The Umbilical Cord Connector Ejection System

The Redesign and Implementation of the Portland State Aerospace Society Rocket's Umbilical Cord Removal System

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Executive Summary

The main power cable, often referred to as an umbilical cord, of a rocket must remain plugged into the rocket until the second that the rocket is launched due to simultaneous data transfer and system monitoring that takes place. The problem with this is that the cable also needs to be unplugged before it is damaged by the rocket's takeoff. Due to safety concerns during the rocket's launch nobody is allowed to stand near the rocket when it launches which creates the dilemma of how to remove the umbilical connector without compromising the safety of the engineers or the efficiency of the rocket takeoff.

In order to solve this problem I developed a system that uses a spring-loaded assembly to eject the connector from the side of the rocket once the rocket is launched. In designing this assembly I analyzed several springs, evaluated measurements, and used a 3D printer to create a model of the connector ejection system so that I could begin to a use it experimentally, taking into account speed, force, and the acceleration due to lift-off. The final analysis was a trial run with the actual model; we evaluated the system as it was used as the primary umbilical cord ejection system for the Portland State Aerospace Society's rocket during Launch 11 in July 2014.

Due to the outstanding performance of the connector ejection system during PSAS's launch 11 and the low cost that is required to produce this system, I believe that the model I have developed should be used for all future PSAS launches that involve a high-level electrical components, such as with the current society's rocket.

1. Introduction

Overview

Safety is one of the most important things an engineer must take into account. In order to ensure the safety of the participants during a rocket launch of an amateur rocket of level 1 or higher people need to stand around 500 feet away from the rocket. On the Portland State Aerospace Society, PSAS, rocket there is a main cable, often called the umbilical cord, that must be hooked up to the rocket to monitor its systems immediately preceding the moment the rocket launches, at which point the controls become passive and the launch computers can only observe occasional data that the rocket has been programmed to output. The main cable of the rocket then needs to be unplugged, however, due to safety concerns, no one is allowed to stand near enough to unplug it. A lever system was eventually developed that would remove the cable as well as operated as a function of the rocket's height. Recently however, the connector for the umbilical cord has been switched out due to an increase in data transfer between the computers and the rocket as well as the outdated nature of the original umbilical cord connector, see figure 1.

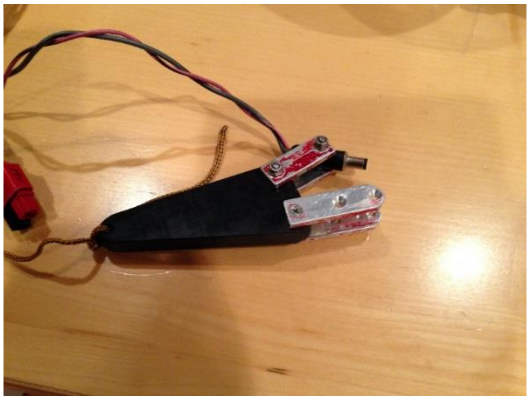

Figure 1 Original Umbilical Cord Remover
Source: Umbilical cord remover property of Portland State Aerospace Society

The old removal system involved drilling a hole through the center of the connector to attach it to the lever while the new connector, however, cannot have a hole drilled through it as it would interfere with the connector's internal wiring. I have developed a new system to remove the umbilical cord connector from the rocket during the launching process. With this change there are a few different design specifications that needed to be made. The new system should be self-contained; as the rocket ignites a plume of smoke and flame shoots out of the tail. If the system is not self-contained it is highly probable that parts of it can get lost. It needed to be able to remove the connector before the rocket reached a height of 1.5 meters at which point the umbilical cable would be ripped apart which could affect the flight pattern of the rocket. As an added feature I made the new system lightweight and more compact than the current system. The system that I have developed meets the preceding guidelines, is cost effective, and efficient. It is because of this that I believe my new system should be used for all future PSAS launches.

The Solution

The system that I have developed uses a compressed spring in order to create the force needed to remove the umbilical connector from the rocket in a timely manner. This system is made up of 4 main parts; the cuff, the spring, the spring stop, and the fork. The connector is glued into the cuff making it a single piece that moves in tandem. The spring is then fixed to the inside of the cuff and the spring stop is fixed to the other side of the spring, see figure 2(a) below. Once the spring is compressed the fork is slid into to cuff and through the side of the spring stop to hold the assembly together as figure 2(b) shows.

