Apr 30th, 1:00 PM

Paper Session III-C - Advanced Mechanisms For Space Applications

Eugene R. Fosness

Richard Madison

Dino Sciulli

David B. Founds

Scholarly Commons Citation

Fosness, Eugene R.; Madison, Richard; Sciulli, Dino; and Founds, David B., "Paper Session III-C - Advanced Mechanisms For Space Applications" (1998). *The Space Congress® Proceedings*. 30.
https://commons.erau.edu/space-congress-proceedings/proceedings-1998-35th/april-30-1998/30

ADVANCED MECHANISMS FOR SPACE APPLICATIONS

E. Fosness[1], R. Madison[2], K. Denoyer[3], D. Sciulli[4], and D. Founds[5]

Abstract

The Air Force Research Laboratory (AFRL) is currently engaged in developing and demonstrating several advanced spacecraft and launch vehicle mechanism technologies. A variety of mechanisms are required to accomplish spacecraft and launch vehicle functions such as deployment, articulation, positioning, and isolation. Current off-the-shelf mechanisms such as pyrotechnics, gimbals, paraffin actuators, and electro-mechanical devices may not be able to meet future satellite requirements. For this reason, advanced technologies are needed that will increase mechanism efficiency in terms of cost, weight, reliability/survivability, and power consumption. In addition to developing these technologies, it is necessary to prove them in flight demonstrations in order to make technology transition feasible. This paper summarizes the status of several space-related programs being conducted by AFRL for developing and demonstrating new technology to support future DoD space requirements. One of these flight programs will fly the first whole-spacecraft isolation system on a Taurus launch vehicle in January 1998 and another will demonstrate the first solar array with overall array specific power greater than 150W/Kg in the fall of 2002. This solar array is being developed for flight on the third New Millennium Program technology demonstration flight.

Introduction

Spacecraft require a variety of mechanisms to accomplish mission related functions such as deployment, articulation, and positioning. Current technologies for these mechanisms include pyrotechnics, high output parafin, and electric motors. While successful in many applications, these technologies have drawbacks that make them unsuitable for the increasingly restrictive requirements of current and future spacecraft. These drawbacks include generation of high levels of shock, contamination, short lifespan, low reliability, low efficiency, safety risks, and excessive weight and volume. The Air Force Research Laboratory (AFRL) is developing innovative technologies for new mechanisms that avoid many of the problems found in current devices. The goal of this research is to develop and transition technologies to advance the state-of-the-practice in spacecraft mechanisms. Specific technology areas being researched include launch isolation for satellites, shape memory alloys release mechanisms, light weight solar arrays, precision gimbals, magnetic bearings for energy efficient reaction wheels and fly wheels, and automation of high-level mechanical tasks.

Whole-Spacecraft Isolation

The most severe vibration that a satellite experiences during its lifetime occurs during launch. Traditionally, designing spacecraft to overcome launch vibration has meant structural stiffening and component isolation. This approach is costly, time consuming, and adds significiant weight. The AFRL is actively investigating an alternative approach, which involves isolating the whole spacecraft from the structural-borne vibrations during launch. The objective of the current effort is to reduce the launch-induced, structural-borne dynamic acceleration at the satellite by a factor of 3 to 4, by inserting an isolator between the spacecraft and the launch vehicle. The AFRL has several programs in the area of whole-spacecraft isolation, targeting the small to medium class launch vehicles. The first ever whole-spacecraft isolation system will fly on a Taurus launch vehicle in January 1998. Additional flights that are scheduled to use whole-spacecraft isolation include a LMLV-II (Fall 99), Minuteman (Fall 99), and an Evolved Expendable Launch Vehicle (2002). It is envisioned that a whole-spacecraft isolation system will replace the traditional adapter used to physically attach a spacecraft to an LV as shown in Figure 1. By integrating an isolation system into the adapter, the whole spacecraft can be effectively isolated from launch loads. Solar arrays and other flexible structures can then be made lighter and from less expensive materials, resulting in both mass and production cost savings. Lower component mass also allows a larger percentage of the payload weight to be dedicated to scientific equipment. It is anticipated that the technologies currently under development will reduce costs and the number of failures. This will be especially important for launching large numbers of similar spaccraft such as those envisioned for proposed satellite constellations necessary to form global telecommunication networks.

