Because of CTE mismatch, an aluminum joint fastened with stainless steel fasteners will experience a change in preload with temperature. Changes in preload have a non-linear amplifying affect on stiffness[6], the primary design driver of separation systems. CTE mismatch is important in missions were the separation event is delayed long enough that the separation system will cool or heat by 30 degrees Celsius. In most Vbands, the aluminum rings are preloaded by a stainless steel or titanium band. If the Vband gets too hot, preload increases and may lead to actuation. If the Vband gets too cold, preload and stiffness decrease. This can be of particular concern on Shuttle missions. If the Shuttle must abort prior payload separation, after a cold soak, the Vband may have insufficient strength or stiffness to react re-entry loading. When intimately connected to rocket motor cases separation system temperatures can also increase substantially and lead to premature separation or weakening of CTE mismatched joints. As an aside, this is the operating principal of so called frangi-bolts: increase the temperature of a preloaded bolt until it fractures.

SUMMARY

The Lightband separation system enables responsive space by simplifying payload integration, lowering cost, delivering rapidly and by the utility of its advanced features. PSC has spent a substantial amount of time improving separation system technology. The Lightband is ready to be adopted by an industry interested in improving space system performance.

ACKNOWLEDGEMENT

Substantial funding and other support came from a Small Business Innovative Research (SBIR) grant via the Air Force Research Lab (AFRL). Specifically at AFRL: Jeff Ganley, Maurice Martin and Steve Buckley. Their faith and support is gratefully acknowledged. Dr Gil Moore of Project Starshine was instrumental in helping PSC get flight heritage.

[1] Jarosz, Don (Editor) Marmon Band Primer (SSPP-REF-016), NASA-GSFC, 1997
[2] Same as endnote 1
[3] Conley, Peter L. (Editor) Space Vehicle Mechanisms John Wiley & Sons, 1998, page 687-688
[4] Conley, Peter L. (Editor) Space Vehicle Mechanisms John Wiley & Sons, 1998, page 251
[5] Same as endnote 1
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