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To: Professor Pierre Kabamba, Aero 285 Instructor

From: Duncan Miller, Aerospace Engineer

Subject: The eXtendable Solar Array System as a Power Bus for CubeSats

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Foreword

The students in the Aero 481 and 483 vehicle design class are investigating potential subsystem designs for their air or space vehicle. Professor Kabamba has asked me to write a report on a subsystem or component of an aircraft or spacecraft of my choice to aid their efforts. He is particularly interested in how the subsystem relates to the aircraft or spacecraft as a whole, what specific vehicles use the module, and any experimental results of revolutionary designs. I am researching the eXtendable Solar Array System (XSAS) as a power source for CubeSats, which are small satellites. The purpose of this memo is to present the importance of XSAS as a renewable energy source for orbiting satellites.

Summary

As a stage to test inventive, high-risk technologies, CubeSats have provided a favorable testing ground for deployable systems. Design-build-test-fly cycles have repeatedly shown that power, rather than volume, is the limiting constraint in these space missions. Thus, researchers at the University of Michigan have designed and prototyped a deployable array of solar panels to provide up to 20 Watts of power. The eXtendable Solar Array System (XSAS) is a modular, 'plug and play' design that can be integrated onto any standard CubeSat to boost the average power supply by a factor of approximately five. Expanding the power budget of CubeSats improves data rates and increases the quality of feasible nanosatellite missions by allowing a larger number of instruments to be flown. The 16 panel accordion style scissor structure deploys to a length of 171 cm and does not exceed the 4 kg constraint for CubeSat launch. Extension is initiated with a Dyneema wire burn and propelled upward by torsion springs in the scissor structure. Moreover, when fully deployed, XSAS can provide gravity gradient stabilization for the satellite in orbit, orienting the payload in the nadir direction (towards the Earth). XSAS has undergone at three major design cycles, culminating with a 2010 flight on the NASA's microgravity plane. Currently, a team at the University of Michigan is optimizing the scissor structure to improve deployment dynamics.

1. Details

The CubeSat, a form of nanosatellite, has been standardized by California Polytechnic State University as a means of providing access to space for small payloads. Several proposals for deployable systems have been suggested over the past decade but few have successfully flown. Similarly, gravity gradient stabilization and on board solar arrays have been popular items of research, especially at the academic level. However, they have all collectively lacked modularity since each article was designed for a specific mission. The eXtentable Solar Array System (XSAS) intends to integrate both power and stabilization into a platform that can be appended to all future CubeSats developed at the University of Michigan. The purpose of the following sections is to document the system, its components and the experimental research currently being conducted.

2. Design Requirements

The CubeSat program has proved particularly attractive to universities due to the inexpensive launch cost and short design lifecycle of these satellites. In the design stage of XSAS development, specific, top level stipulations were proposed to ensure that XSAS serves as a versatile and modular power system.

- Solar array provides at least 20 W of continuous power when deployed
- Successful expansion of redundant release mechanism can be confirmed by the ground station
- Passive locking mechanism does not apply shock to the payload
- Gravity gradient stabilization re-orientates XSAS in the longitudinal axis
- Release mechanism is redundant, reliable and able to be reset in a maximum of ten minutes.
- All components of XSAS originate from commercial products, being modified only through student accessible machinery

In 1999, California Polytechnic State University standardized the size and mass constraints of CubeSats for launch in the Poly Picosatellite Orbital Deployer (P-POD). The P-POD strategy of ejection limits violent tumbling and rotation through controlled deployment of CubeSats. P-POD payloads are measured in multiples of their “units.” A single unit, “1U,” is defined as a 10x10x10 cm cube, and multiple units are stacked linearly on top of one another. A 1 kg mass constraint is enforced for every unit of volume. When stowed, the XSAS chassis compresses to 1.5U longitudinally. This payload includes a 1U array of stowed solar arrays and a 0.5U power bus.

