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SUMMER RESEARCH TECHNICAL REPORT

Tactical Means to Stow Super-Caliber Tailfins of a Developmental Flight-Controlled Mortar

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14. ABSTRACT
The active control systems being used in new ?smart? munitions often require greater aerodynamic stability to properly operate. In the case of the Flight Controlled Mortar (FCM), this stability is provided by a set of super-caliber, spring-loaded, deployable fins that must be stowed prior to launch. For the testing and evaluation process, the FCM tail fins were secured using a single strand of thin Kevlar string. In an attempt to produce a more rugged tactical solution, research and development into alternative Fin Retention Devices (FRDs) was initiated at the start of the summer. After a thorough review of existing FRDs, I determined that a custom solution was needed to fulfill the needs of FCM. Using an iterative design process, concepts were modeled using SolidWorks, and physical prototypes were produced. Based on the analysis of these prototypes, further changes have been identified for ongoing revision. I believe that at the end of this project, a tactical FRD will be produced for testing and evaluation, and may one day be used for the FCM or similar systems employing folding fins.

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Abstract

The active control systems being used in new “smart” munitions often require greater aerodynamic stability to properly operate. In the case of the Flight Controlled Mortar (FCM), this stability is provided by a set of super-caliber, spring-loaded, deployable fins that must be stowed prior to launch. For the testing and evaluation process, the FCM tail fins were secured using a single strand of thin Kevlar string. In an attempt to produce a more rugged tactical solution, research and development into alternative Fin Retention Devices (FRDs) was initiated at the start of the summer. After a thorough review of existing FRDs, I determined that a custom solution was needed to fulfill the needs of FCM. Using an iterative design process, concepts were modeled using SolidWorks, and physical prototypes were produced. Based on the analysis of these prototypes, further changes have been identified for ongoing revision. I believe that at the end of this project, a tactical FRD will be produced for testing and evaluation, and may one day be used for the FCM or similar systems employing folding fins.

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Student Bio

I am a member of the Massachusetts Institute of Technology's (MIT) class of 2012, majoring in Aeronautics and Astronautics. In my time at MIT, I have participated in many hands-on research and engineering projects through the MIT Rocket Team as well as through coursework. In the 2010–2011 school year, I lead the Rocket Team in the National Aeronautics and Space Administration's (NASA) University Student Launch Initiative, placing second overall with the team's novel rocket-launched unmanned aircraft system. In the spring of 2011, as part of a senior capstone course, I and a partner developed and planned an experiment to test a face shield addition to the Advanced Combat Helmet in an effort to mitigate blast-induced mild traumatic brain injuries for Soldiers. The experiment is slated to be conducted in fall 2011. After completing my undergraduate degree, I plan to explore opportunities to gain secondary degrees while gaining hands-on research experience.

1. Introduction/Background

In an effort to provide the warfighter with precision indirect fire capabilities the U.S. Army Research Laboratory (ARL) is working in conjunction with the Naval Surface Warfare Center (NSWC), Dahlgren, VA, on an 81-mm Flight Controlled Mortar (FCMortar or FCM) program. The FCM project focuses on the development of a guidance and control system that is compatible with the standard 81-mm mortar system already in use. However, due to the active control surfaces used in this system, the standard M24 fin set cannot adequately provide the necessary aerodynamic stability. Therefore, a fin set employing spring-loaded super-caliber folding fins has already been developed for use with the FCM.

In the folded state, the new fin set allows the FCM to function with the standard M252 mortar tube. However, because the springs on the fin hinges are pre-tensioned for rapid deployment upon firing and muzzle exit, a fin retention mechanism must be employed to allow for proper travel down the length of the mortar tube upon "hand-drop." Furthermore, due to stability requirements, the fins must be deployed immediately upon mortar tube exit, within about 30 ms. For the purposes of testing and evaluation, this task was accomplished with the use of a single length of 0.014-in-diameter Kevlar (para-aramid) string located in notches on the trailing edge of the fins and secured with a single hand-tied square knot. Upon ignition of the mortar's propelling charges, the para-aramid string burns through and the FCM moves up and through the mortar tube, allowing for fin deployment upon muzzle exit.

Although this retention mechanism has worked for the test flight events in the testing and evaluation phase, there are two main concerns about its tactical use. First, the use of a single string lends itself to getting caught on items during storage and handling by the user. This increases the likelihood of the string being cut or broken, leaving the mortar in an unusable state until replaced. Secondly, properly installing the sting and tying the knot requires a great amount of time and effort. The increased difficulty in installing the string has tactical disadvantages as it would be difficult to accomplish in the field should the string need to be replaced. As such, it was tasked over the summer to research and develop possible tactical solutions to this fin retention issue. A tactical solution would be easier to install and be less prone to snagging or cutting damage, while still allowing for proper FCM operation.

