Abstract

The Tactical Assault Ladder Capstone Project is based on a Department of the Army Broad Agency Announcement (BAA). The BAA is seeking a design for a lightweight, 27ft ladder that fits into a portable sized backpack and can hold a climber safely. The most suitable design idea for this problem involves flexible, composite strips that roll into a backpack while rungs constrain their geometry when extended. Significant design work was put into the mast geometry, the mast constraints, the mast material, the rungs, and the backpack. Extensive testing was performed to determine which composite material would be able to withstand the greatest load. A final system was designed while a proof of concept prototype system was fabricated with the resources available.
The Need for Project

A portable, free standing ladder is valuable for the modern soldier. On the modern battlefield it is critical that soldiers have the necessary equipment to quickly and safely maneuver through any obstacle they may encounter. Ladders can help soldiers trek through difficult terrain, scale enemy walls, buildings and other obstacles. Any military ladder must be lightweight so that the soldiers’ mobility is not impaired, while also robust enough to endure a variety of terrains and operating conditions.

The Design Project Objectives and Requirements

The objective of this project is to design a lightweight, portable, and tactical ladder to be used by the military. Design Objectives

The goal of this project is to meet as many of the requirements as possible stated in the Lightweight Assault Ladder Broad Agency Announcement (BAA) released by the Army Natick Soldier Research, Development and Engineering Center (NSRDEC). Within the BAA the Army has specified 11 requirements that any proposed system should meet.

Design Requirements

The main requirements are that the ladder fits within an initial volume of 24in X 18in X 10in and reaches an extended height of 27 feet. When collapsed the ladder must incorporate a pack like carry system that does not restrict the soldiers movement and is compatible with body armor systems. The ladder should weigh less than 30lbs and support a safe working static load of 350lbs with a 2:1 safety factor. It must also be stealthily deployed in under 30 seconds by two soldiers in low light conditions. Other requirements include that the ladder function in a variety of environmental conditions and be finished in a non-reflective tactical color.

Design Concepts Considered

Three design concepts were researched and considered including folding, telescoping, and single mast designs. Three alternative designs were researched before the final design was chosen. The first alternative was a folding ladder. After performing some preliminary calculations, it was found that this idea would be difficult to pursue. In order for a folding ladder to fit in the required initial volume, the main supports would be too thin to withstand the loads.

A telescoping ladder was also discussed. This design involves
many concentric shapes sliding into each other. To allow for all the concentric sections necessary, the base would be too large to fit in the initial volume. The tolerances between the tubes would also be difficult to manage and a telescoping system could be susceptible to jamming.

Another design that was considered was a single mast approach. It consisted of a single, sturdy mast with peg-like rungs extending out either side for the user to climb up. There are similar ladder systems like this available, but not at a comparable height. It was concluded that a single mast would not be sturdy enough and would have to be either folding or telescoping which was already proven to be a non-viable solution.

**Recommended Design Concept**

The recommended design will involve flexible, composite strips that roll into a backpack while rungs constrain their geometry when extended.

The recommended design includes roll up composite side rails that behave similarly to a tape measure. Rungs will constrain these composite rails together and keep the geometry of the ladder consistent.

**Design Description**

Two curved, flexible, composite strips make up each 27ft mast. The strips are able to roll up on spools inside of the backpack. The mast has a lens shaped cross-section when extended and is held together intermittently with aluminum collars. These collars also serve as the mating component for the rungs. Additionally, there are two ribs positioned between each of the rung collars to provide additional geometric constraints on the masts.

The rungs are made of composite tubes and are staggered along the ladder, so when packed, they lay in rows in the backpack to maximize packing efficiency. They are strong enough to support heavy loads and light enough to keep the overall weight low.

The collars are responsible for mating the rungs to the mast supports. They contain symmetric slots for the mast strips to slide through. They are strung together with cord and stacked in the upper section of the backpack.
The backpack contains a frame to support the contents of the ladder when rolled up. The backpack contains spools that the composite strips roll up on and a cam system to lock the strips when extended. A gear system is used within the pack to allow for the ladder to be rolled back up after use and to keep the spools timed relative to each other.

**Analytical Investigations**

Initial calculations showed the ladder will see a 7098lb-in moment when fully extended with a 350lb load at the center. With this moment and the cross-sectional area of the mast, the maximum stress the material will see is 9ksi. This is a similar result to the ANSYS finite element analysis that was also performed on the model. ANSYS calculated a maximum stress of 11ksi and a maximum deflection of 0.48in in the center as expected.

**Experimental Investigations**

Small scale three point bending tests were designed and performed to replicate the calculated full scale stress on the masts. Multiple composite materials were tested including fiberglass, carbon fiber, and Kevlar. A variety of weave patterns and thicknesses of the materials were also tested. Based on the data collected from the tests, the strongest composite was chosen. All of the masts failed by the distortion of the cross-sectional geometry. These results proved the value of additional ribs between each collar to properly constrain the mast geometry. These tests provided valuable data which allowed for the necessary mast geometry to be determined.

**Key Advantages of Recommended Concept**

The recommended solution will provide a compact 27ft ladder system that is easily deployable. This concept does not require complex hinges (as seen in the folding ladder) or tolerance issues (as seen in the telescoping ladder). This design is also not limited to a 27ft extension and can be used at any intermediate height.

**Financial Issues**

A prototype system was developed for $1,800. A significant amount of that money was spent fabricating a 30ft one part mold to enable to hand lay-up of the composite strips. Full scale manufacturing would not use this time consuming and complicated
process. Instead a manufacturing process called pulltrusion would be used. This technique was too expensive for a single prototype system but would lower costs as production quantity increased. This project is currently being marketed towards the military and is not intended for commercial sale.

**Recommended Improvements**

Mast and component refinement will allow for a stronger and more lightweight system. Data collected from testing allowed the necessary mast geometry to be determined in order to withstand the maximum stress. The required composite tape width is not a common stock size and the lead time needed to acquire it did not fit within the project schedule. Larger strips are significantly more expensive and would have to be cut down, resulting in a large amount of waste. A new mold would need to be fabricated along with an overhaul in the collar design to accommodate the new dimensions of the strip. Due to this, a prototype was fabricated with the test geometry that supports a lower maximum load than the 350lb stated in the BAA. Further fabrication and testing is required to develop the as designed components to ensure the final system will meet the required load.

One of the BAA requirements specifies a total weight of less than 30lbs for the entire assembly. Through structural refinements and the incorporation of more composite components, the weight of the current system can be further reduced.