2.1 Chassis Design: The chassis structure houses the scissor structure of solar arrays. It consists of the upper level ballast plate and lower level power bus. Above the panels rests the ballast mass and standard interface for P-POD attachment. The added mass serves two purposes. First, it shifts the center of mass of XSAS to coincide with the center of drag, which passively improves the altitude control system. Second, the ballast redistributes the mass according to the gravity gradient stabilization theory as discussed in section 2. Four release panels envelope the sides of the chassis joining the upper assembly with the lower assembly in the compressed configuration, as seen in Figure 1.

The power bus houses the release mechanism, the batteries and the electrical equipment below the collection of solar panels. Release panels fit into the panel walls of the lower assembly to maintain closure during storage. The 'skirt' of release panels serves to transfer vibrations to the attached CubeSat structure. The lower assembly panel walls are removable to accommodate changes in the interior design of the power system. Moreover, the panels protect the solar array structures and mechanism while stowed. Rigidity is maintained using solid aluminum posts on the corners for both the upper and lower assemblies.

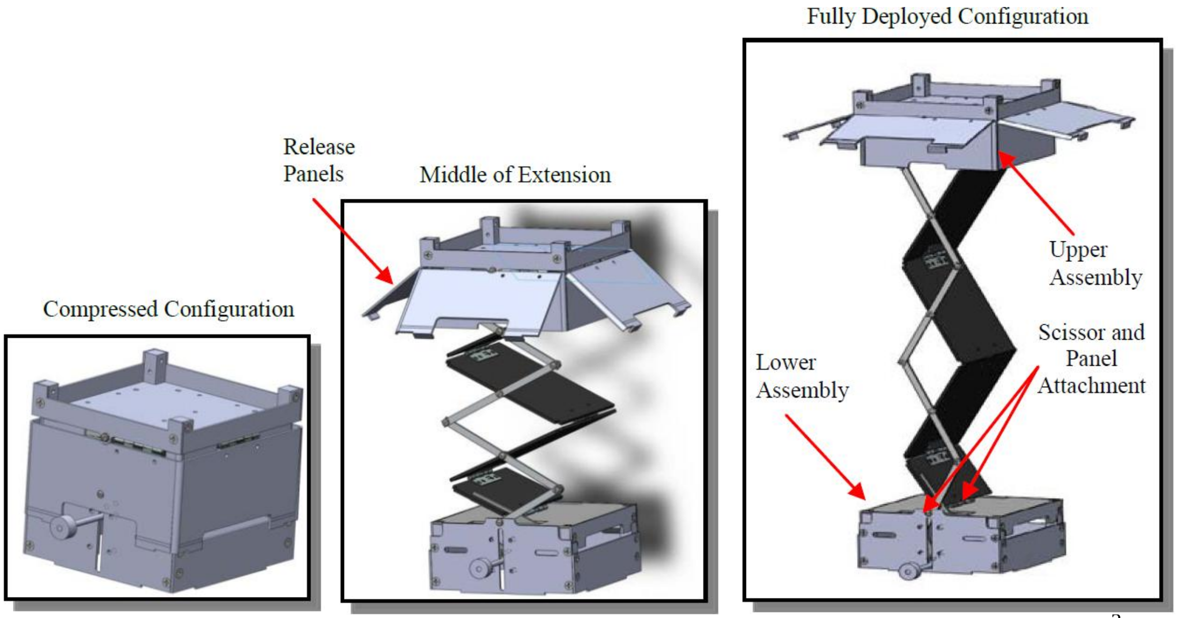

Figure 1. XSAS Configuration and Deployment Sequence (replicated from Trabert[3])

2.2 Release and Deployment: The spring-loaded torsion hinges that connect adjoining solar panels drive the extension of the scissor structure. Each panel is attached to the scissor structure at a single constrained point that still allows rotation for deployment. The release panels, propelled by the same torsion springs, are held down during storage using a Dyneema wire that encircles XSAS and rests on a pair of 10 Ohm resistors. When a 9V burst is shorted across this circuit, the 900 mA produces enough excess heat to melt the Dyneema wire, initiating the deployment sequence. Dyneema wire was chosen due to its extremely high tensile strength, surpassing that of steel. Inspired by the familiar scissor lift, the scissor structure inherently manages the orientation of XSAS during deployment.