2. Design Process

To complete the design of a fin retention solution in a systematic method, the design process was broken into three distinct phases: open literature review, modeling, and prototyping. Using this method it was possible to quickly move through the design process while minimizing time spent on fruitless paths. Furthermore, by using iterative design in the modeling and prototyping phases allows for the fin retention device to be further refined until all design requirements are met or exceeded.

2.1 Literature Review

By researching published documentation on deployable fin retention systems, as well as comparing existing products on the market, it was possible to learn how other systems tackle the challenge of fin retention. To begin this process, a market survey was completed, examining similar projectiles using deployable fins. It quickly became apparent, however, that the challenges of using spring-loaded fins on a mortar-type projectile are fairly unique in the field. This is primarily due to the fact that mortars are muzzle loaded and must travel through the launch tube under the influence of gravity alone before being propelled out of the barrel. Most systems employing super-caliber fins are breach loaded, and therefore, only travel through the barrel when being propelled by their primary charges. In many cases, these products also do not require fin retention systems because the launch tube can constrain the fins throughout the launch process. Of all the systems investigated, the only other mortar system identified was the 120-mm XM395 Precision Guided Mortar Munition. Some versions of this mortar system used a folding fin design very similar to that used in the FCMortar; however, no information was openly available on the fin retention system (*1*).

Finding no suitable solution in the market survey, a patent search was conducted in an attempt to identify other solutions applicable to the FCMortar project. Using the U.S. Patent and Trademark Office's searchable patent database and Google Patent Search, approximately 2,000 patents describing deployable fin retention methods were examined. Again due to the unique nature of the FCM's tail boom, no patents were identified that would be directly applicable. However two promising patents were identified providing the groundwork for future solutions. The drawings from these two patents can be seen in figure 1.

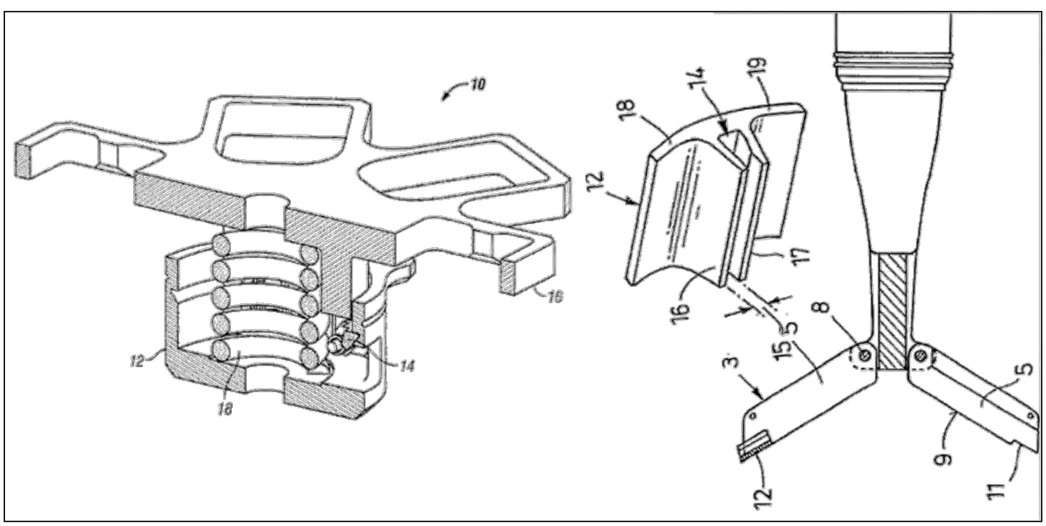

Figure 1. Patent No. 7851734 (left) and Patent No. 6314886 (right).

U.S. patent No. 7,851,734, seen on the left, describes a latch-based system that is actuated by the setback acceleration seen at launch. The mechanism shown in this drawing is located within the central core of the intended round, with the upper ring structure securing the fins until the initial setback acceleration of launch dissipates (*2*). Because of its central location, this patent would not work on the FCM. However, based on this patent, a spring-loaded ratcheting ring concept was developed, which would allow for external mounting around the tail boom. A conceptual diagram of this idea can be seen on the left of figure 2. U.S. patent No. 6,314,886 on the other hand described a completely passive device, labeled as number 12 in the drawing, which attaches to notches in the fins. The fins in this patent, however, are not spring loaded. Instead the patent describes a method of allowing the fins to ride along the gun barrel, and then deploy upon exiting the muzzle due to aerodynamic forces (*3*). Drawing on the topic of this patent, a ring structure was conceptualized, which would attach to the fins like in this patent, securing them while in barrel. A graphic of this ring structure can be seen on the right side of figure 2.

