Deployable Stable Particle Deflector for Nano Satellites

Joshua C. Thibaudeau[1] and Blake A. Krause[2]
University of Alabama in Huntsville, Huntsville, AL, 35816

At the University of Alabama in Huntsville (UAH), a particle deflector is being developed for application on CubeSat orbital operations. The design and implementation of a stable particle deflector is to allow for passive deorbit of satellites. This can increase mission time and allow for extended research conditions. This technology could be applied to deorbiting decommissioned satellites currently stranded in overpopulated orbits. Development of a compact deployable particle deflector will allow for CubeSats to induce an accurate and predictable stable drag force upon the system. Currently the system is developed to the form of a mechanical prototype with work being done on the supporting electronics for the system as well as the programming. A microgravity flight is scheduled for mid-2013 where 3D imaging and a functional test of the system as a whole under flight like conditions. The system shows promise for the CubeSat community and will deploy from a minimal volume to meet our needed accelerations for the mission.

Nomenclature

ADCS = Attitude Determination and Control System

CG = Center of Gravity

CP = Center of Pressure

UAH = University of Alabama in Huntsville

U = 10cm x 10cm x 10cm CubeSat specification

I. Introduction

Every satellite that is put into orbit today must remove itself from a useful orbit after a 25 year life cycle to prevent an accumulation of space debris. Some satellites that wish to be placed into orbits higher than 600 kilometers must be equipped with a change of velocity device to ensure deorbit in the 25 year period. The particle deflector for CubeSats under development by the University of Alabama in Huntsville (UAH) Space Hardware Club will be used to safely deorbit CubeSats that are placed into high altitude orbits.

Proving this technology will allow the Space Hardware Club to place CubeSats into higher orbits and still guarantee the ability to deorbit in the 25 year window. Additionally, it will provide and aerodynamically stabilized system if need be; due to the pyramid-like structure of the particle deflector, the Center of Pressure (CP) of the satellite with the particle deflector deployed will be behind the Center of Gravity (CG), making the vehicle passively stable. A passively stable vehicle allows the vehicle to "point" into the velocity vector without an active control system. Because of the aerodynamic stability provided by this device, a satellite does not need to be equipped with a complex and expensive Attitude and Determination Control System, or ADCS for short.

[1] Student, UAHuntsville Space Hardware Club, AIAA Student Member, jct0011@uah.edu.
[2] Student, UAHuntsville Space Hardware Club, AIAA Student Member, bak0004@uah.edu.

II. Particle Deflector Theory

The major mode for changing velocities currently consists of some form of a booster that moves the satellite into a graveyard orbit. Once a satellite enters a graveyard orbit the satellite spends the rest of its time slowly orbiting the Earth and will not reach the upper atmosphere of the Earth to burn up. Instead, these satellites collect in these higher orbits like dust on a set of records. At some point in time these orbits will also fill up and then future spacecraft will need to be engineered to clean out these orbits. The major reason satellites are boosted into these high altitude orbits is because the cost of attaching a deorbit system greatly exceeds that of adding the small boosters required to move up to the graveyard orbit. The Particle Deflector is an attempt to study of the feasibility of a cheap and light-weight deorbit system. The extra surface area provided by the Mylar sheets greatly increases the frontal surface area of the vehicle and collides with many more particles of the upper atmosphere and space particles. The collision of these particles with the Mylar sheets will produce a drag-like force on the satellite causing a steady decrease in velocity and expose the system to a greater density of particles from the upper atmosphere as the orbit decays. Eventually, the satellite's orbit will decay and then the satellite will burn up on reentry, thus keeping the graveyard orbit a little cleaner.

Every satellite is placed into orbit for its own reason. Since the purpose of each satellite is different from the next. On payloads and Satellites where minuscule accelerations are required, the Particle Deflector can also be deployed to counter the wobble that the satellite may experience from its deployment and greatly decrease the accelerations the satellite experiences. Once stable, the Particle Deflector has the ability to retract and prevent the satellite's orbit from decaying further but provides an alternative to complicated ADCS's. Therefore this reusable Particle Deflector can be used to stabilize a satellite if any on-board action causes wobble.

For ChargerSat 2, the Particle Deflector must fit into a compact volume at the back of the satellite and be able to both deploy and undeploy a sail producing a net acceleration of 10^{-5} in order for the primary science payload of the mission to collect data from multiple accelerations. The sail needs to undeploy in order to maintain orbit time in order to downlink the greatest amount of data possible from the mission.

III. Manufacturing and Materials

All prototypes and flight units for the particle deflector will be manufactured at the Student Prototyping Facility at UAH. The facility contains CNC mills and lathes as well as numerous manual machines, rapid prototyping equipment and several other manufacturing techniques. The mechanical pieces of the particle deflector will most likely be machined on the three or four axis CNC mills.

The mechanical aspects of the particle deflector will be machined from aluminum. The aluminum material was selected due to the lightweight characteristics as well as the strength of the material. The Aluminum will be anodized for surface finish and durability. The aluminum will be utilized for the mounting plate, the internal and external hub, as well as the gears for the device.

The support structure for the sail of the particle deflector will be composed of Nitinol memory wire. This material was selected due to its flexibility in shape as well as the ability to retain both strength and structure over hundreds of cycles of the system. This integrity of the material is key in the particle deflector remaining consistent throughout deployments and retractions.

The material selected for the sail of the particle deflector is Mylar. Mylar was chosen for the sail due to the extremely low mass necessary for the sail. The Mylar will be folded for compactness before deployment and will retain surface flatness upon deployment by being backed by Kapton tape. The tape will leave the folds consistent as well and allow for the sail to refold itself into the compacted position as it is undeployed.