2.3 Latching Mechanism: Once XSAS concludes its extension phase, an integrated latching mechanism engages, locking the structure in place as a rigid body. Two methods have been proposed and tested. Originally, latching of the hinges involved hooks that, when in position, prevented further movement. However, this custom locking latch proved difficult to machine, violating one of the design parameters.

More recently, designers have explored latching within the power bus, using a tab that slides the length of the inside panel until reaching an indentation. Figure 2 visually displays the process. When this tab arrives at the recess, XSAS has fully deployed, and the tab prevents any reversal of movement. The external knob allows operators to recompress XSAS, which is required for flight tests. Pushing in on the knob displaces the tab, permitting the operator to smoothly collapse the scissor structure.

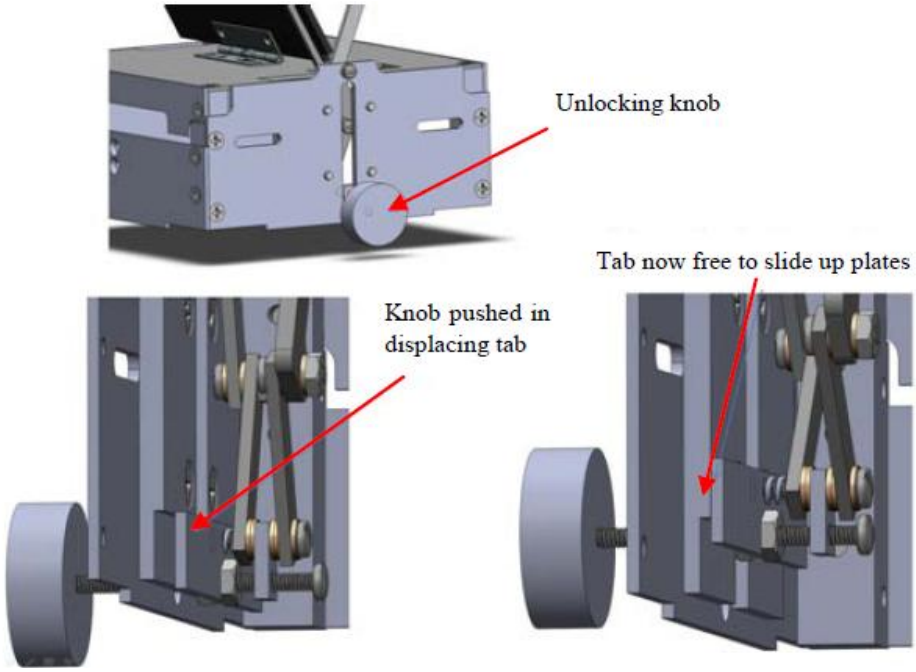

Figure 2: Latching Mechanism Locking and Release Process (replicated from Trabert[3])

3. Gravity Gradient Stabilization

By utilizing its own inertial properties when fully extended, XSAS can keep its longitudinal axis directed down towards the Earth. Acting as a ballast boom, XSAS will naturally orientate its elongated axis perpendicular to the Earth's tangent plane beneath it. Applying Newton's second law and Euler's equations to the body fixed axes exposes a restoring torque that re-orientates the vehicle to point in the nadir (towards the Earth). Thus, separated ballast masses on the top and bottom assemblies enhance the de-tumbling of XSAS after ejection from the P-POD. Aerodynamic drag and solar radiation drag exert nontrivial reactions on the solar array system. As a result, the gravity gradient, should ensure that the restoring torque be greater than any other acting moments. Since the XSAS boom will settle in its nadir stable equilibrium position, any disturbances will be damped.