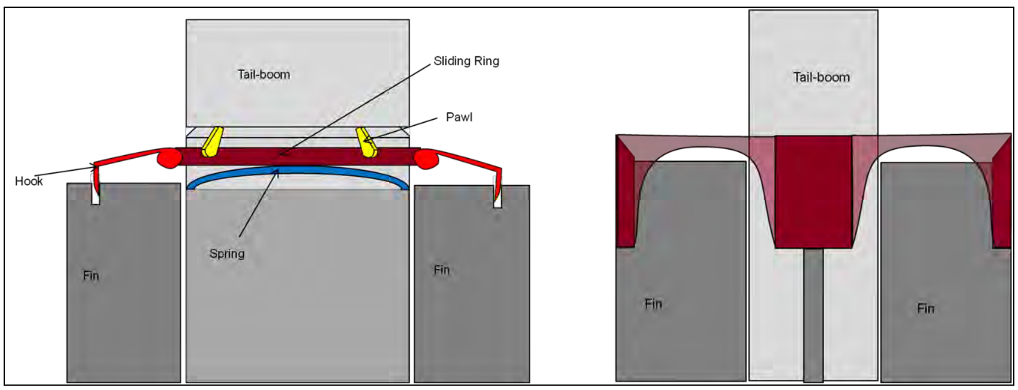

Figure 2. Conceptual drawings, active (left) and passive (right).

2.2 Modeling

After completing the literature review, concepts for possible Fin Retention Devices (FRDs) were explored and roughly grouped into two categories: active or passive. These categories were selected based upon the way the FRD would release the fins. After a brainstorming period, the best examples of passive and active FRDs were translated into conceptual drawings and briefed to some of the engineers and technicians working on the FCM project for additional input. These conceptual drawings can be seen in figure 2. From this meeting, it was decided that it was best to pursue a passive FRD as it would reduce the complexity of the tail section and simplify integration with existing aspects of the FCM.

With the determination to develop a passive FRD, the original concept, shown on the right of figure 2, was developed further and modeled in SolidWorks 2010 Professional. Using SolidWorks allowed for the rapid transition from concept to a virtual three-dimensional (3-D) component. SolidWorks also offered a chance to test interactions between the FRD and the fin set in a virtual state. This fact allowed for multiple revisions of the FRD in a very limited time span. Through this revision process, the original concept of a single section ring retainer transformed into a set of four simple snap-fit devices that attach to each fin and link together in the span between fins. A selection of revisions created in this modeling process can be seen in figure 3, with the original concept on the far left and the most recent revision on the far right.

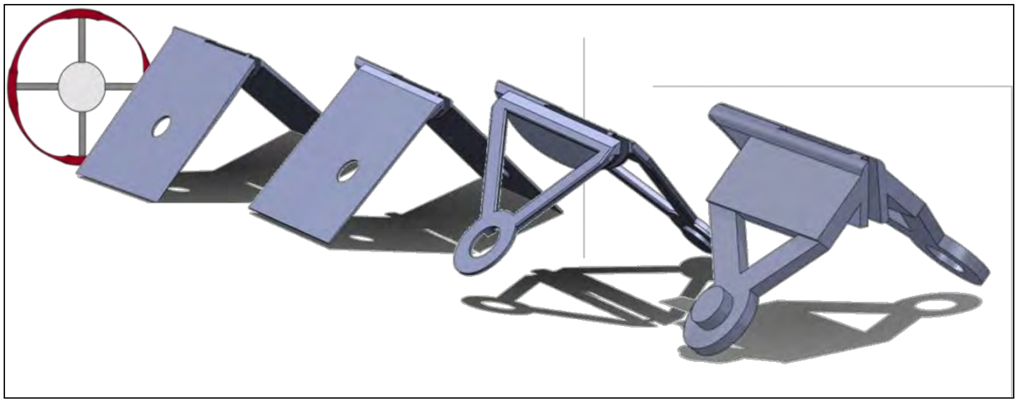

Figure 3. FRD revisions.