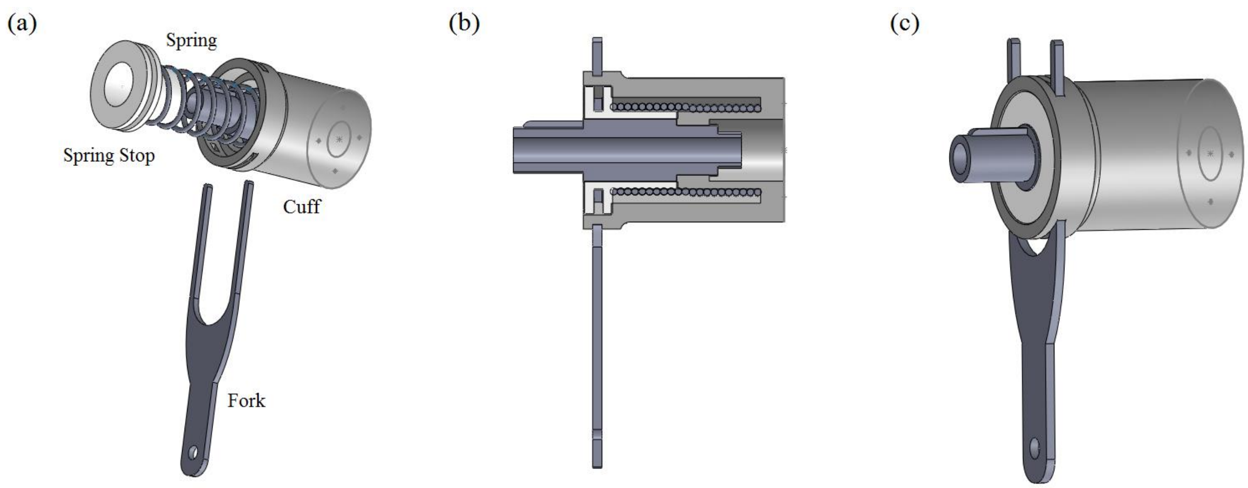

Figure 2 (a) The system is made up of four main parts; the cuff, the spring, spring stop, and the fork. (b) Once the spring is compressed the fork can be placed in the slots in the cuff and the system is held together until the fork is removed. (c) The system with the spring compressed. *(Photo and draft by Dylan Stephens)*

The assembly, as one piece, is plugged into the side of the rocket and the fork is attached to a cable that is staked into the ground. When the rocket lifts off, the fork is pulled from the assembly and the spring is released, which disconnects the connector and expels the cuff and assembly away from the rocket. In the development of this system I used both trial and error, as well as mathematical analysis in unison.

2. Analysis

Springs and Design

In order to determine the correct force that was required to remove the connector from the side of the rocket, I purchased and tested four different compression springs. I went about testing them by measuring the different dimensions ("Shigley's Mechanical Engineering Design" 521, Table 10-1) of each spring and calculating the spring constant using the following equation: F_x=kx ("Fundamentals of Physics" 149, eq. 7-21) Where my F_x was the force required to close the spring and x was the distance between the solid length and the free length. The measurements and calculated spring constants can be seen in table 1 below.

	Spring A	Spring B	Spring C	Spring D
Coil Mean Diameter, D (cm)	1.7	1.96	1.98	1.8
Wire Diameter, d (cm)	0.152	0.127	0.203	0.127
End Type	Squared	Squared	Squared	Squared
Number of coils, N_t	11	12	14	14
Free Length, L_o (cm)	5.5	7	8.5	8
Solid Length, L_s (cm)	1.75	1.5	3	1.75
Force required to closure, F_s (N)	55.2	14.23	124.6	19.57
Spring Constant, k (N/m)	1472	258.73	2265.5	313.12

Table 1 Spring Dimensions of Purchased Springs

One of the requirements was that the spring be a length that can fully disengage the connector before it has reached the spring's free length. The minimum length required is 2 cm, since that is the distance of the connector's plug. To ensure that the connector is ejected to a safe distance and that the connector does not get hung up in 'the female end', which is mounted inside the rocket, I factored in an additional 2 cm for safety making the required distance between solid length and free length a minimum of 4 cm. This eliminated spring A as a possibility.

I decided to use spring B as it was the weakest and made a model of the assembly on Solidworks, a 3D drafting program, which accommodated the dimensions I had measured earlier. Once the model was designed I was able to print it using a 3D printer and then began to test and analyze the design. I quickly learned that there were certain aspects that I needed to change due to alignment issues between the spring and the cuff, over-designing of the cuff, and even minor flaws caused by the printing process. Once I made those changes to the 3D drawings, I printed another set and contemplated how I was going to make the system self-contained. I needed to attach the spring, cuff, and spring stop so that the constant motion of compressing and releasing the spring would not break the mechanical bonds that held everything together. I finally figured out that I could drill small holes in the cuff and spring stop, and tie each piece to the spring with fine wire. With this epiphany I needed to change the 3D drawings again to make space for the holes in the cuff and spring stop. I finished the design by crafting a fork in SolidWorks and then cut it out of 0.06 mm aluminum using a laser cutter. Once everything was made and bound together it was time to begin testing the system to ensure that it would work properly and consistently succeed in removing the connector from the rocket.