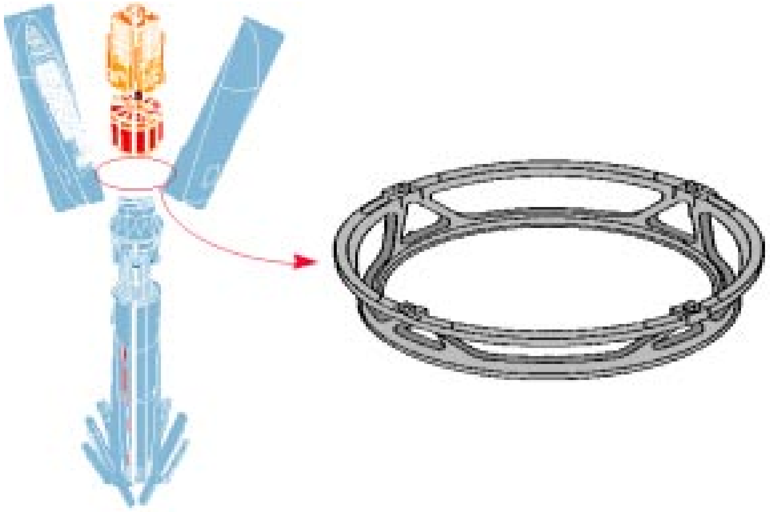

Figure 1. Launch Vehicle, Spacecraft, and Payload Attach Fitting (Adapter)

Release Mechanisms

Spacecraft require separation and release mechanisms to separate from the launch vehicle and deploy appendages such as solar arrays. Pyrotechnic bolts are currently used for most of these tasks, but their presence on a spacecraft has several negative impacts. Detonating pyrotechnic charges produces high frequency shock, which can damage fragile sensors, electronics, and lightweight structures. The explosions also release contaminants, which can reduce the effectiveness of sensitive optics. A 1985 survey of pyroshock flight failures (Moening, 1985) found that pyrotechnics related problems caused 83 spacecraft failures in 600 launches, and over half of the failures caused catastrophic mission failure. In addition to a propensity for these types of failures, pyrotechnic bolts have the potential for accidental explosion. According to a NASA study (Shapio, 1995), this necessitates special handling and storage procedures, significantly increasing the cost of satellite integration.

To eliminate the problems associated with pyrotechnic release devices, the AFRL, and Lockheed Martin Astronautics have developed a non-pyrotechnic release device that uses shape memory alloy (SMA) technology. The SMA mechanism retracts a bolt without producing contaminants or presenting the threat of an accidental explosion. The mechanisms can be tested in-situ, because unlike pyrotechnic bolts, SMA mechanisms can be reset. This means that the same bolts used in ground tests can be used in the actual flight. Release is not instantaneous (≥ 50ms), but is still fast enough to allow sufficiently synchronous release of multiple bolts. An additional advantage of SMA devices is that they reduce shock produced during release by an order of magnitude over pyrotechnic bolts. To demonstrate this, shock spectra, shown in Figure 2, were experimentally measured for several release mechanisms: a pyrotechnic device, a non-pyrotechnic device, and two SMA mechanisms (Carpenter, 1996). The SMA actuators keep the acceleration (shock) below 500g, avoiding the need for space qualification testing, while the non-SMA mechnisms do not. Because of their advantages over current release devices, the new SMA mechanisms will be demonstrated as an experiment on the Mightysat 1 spacecraft in 1998.