4. Prototype Tests

In order to adequately study the mechanics and responses of the solar array system, an extensive range of both ground and flight tests are being conducted. The Technology Readiness Level (TRL) measures the maturity and advancement of a technology for implementation in a larger system. A series of repeatable, successful trials would prove experimentally that XSAS can be realistically refined for eventual incorporation onto a CubeSat.

4.1 Ground Tests: Fabrication and cost requirements of XSAS dictate that all components of XSAS originate from commercial products, being modified only through student accessible machinery. This allows for rapid prototyping of designs and facilitates ground tests and feasibility studies. Early testing demonstrated functionality, manufacturing methods, and system integration. Experiments focused on the latching mechanism and Dyneema burn. Since ground tests feature an influence of gravity that will be absent in flight, deployment was reproduced horizontally using bearing balls on a near frictionless surface. Thermal tests on the hinges assuaged any concerns regarding the impact of the harsh thermal environment of space.

4.2 Flight Tests: NASA's Microgravity University provides a unique opportunity to test the deployment of XSAS as a free-float, zero-gravity experiment on the G-Force One. Such a free-float microgravity test flight was conducted in June of 2010 in order to increase the Technology Readiness Level (TRL) of XSAS. The six degrees of freedom provided a realistic experimental model to measure the stresses and strains on the scissor structure and panels. The bending due to gravity and the contact points of a ground test severely inhibit accurate data collection. Moreover, a frictionless environment changes the latching dynamics during extension, since small angle oscillations are not damped out. To simulate deployment in space, an independent structure rotated and then released the system similar to a P-POD ejection. Two arms on the structure spun the XSAS payload along its longitudinal axis until the electromagnets disengaged, allowing XSAS to float freely and extend.

The flight test measured acceleration and rotation rate, in addition to strain on the hinges. An Inertial Measurement Unit (IMU) was located on the upper and lower assemblies of XSAS and synchronized through an independent video camera. An onboard datalogger digitized these analog signals and recorded them on a microSD card. On average, XSAS deployed in 0.43s and maintained a 56 deg/s rotation about the longitudinal axis

5. Future Operations

Unexpected behavior in the microgravity environment indicated that additional experimentation is required before final integration on a CubeSat. Since XSAS deployed faster than expected, researchers observed a visible bounce-back at the end of the extension. This could be mitigated by slowing down deployment by including a hinge damper. The latching mechanism is currently being shifted horizontally to allow for more space for solar panels. To date, researchers have focused only on the mechanics of the scissor structure. Solar cell technology has yet to be incorporated into the electrical system. Moreover, a future microgravity mission is being considered before launch approval on a satellite.

6. Conclusion

Researchers at the University of Michigan are developing the eXtendable Solar Array System (XSAS) to provide 20 W of continuous power for mini-satellites, called CubeSats. XSAS, a 10x10x15 cm structure can modularly attach to any generic CubeSat, which can use the increased power to expand mission criteria. The deployment sequence begins by burning the Dyneema wire, allowing the hinges to exert a net torque on the panels and extend the assembly. Movement terminates after a latching mechanism engages. The extended system also acts a boom to stabilize the structure using the passive gravity gradient of the Earth. While functioning prototypes have successfully demonstrated a concept infancy, additional simulations, design iterations, and flight tests are required before this novel design reaches flight hardware status.

Resources

[1]Martincheck, Patrick. “Evaluating the Extendable Solar Array System in a Microgravity Environment.” The Microgravity University, Johnson Space Center Houston, NASA, October 27, 2009.

[2]Senatore P., “Concept, Design, and Prototyping of XSAS: A High Power Extendable Solar Array for CubeSat Applications.” Proceedings of the 40th Aerospace Mechanisms Symposium, CP-2010-216272, NASA, May 12, 2010, pp 431-444

[3]Trabert, Rachel. “The eXTendable Solar Array System: A Modular Nanosatellite Power System.” American Institute of Aeronautics and Astronautics Conference. July 24, 2010.