Testing of the Assembly

In changing the design from a lever system to a spring-loaded design there was a concern that the spring would not remove the connector quick enough and the flight path would be affected by the remnants of the assembly and a damaged, still attached umbilical cable. This concern was brought to light with the realization that the old system operated as a function of the height of the rocket only; when the rocket moved up one millimeter the end of the lever would move down one meter. This new design operates as a function of height, with the removal of the fork, and as a function of the spring force, as the tension of the compressed spring is released. To verify that the spring would be able to remove the connector quick enough I used a high speed camera to review the time lapse between the removal of the fork and the complete release of the connector from the rocket. I was able to gain access to a high-speed camera and, at 600 frames per second, recorded the assembly as the fork was removed and the connector expelled from the rocket. I then counted the frames that had elapsed between the removal and complete disconnect. The time between the removal of the fork and the complete separation of the connector from the rocket was captured in 6 frames, meaning the time lapse is 0.01seconds. The outside diameter of the cuff where the fork fits is 3.4 cm thick. This means that the rocket has to travel a minimum of 3.4 cm before the fork is removed and the spring is released. Since the fork will actually be a little longer we can estimate that the rocket has to travel at least 4 cm upward to remove the fork. With that knowledge and the data obtained through the use of the high speed camera we can estimate where the rocket will be once the spring has released and the connector has been disconnected. One of the students that is part of the Portland State Aerospace Society, or PSAS, has made a highly realistic model of the current rocket that Portland State University uses ("Re: OpenRocket Model of PSAS launch vehicle lv2.3"). With his help we were able to input the size of motor that will be used in the upcoming launch, then map out and calculate that the rocket would be 7 cm upward from the starting position 0.01 seconds after it has already traveled 4 cm upward. This meant that the spring is more than strong enough to disconnect the umbilical cord connector before it reaches the required height of 1.5 meters. While talking to another member of the PSAS team I discovered that there was one factor that I had neglected when considering this type of assembly; the forces caused by acceleration. The motor that is being used in the PSAS Rocket has a peak thrust of around 3,500 N ("Motors: CTI 15227N2501-P") and the rocket weighs approximately 34 kg ("Psas/Launch-11"). Given those statistics it can experience a maximum of 10.5 g's. To simulate the force caused by this rapid acceleration, I weighed the assembly with the cable that will be attached to it and multiplied that weight by 10.5 then suspended that weight from the cuff while the connector was plugged in. I then proceeded to remove the fork to see if the assembly would eject; the system bound and would not operate properly. I attempted to fix the problem by filing down the cuff at the point of contact, but was unsuccessful. Since there is a level of uncertainty about the exact amount of force that would be applied during the acceleration, and since the failure to remove the connector could cause the rockets path to be altered as well as damage the umbilical cable, I opted to take the safe route and use spring C as it had the largest spring constant. With the change in spring, the cuff and spring stop had to be minimally redesigned a final time and then tested. The fork also needed to be made out of a stronger material to prevent it from bending; for this I chose 1.5 mm steel. With those changes the system was ready to be tested and analyzed again. The final assembly operated perfectly with the weight hanging from the cuff.

As a final step in the analysis process I was able to test my design out at the most recent PSAS launch, launch 11, which took place on July 20th, 2014. It worked flawlessly and had no negative effects on the rocket's flight path.

3. Conclusion

The design was tested and analyzed mathematically and was proven to be our best option for various reasons; I had finally found a system that worked successfully, and that met all the requirements. The new assembly is compact, made up of a cylinder that is 3.4 cm in diameter and 4.3 cm long. With this new design I was also able to make the assembly self-contained, as well as efficient, and compact.

Recommendations

There were a few natural objections that came up while designing this system. The first was due to the addition of the spring. With the spring being added the removal of the connector became function of the spring force as well as the height, instead of just the height. To resolve this objection I tested the assembly and filmed it using the high speed camera and it was found that the spring force moved so rapidly that the change would not make a difference. The other big objection was whether the system would be able to overcome the downward force that was present due to the acceleration. This problem was also easily resolved by applying a downward force equivalent to 10 g's on the rocket cuff and testing its operation.

If I had a little more time I would test the speed of the assembly with spring C in it using the high speed camera so I could compare it to a different simulation in case one wanted to use a different motor. Another thing I think should be done is design a fail point in the assembly so that if the system binds then the connector will still be removed somehow.

I believe that the system that I have developed would be easy to implement into the current PSAS protocols for the umbilical cord remover for all future PSAS's rockets that deal with the same high-level electronics that the current rocket contains. In doing so, multiple connectors should be printed in the unlikely case that one should become damaged in either transit or on the launch platform. This, however, would not be difficult due to the access PSAS has to a 3D printer, as well as the low cost of production for the assembly. The total cost in designing the umbilical cord ejector was approximately $60. The cost per assembly is under $20 for parts and aside from the time required for the 3D printer to print the parts and epoxy-drying time, the assembly takes less than an hour to assemble.

4. Concluding Remarks

The umbilical cord connector ejection system is a well-designed model that goes above and beyond the requirements for the tasks that it must complete. It is a cheap and efficient model to replicate, and has been tested thoroughly both in the field and a laboratory setting; in both situations it has surpassed expectations. I believe that due to these results the system should be used on all future PSAS launches that involve a launch vehicle with the same high caliber of electronics that the current rocket uses. I further propose that PSAS post the documentation of this system in an open source forum to help aid other societies of amateur rocket users who may be dealing with the same type of problem that PSAS had encountered with past models.

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