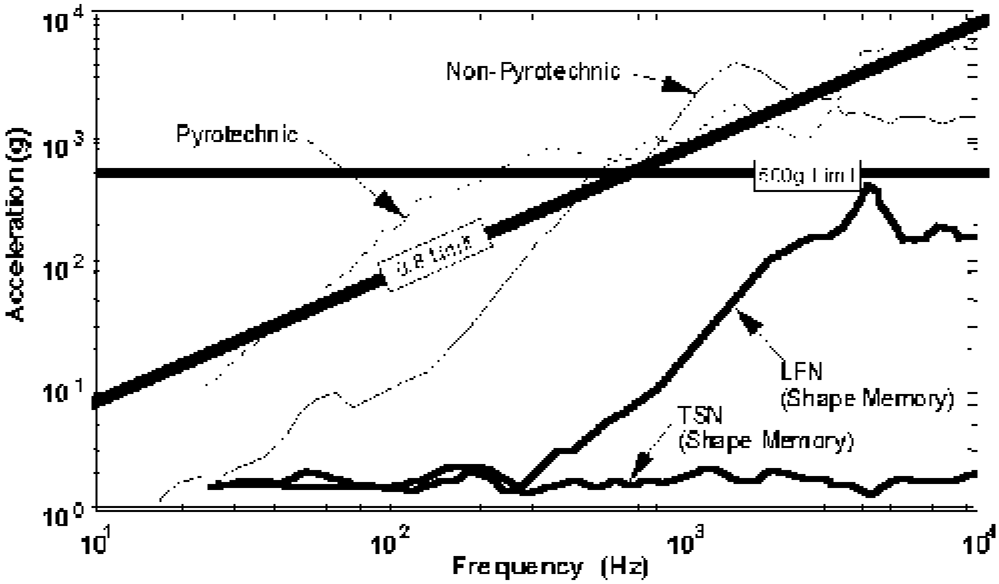

Figure 2. Typical Shock Response Spectra for Two Conventional and two Shape Memory Actuated Release Devices

Lightweight Solar Arrays

Conventional solar arrays typically use Silicon or Galium Arsinide cells supported by rigid honeycomb substrates. Rigid panel composite facesheet thicknesses (around 0.010”) and honeycomb densities (1.6 kg/m^3) have reached their practical producible limits, capping rigid panel solar array technology at a specific power of roughly 50 watts per kilogram. A revolutionary solar array approach is required to meet the evolving DoD and NASA specific power (>150W/kg), packaging (300 W/m^2), and stowage (<0.15 m^3 for 750 W array) requirements. The AFRL, NASA Langley, DARPA, and Lockheed Martin are jointly developing and demonstrating advanced technologies for solar array applications. These technologies will be combined to reduce cost, weight, and risk, while increasing reliability and power from solar arrays. The technologies developed in this program will be integrated into a solar array with specific power greater than 150W/Kg. Two arrays will be designed, fabricated, and tested by Lockheed/Martin, then flight qualified and flown as two experiments in the Third New Millennium Program technology demonstration. The first experiment will be two 20 cm by 50 cm panels on NASA’s Earth Observation 1 (EO-1) in the fall of 1999. The second will be a full size solar array, like the one in Figure 3, on NASA’s EO-2 spacecraft in 2001.