An additional benefit of using SolidWorks is that it allows for basic structural analysis using its built-in simulation tool. By employing these tools, a preliminary determination on the strength of each model was determined, allowing for each successive revision to become stronger. One way this was done was by analyzing the deflection and resultant stress in the arms that span the space between the fins. A graphical representation of this analysis can be seen in figure 4. On this plot brighter colors represent higher stresses, and the sections on the inner corners show plastic deformation.

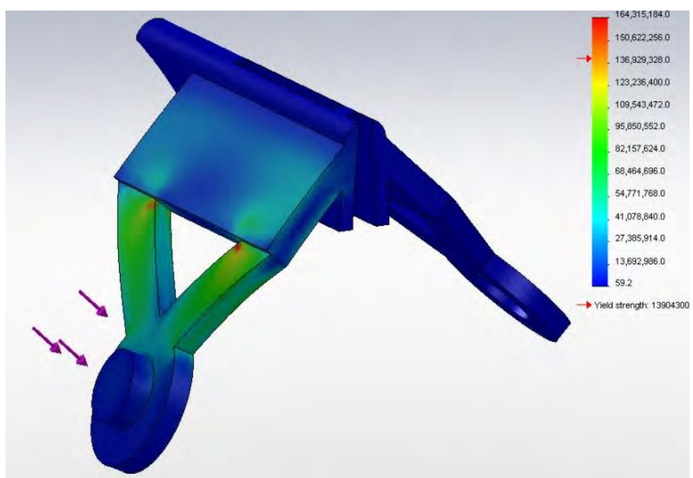

Figure 4. Stress plot of device under a 10-lbF load, applied at snap position.

The plastic deformation observed in the simulation was a sign that the arm section could fail in some cases. Therefore, one final revision was to add a leg extension to one of the arms to help support the structure. The addition of the support leg would allow for a reduction of the stress in the overall structure. This allowed for only elastic deformation to result in the new model when further simulations were conducted. These two versions can be seen in figure 5.

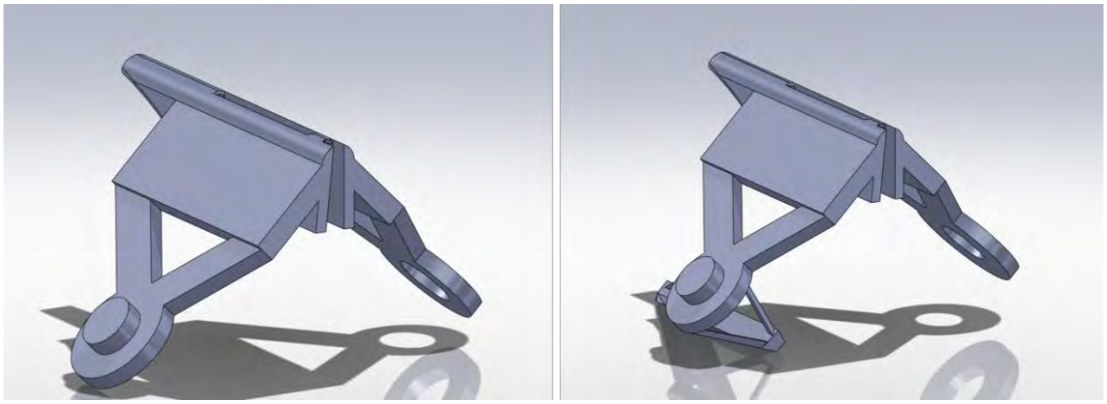

Figure 5. Final revisions.

Note: The leg is seen on the right figure, opposite the circular tab feature.

2.3 Prototyping

Although SolidWorks allows for the virtual testing of integration and loading of the parts, it is not enough to work based on computer models alone. Therefore, it was decided to send the final two revisions of the FRD to the rapid prototype shop so that physical models could be used for evaluation purposes. To keep the prototypes as accurate to the computer model as possible, they were constructed out of a photosensitive polymer using a stereolithography 3-D printing process. This process resulted in highly accurate prototypes with physical properties close to what would be used in a production setting. With a full set of these prototypes it was then possible to physically inspect the strength and performance of the FRD design. A SolidWorks rendering and the assembled physical prototype can be seen in figure 6.