IV. Design of the Particle Deflector

Design of the particle deflector then began in order to meet these requirements. The first design involved a ¼ inch thick 2 inch outer diameter ring with a parabolic cutout for the Nitinol wire to be held in with set screws. This design was centered on a slotted peg with an outer diameter of 9/16". The peg's slots are for the Nitinol to run through and then wrap around the peg upon undeployment and packing the sail.

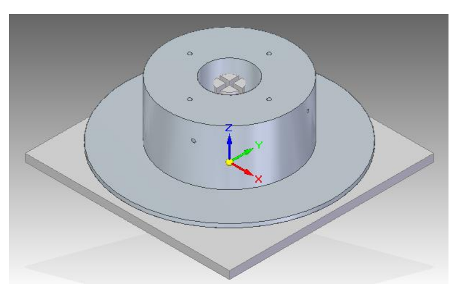

Figure 1: Particle Deflector design 2 pictured without sail or Nitinol.

The main flaw of this design was that the set screws to hold the Nitinol and the U shape in general did not do much for retaining the shape of the Nitinol beyond the structured device. The device also would not wrap itself around the peg and remain within the cutouts on the outer piece. Retained from this initial design were the center peg design and the use of Nitinol.

The second design was then a redesign of the outer Nitinol holder. The dimensions remained the same for the radii but the device was made taller to a new dimension of 1” with angled holes for the Nitinol to deploy at the desired angle of thirty degrees. This design also incorporated a plate on the bottom in order to keep the Mylar from tangling itself in the rotating assembly. The final CAD model of the second design is shown in **Figure 1**. This system brought to light a major flaw with the peg and base configuration. For the ABS model of the system, the torque of the system on the slotted peg would bend before the Nitinol would deform as intended. Then after this deformation in the peg and base, the Nitinol would then wrap itself upon the peg from the slot normal to the curve. These sharp turns caused the Nitinol to kink and restrict rotation. Also the drilled slots in the outer seemed to restrict the outward flexibility of the Nitinol. This angle also did not seem to aid the deployment at the desired angle. The slots did however provide a lot of friction to the system.

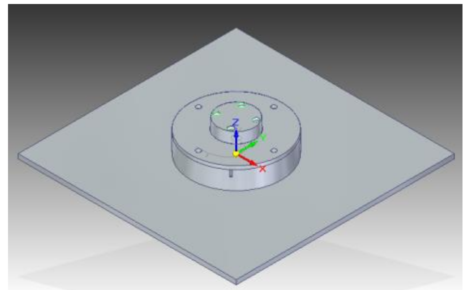

Figure 2: Third design of the Particle Deflector showing the change in center section and hub as well as the change in outer dimensions

The second design was then overhauled over several iterations to create a third design. The final result was a ½” tall 1 inch outer diameter outer piece and an inner piece with a radius of ¾” for the Nitinol to wind around. Also the exit of the Nitinol from the inner spool was altered to make the Nitinol exit the spool near tangent to the spool. These improvements were determined to be a sufficient radius for the Nitinol to not kink itself. The design was also improved to incorporate a closed off center section to keep the Mylar from getting tangled between the moving and non-moving parts. Finally the outer holes were changed to slots in order to relieve the friction from the original holes. This design is shown in **Figure 2**. This system was tested and worked very well but the Nitinol tangled with itself as it wrapped the core after twenty plus rotations. The pieces retained from this design were the center piece and the slots of the outer, moving piece.

The fixes to the issues with the third design were then worked into a current model (shown in **Figure 3**). The outer rotational part now incorporates a gear and limits the winding surface of the Nitinol on the spool to just over a diameter and a half of the wire. This limitation of the Nitinol’s winding area limits the ability of the Nitinol to tangle amongst itself. The gear along with an added motor and mating gear makes the device operate electronically via a microcontroller. The model also incorporates photodiodes and a laser system to encode rotation of the device. These improvements should produce a nearly finished mechanical prototype for the unit.

This hands-free operation is one of the final steps needed for flight operation and will allow for deployment and undeployment upon orbit.

V. Conclusion

Every satellite today has to have an end of life plan set in place in order to keep our usable orbits clean for future missions. Devices such as UAH’s Particle Deflector are one possible solution to deorbit satellites while still keeping costs low. In addition to the low cost of this system, it also has the ability to double as a stabilizer for the satellite and will then retract in order to maintain the vehicle’s orbit. The Particle Deflector will be machined from aluminum and will also utilize Mylar and Nitinol for the sail. The current design of the Particle Deflector meets all of the mission requirements for the mechanical system and should fit within 1/3 U when packed in the launch configuration. Extended testing of this model is planned over the coming months along with a microgravity flight opportunity in mid-2013.

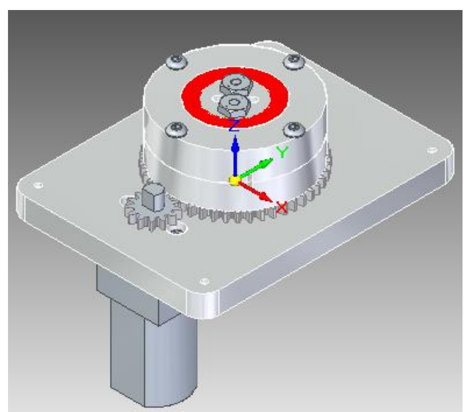

Figure 3: Current design of the particle deflector with a smaller plate and added motor and gear system.