Altitude-Limiting Airbrake System for Small-Medium Scale Rockets

Robert F. Aaron, III
Kennedy Space Center
Undeclared Engineering Major
Mechanical Design Engineer Intern, Fall Session
December 20th, 2013

Abstract

The goal of the overall internship opportunity this semester was to learn and practice the elements of engineering design through direct exposure to real engineering problems. The primary exposure was to design and manufacture an airbrake device for use with small-medium scale rocket applications. The idea was to take the presented concept of a solution and transform said concept into a reliable fully-functioning and reusable mechanism. The mechanism was to be designed as an insurance feature so that the overall altitude of a rocket with relatively undetermined engine capabilities does not unexpectedly exceed the imposed 10,000 foot ceiling, per range requirements.

The airbrake concept was introduced to the Prototype Development Lab as a rotation-driven four tiered offset track pin mechanism, i.e. the airbrake was deployed by rotating a central shaft attached directly to the bottom plate. The individual airbrake fins were subsequently deployed using multiple plates with tracks of offset curvature. The fins were created with guide pins to follow the tracks in each of the offset plates, thus allowing the simultaneous rotational deployment of all fins by only rotating one plate. The concept of this solution was great; though it did not function in application. The rotating plates alone brought up problems like the entire back half of the rocket rotating according to the motion of the aforementioned base plate. Subsequently, the solution currently under development became a static linear actuator-driven spring-loaded fin release system. This solution is almost instantaneously triggered electronically when the avionics detect that the rocket has reached the calculated altitude of deceleration. This altitude will allow enough time remaining to the overall ceiling to adequately decelerate the rocket prior to reaching the ceiling.

Working at the Prototype Development Laboratory at Kennedy Space Center quite consistently brings unexpected occurrences. This internship opportunity was designated "engineering design" internship, and although the title may sound slightly vague, it is necessarily done, so as to best envelope all that was completed and learned throughout the opportunity. Among many other things, projects during the allotted 16 weeks of internship study ranged from modeling a heat exchanger/cold plate for use with an existing model to using an advanced CMM (coordinate measuring machine) for locating an essential hole pattern, to designing a reusable air brake for small to medium-scale rockets. The later became the main focus of the internship and it was designed essentially from start to finish during the opportunity.

The idea for the airbrake originated with the establishment of the Rocket University program at the Kennedy Space Center. Rocket University was instituted as an inter-center post Space Shuttle training program to help fill the gap until the SLS/ Orion programs are up and fully running. The program has multiple branches/ sub programs designed to further the overall NASA systems engineering prowess while time is available to do so. One of said sub programs is to design a small to medium-scale rocket from start to finish. The rocket was to be completely original in design and built to satisfy certain learning outcomes. The outcomes were imposed as means of further progressing systems engineering knowledge of NASA engineers from various disciplines.

At the initialization of the rocket design sub program, the intent was to launch near Palm Bay, FL, where there is a strictly enforced FAA 10,000 ft altitude ceiling for craft without an airspace permit. Although the firing range has since been relocated to

Kennedy Space Center and the ceiling is no longer required, it remains as a self-imposed goal of finding ways to manipulate a craft with relatively unknown capabilities.

Intended to portray the raw idea of having an airbrake on a rocket, the airbrake solution arrived at the KSC Prototype Development Laboratory more as a concept than a solution. Such a device had never been needed before. Subsequently, many different design iterations were considered, per the engineering process. Originally a 3D printed concept device (shown at right), the job of the PDL became discovering a way to realistically initiate a near perfectly- immediate deployment of the brake mechanism, while also insuring structural integrity of the rocket. The later became highly relevant upon discovering the abnormally transferred loads through the fuselage. Initially, the presented rotation-driven system seemed viable, pending some necessary innovations. This design concept revolved around three essential plates and a separate tier for the brake fins. The four-tier system (shown below, left) contained a central mast connected to the bottom exterior plate. Therefore, by applying rotation to either the mast or the attached plate, all three brake fins could be rotationally deployed simultaneously using track pins and offset curvature through the plates. Conceptually, a design that could be activated by moving only one component sounds highly logical, especially by Murphy's Law. However, in this application, moving only one component provided many more problems than an easily-activated device solved. Most notably, if the primary brake module contact points were allowed to rotate, either the anticipated 9-10 g loads would have transferred through three

Figure 1. Top View of Original Concept Device

Figure 2. Oriented View of Original Device Showing Four-Tier System

thin slivers of body fiberglass or the entire aft section of the second stage had the potential to rotate according to the motion of the plates. Therefore, encountering alternative design possibilities became essential.

After progressing through a handful of design iterations, the integrated simultaneous rotational fin deployment concept was abandoned. Designing such a mechanism was deemed possible, but definitively not the most practical solution. It was decided that the fins should be individually deployed by a central system, thus eliminating the possibility of one stuck fin jamming the whole system. This solution also allowed the deployment to become significantly faster- on the scale of tenths of a second after detection of the calculated deployment altitude. Subsequently, developing a spring-loaded system governable by a centralized static linear release mechanism (right) became the focus. All that currently remains of the original concept is the actual geometry of the brake fins and the idea of tracks and guide pins, although the application has been intensely modified.