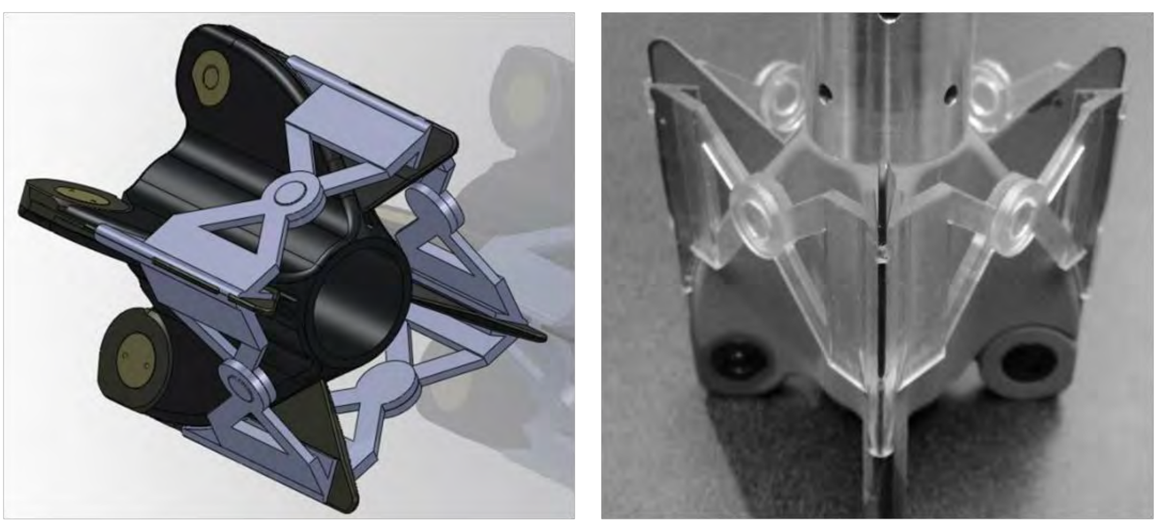

Figure 6. SolidWorks rendering and prototypes assembled FRD on existing fin set.

3. Evaluation and Discussion

With the arrival of the physical prototypes, it was possible to test the interaction between the existing fin set and the FRDs. From this simple test, it became immediately apparent that there were many small issues with the design. Most importantly, the notch in the fins that was previously used for securing the string during testing and evaluation was not large enough for the FRD design. Because of this fact, there was an obvious clearance issue between the FRD and the mortar tube. This clearance issue is one of the most critical issues, but could be solved in a variety of ways. One such method would be to increase the size of the notch; another would be to reduce the amount of material on this portion of the FRD. One other key issue discovered was that the leg addition did little to support the FRD because the supports would buckle under "finger-loading." A solution to this would be to replace the thin supports with solid plate structures, which would be less likely to buckle under similar loading conditions.

The evaluation of the FRD also showed a number of positive aspects not seen in the computer model. First, the snap mechanism proved to work well even when a clearance fit was selected for the prototypes. This aided in the simplicity of assembling the full FRD and suggests that the tolerances for a production run could be relaxed, lowering costs and easing manufacturing. An additional unexpected aspect of the design is that it has built-in redundancy, needing only one of its two connections to secure the fin in the stowed position, suggesting two key things. First, this means the chances of the FRD failing (prior to mortar firing) are reduced in the current design, because both sides of the device must fail before a fin would be released. Secondly, it means the system could be simplified by removing one side of the span attachments. A simplification of the design would remove the redundancy but would also simplify the assembly procedure and reduce production costs.

With these observations in mind, it is now possible to return to the design and prototyping phase of development to further refine the design of the FRD. In the next iteration of design changes, a new version will be made based on team feedback to address the issues previously mentioned. This iteration will also allow for a greater degree of structural analysis with a more powerful version of the SolidWorks simulation tool that was recently made available to this project. With the combination of better analysis and a new design, the next iteration should fulfill a greater number of the requirements identified at the start of this project while further simplifying the part design.

4. Summary and Conclusions

The task of designing an FRD for the FCM system is an interesting challenge due to the specific requirements of the system. However, the development of a simple and reliable system may have an extended effect on a larger group of projects using deployable fin sets. With this goal in mind, a systematic approach was applied to the design process and a working prototype was developed. With the evaluation of this prototype, many design changes were planned and are pending the next design iteration. With further work on this project, a novel FRD will be completed to the point where it can be used for later testing and evaluation of the FCM project.

5. References

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2. Hash, G. D.; Bojanowski, A. J.; Hightower, R. M.; Lishin, G. U.S. Patent No. 7,851,734. Washington, DC: U.S. Patent and Trademark Office, 2010.

3. Kuhnle, J.; Heitmann, T.; Niemeyer, T.; Arendt, N. U.S. Patent No. 6,314,886. Washington, DC: U.S. Patent and Trademark Office, 2001.