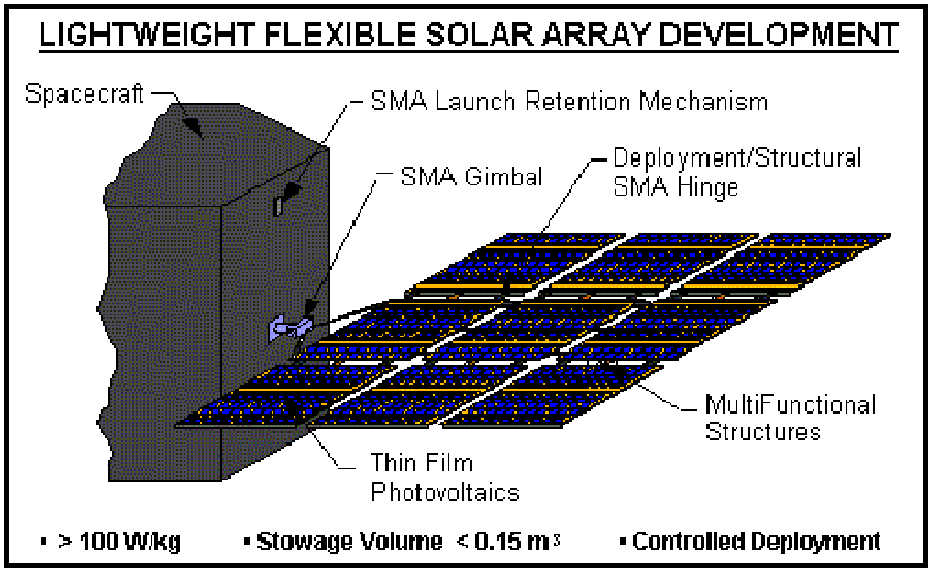

Figure 3. Advanced Solar Array Technologies

Spacecraft Sensor Gimbal/Bearing System

Another AFRL technology area of recent interest is the development of a long life, high reliability, ultra-smooth, fault tolerant, low cost gimbals for slow scan sensors. As DoD, NASA, and commercial payload requirements increase, so does the need for precise, vibration free, sensor gimbal functionality and reliability. Conventional gimbals are limited by their susceptibility to mechanical wear, need for lubricants, and inherent vibration. Eventually, performance requirements will exceed the capability of current gimbals. Recent advances in electromagnetic suspension technology provide an alternative to electromechanical designs for satellite sensor gimbal mounting. Suspended gimbals will be immune to the problems limiting current designs.

Momentum Storage

The AFRL is developing advanced technologies to more efficiently store momentum in rotating wheels. Spacecraft attitude control mechanisms typically use such wheels to store angular momentum and generate torques. More efficient storage will allow wheels to be used not only for attitude control but also as energy storate devices (mechanical batteries). One important technology is high precison magnetic bearings, such as those depicted in Figure 4. Magnetic bearings are not required to construct momentum wheels and multi-functional flywheels, but incorporating them will significantly decrease friction and vibration in the wheels. This in turn will increase energy efficiency and lifespan, allowing higher rotational speeds. The latter is critical, given that flywheel rotor speeds must exceed 40,000 rpm for weight-efficient energy storage (Ginter and Mahoney, 1997). In addition to developing low-power magnetic bearings, the AFRL has several other ongoing efforts. These include rotor health monitoring, a new form of homopolar magnetic bearing, and new touchdown bearings that can withstand launch shocks and high speed operation. Additional areas of interest are containment of flywheels during failure and advanced composite materials for rotors.