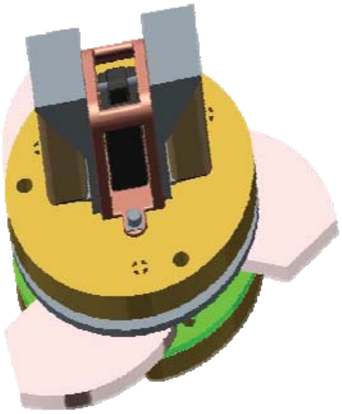

Figure 3. Trimetric View of Developed Mechanism (Fuselage and coupler sections not shown)

Upon the designation of the release concept, the major design issues became the fin release driver and the method of attachment to the rocket fuselage. At various stages along design process, the release driver has matured from an explosive charge to a linear solenoid, then to a programmable servo, and ultimately a Firgelli® Micro Linear Actuator. Although it would allow nearly instantaneous release of a spring- loaded fin system, the explosive charge release was abandoned primarily due to possible ventilation issues. Also, despite sounding fantastic for such application on paper, inconsistent force output values eventually doomed the solenoid. Selecting an actuator over the programmable servo was merely a convenience for ease of use. Use of a servo with a built-in limiter required an additional external Arduino board, whereas a linear actuator only requires a DC power supply. Such a power supply, readily provided by two 9V batteries, is an easy tie-in to the existing rocket avionics infrastructure. The polarities can also be easily reversed to reset the device after use. Calculated using a force vs. time curve from the manufacturer and anticipated friction loads, the aforementioned actuator's release time is anticipated to be approximately 0.47 seconds from initial activation. "Release time" here is the interval between the signal being sent by avionics and deployment of the fins by high-torque torsion springs. This number will be included in the calculations for the airbrake deployment altitude to allow adequate deceleration prior to 10,000 ft.

Over the course of the design cycle, designing the attachment method to the rocket fuselage became greatest design challenge. One of the primary design constraints presented to the PDL was that the device be included as a removable module. The main implication of this constraint is that the brake module cannot be simply adhered to a fuselage coupler section. The obvious solution is to place the actual brake module into a fuselage section and then screw the coupler sections together to make the module optional. However, if performed crudely by directly attaching a button screw, or worse, a countersunk screw to the fiberglass fuselage, the issue quite rapidly becomes control of shear stresses. The fiberglass used for the fuselage is, like most fiberglass products, very strong in compression but troublesome when tension is applied over a small area. Therefore, the issue became whether or not the screw holes in the fiberglass would be able to sustain the shear loads applied throughout the flight without tearing out or otherwise damaging the fuselage. Such loads primarily included launch g- loading, but tensional drag loading following fin deployment is also being analyzed. The total drag force estimated on the post-deployment fin area is approximately 46 lbs., which alone does not sound like a high shear value. However, when applied across a shear area like the diameter of a #6 screw (maj. .138 inches) and the small thickness of the fiberglass, it is realized that the stress values on the fuselage near the screws is actually relatively high. Therefore, the solution found by the Prototype Development Lab is the addition of a stress ring to the outside of the fuselage section. This ring will be adhered with epoxy to the external surface of the fuselage in order to distribute applied stress away from the countersunk screw holes. Impossible without the ring due to outright cracking issues, added countersunk holes in the ring will allow increased aerodynamic efficiency.

Although still pending further review from the KSC Chief Engineers Office, some analysis on the device has been done to date. Starting with fuselage attachment regions, the attachment medium will be HySol structural adhesive. With a possible 10 g launch load and up to 20 lbs. above the airbrake module, a theoretical load of 240 pounds was used in all of the calculations where launch loading issues are most probable. The first load transfer section will be the device's end cap-fuselage interface. 3D printed upper and lower end caps will be adhered directly to the fuselage section. Over a shear area of the end cap circumference multiplied by the thickness, the factor of safety has been calculated to be 252.9, assuming uniform distribution of the resin. Both end caps have the same thickness and circumference; therefore calculations were the same for both. Between these end caps, loads will be transferred via three steel pins. These pins are also the pivot points for the fins being deployed, as well as the axial anchor for the deployment torsion springs. Therefore, due to the crucial nature of this junction, redundant features were instilled in the design to ensure the integrity of the device. Such features include a .625” cross printed in to the end cap pin hole to add strength to the joint. The pin hole will also be filled with HySol adhesive to hold the pin in place. Calculations were performed at this junction assuming multiple failure scenarios. The primary and most probable scenario assumes total blow out of the 3D printed end cap material. If this should occur, the load would be entirely transmitted through the resin to the pin. However, with the designed .25” insertion of the pin into the end cap, even with no additional support and a high theoretical max load, the factor of safety for this junction was calculated to be 8.1. For adhered junctions, a factor of safety approaching 10 is desirable due to possible inconsistencies in the adhesive or its application. Although this F.O.S. is slightly on the low side for a resin junction, the pin will also be redundantly supported by the end cap cross. The Finite Element Analysis image at right illustrates the anticipated stress region and an exaggerated demonstration of potential deformities.

Figure 4. Finite Element Analysis View of End Cap Under Predicted Loads

Although the mechanism design is currently pending review, the device should be complete by the beginning of the coming year. We believe that this airbrake system will successfully decelerate the Rocket University rocket such that the altitude will not exceed 10,000 feet. Such deceleration will be ensured by the airbrake device after a successful two-stage launch and activated using a micro linear actuator, which will be directly linked to the rocket avionics system. Upon retraction of the fin release cup, the three fins will be made to pivot using high-torque torsion springs surrounding the three main structural/pivot pins. Once these fins are released, approximately 46 lbs. of drag force will be applied to the system to aid in decelerating the rocket. Assuming a successful launch and safe return to ground, the airbrake system for will then be re-loaded by depressing the fins/ torsion springs and reversing the polarity on the actuator, thus concluding the recycle process and preparation for its next flight.