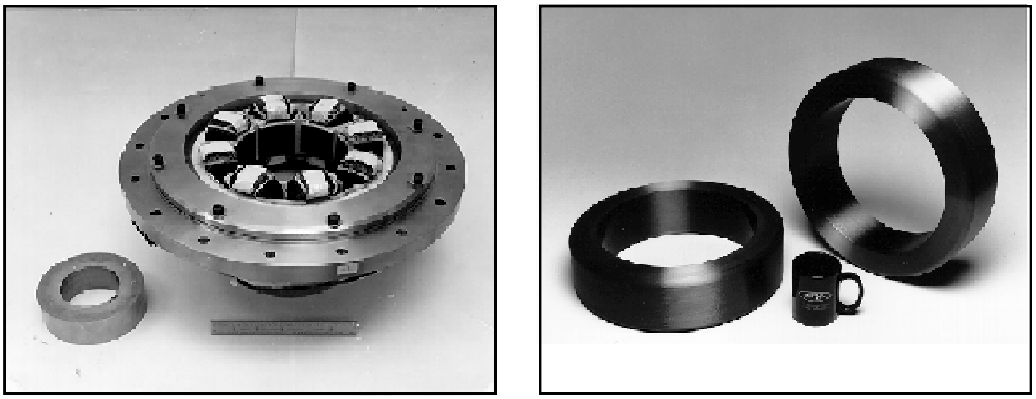

Figure 4. Magnetic Bearings and Flywheel Rim for Spacecraft Applications

Automation

The AFRL is also investigating automation of high level mechanical functions for on-orbit spacecraft maintenance. Maintaining spacecraft by resupply, retrofitting, and repair can increase the life span of a satellite and result in lower life-cycle-costs. This is particularly true of geosynchronous satellites, because of the high cost of launching replacement support structure and the need to tow abandoned satellites to a parking orbit. To date, spacecraft have been maintained by extravehicular activity (EVA), limiting the set of maintainable satellites to those in the few orbits accessible to the space shuttle. Astronauts or ground operators could extend their range by teleoperating robotic manipulators on spacecraft or maintenance spacecraft dispatched to aid ailing spacecraft. An extension of this idea is to automate these manipulators and craft, to operate without human intervention. This offers significant benefits when communications delays, limited communications bandwidth, or low duty cycle would prevent a human teleoperator from working effectively. Several technologies are required to meet identified maintenance needs such as resupply, retrofitting, inspection, decontamination of solar cells and sensors, assembly and repair of structures, and debris collection. Technologies being investigated include autonomous navigation, collision avoidance, path planning, and robotic end effectors for tasks such as docking, cleaning, and grasping.

Conclusion

This paper summarizes several technology areas that the AFRL is currently investigating to advance spacecraft mechanisms. The near-term goal of these technology programs is to advance the state-of-the-practice rather than the state-of-the-art. This is especially true in the area of whole-spacecraft launch isolation. Spacecraft have been launched for decades without the benefits of even rudimentary isolation from launch vehicle loads. The insertion and acceptance of whole-spacecraft isolation came about only after a very simple, lightweight passive design was recently introduced. This approach was taken to lower risk concerns that a fully active system might generate, despite the promise of superior performance. By incrementally advancing this technology, AFRL has been successful in inserting isolation technology on several different launch vehicles, with the first demonstration in January '98 on a Taurus launch vehicle. Because of the program success, several launch vehicle manufacturers have indicated that they intend to insert this technology into their launch vehicle fleet as well. To extend the technology further and achieve greater performance, AFRL is now developing active/passive (hybrid) whole-spacecraft isolation.

In addition to launch isolation, this paper also discusses AFRL research in the areas of SMA release mechanisms, lightweight solar arrays, precision gimbals, magnetic bearings for flywheels and reaction wheels, and mechanical automation. Continuing work in these areas will provide technology that will meet the increasing requirements of spacecraft mechanisms. It is expected that the successful implementation of these programs will have an impact on all future military and commercial spacecraft programs by providing more efficient and reliable spacecraft systems.

References

1. Moening, C. J. "Pyroshock Flight Failures," Proceedings of 31st Annual Technical Meeting of the Institute of Environmental Sciences (IES), 3 May 1985.

2. Shapio, W., F. Murry, R. Howorth and R. Fusaro, "Space Mechanisms Lessons Learned Study: Volume I – Summary," NASA Technical Memorandum 107046, September 1995.

3. Carpenter, B. F., "Shape Memory Actation and Release Devices", USAF technical report PL-TR-96-1123, October 1996.

4. Carpenter, B. F. and T. Gillespie, "Lightweight Flexible Solar Array", Lockheed Martin white paper, August 1996.

5. Ginter, S. and D. Mahoney, "An Assessment of Flywheel Energy Storage System Reliability", USAF technical report PL-TR-97-1039, February 1997.

[1] 1. Research Structural Engineer, AFRL/VSDV, Kirtland AFB, NM 87117-5776.
[2] 2. Research Computer Engineer, AFRL/VSDV, Kirtland AFB, NM 87117-5776.
[3] 3. Research Aerospace Engineer, AFRL/VSDV, Kirtland AFB, NM 87117-5776.
[4] 3. Research Aerospace Engineer AFRL/VSDV, Kirtland AFB, NM 87117-5776.
[5] 4. Deputy Chief, AFRL/VSDV, Kirtland AFB, NM 87117-5776.