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STUMP: SUPER-STRONG TUBE THAT'S AN ULTRALIGHT MODULE AT PRESSURE

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ABSTRACT

Motorized ground forces spend considerable resources in equipping for situational awareness capabilities. Given requirements spanning command, control, surveillance, and reconnaissance of a battlefield, there has been no single mast technology that can support each of these with elevated sensors and weapons. A tough, extremely low weight modular mast system has been designed to be quickly attached or removed from a ground vehicle to provide different operational capabilities depending on the payload. The design allows for easy modification to fit functional needs on different vehicles and platforms.

At the heart of the technology is a proprietary super-fiber pressurized tube which elevates the payload on a column of moderate gas pressure eliminating cumbersome hydraulic/mechanical systems. An internal, simple alignment system and gyroscope-maintained verticality allow a stable, elevated platform without introducing instability to the vehicle. The system is capable of withstanding extreme external forces and impact as typical of field operations. This innovation promises such light weight that unprecedented heights may be reached faster.

INTRODUCTION

A battle can be won or lost based on your ability to see beyond the obvious. Motorized ground forces, therefore, spend a major amount of effort and resources in equipping their vehicles with situational awareness capabilities. This helps them to see and project their forces as far as possible, thereby, increasing their area of control.

Given often unforgiving battlefield requirements spanning command, control, surveillance, and reconnaissance, there has not yet been a single mast technology that can support each of these needs. Ideally, the solution should be lightweight for mobile stability and capable of working on multiple mobile platforms.

A FLEXIBLE SUPER-FIBER MODULAR MAST SOLUTION

Given the motorized ground forces' stringent situational awareness needs, no single mast technology is capable of simultaneously meeting these diverse and often conflicting needs. An extremely low weight modular mast system capable of being quickly attached or removed from a ground vehicle to provide different operational capabilities depending on the payload is possible.

At the heart of the technology is a proprietary pressurized, super-fiber tube which elevates the payload on a column of moderate gas pressure eliminating cumbersome hydraulic/ mechanical systems. A key, patented concept is separating the lifting force from the alignment force. Inside the column, alignment of the mast is provided by a sliding column made of high performance reinforced polymer. A standard gyroscopic control package assures that the column is vertical to the earth, and not vertical to the vehicle. Pneumatic pressure to the coated-fabric cylinder extends the system and lifts heavy payloads. Dumping of the gas through a valve quickly lowers the system quickly as needed. The system is capable of withstanding extreme external forces and impacts as typical of field operations.

In this innovation, we have drawn from designs and approaches used on NASA's experience with the International Space Station; from factory robot constructions; and from advanced transportation systems. Pulling together all of these seemingly disparate design concepts with proven materials and techniques results in good manufacturability and great resistance to extreme environments.

While there were several contenders for the super fiber fabric, we chose Kevlar® for its unique strength and load bearing characteristics. Also, strength and toughness are high at very low and very high temperatures, suiting arctic and desert environments. Vectran was a strong contender but was not chosen because of its more limited sourcing and availability. (See comparison table attached at the end of the paper). For the purposes of comparison we have used Kevlar 1420 denier fiber in a tri-axial braided sleeve that has 3 ends in the biaxial direction (66 degrees) and 5 ends in the axial direction. For the current application it will need to be lined internally and coated for protection. This fabric has been extensively tested in the automobile industry. It has been used for making airbags (a tubular inflated device to withstand side impacts) on BMW's. Therefore, the mechanics for designing this type of structure is pretty well understood and has been tested extensively.

The core concept which enables our military mast to outperform alternatives is ultralow weight with high lifting forces, combined with extreme toughness. As opposed to using hydraulic or mechanical force to do the lifting, use of moderate pressure gas is a crucial way to save weight. Containing the gas with a braided, seamless column of coated superfiber (such as Kevlar®) is the other component of ultralow weight. But a Kevlar® column is floppy; how does this column rise and descent vertically? The design allows this by separating the 2 components of the force vectors needed to resist the payload.

In Figure 1, the force vectors needed to resist the payload are shown as 2 component vectors. During lifting of the payload, the vertical component is resisted by the gas pressure on the top cap of the cylindrical gas power cylinder:

This is no different than it would be with a hydraulic cylinder, but in this case we design for a large diameter and area, with a much lower gas pressure (p), producing the needed force with much less weight.

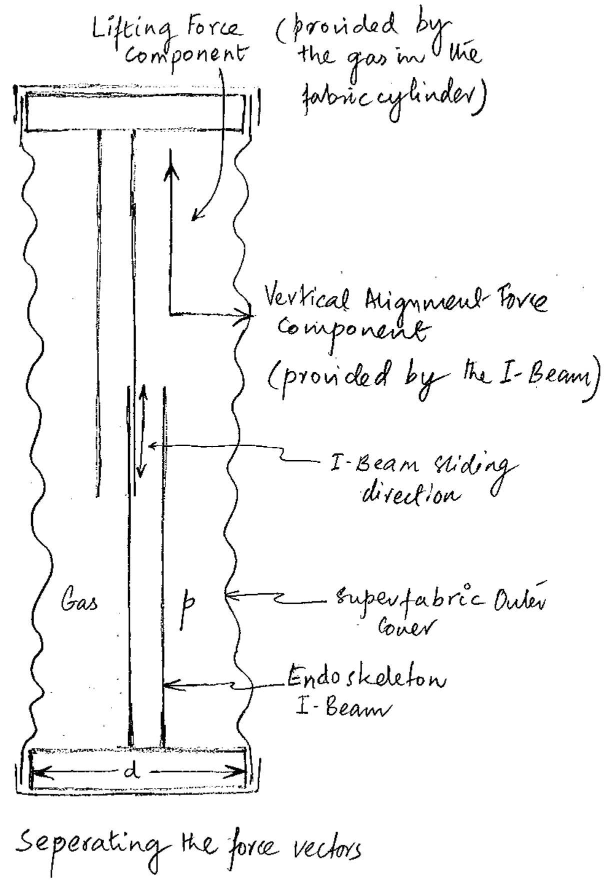


Figure 1.

As Figure 1 shows, we must counteract whatever horizontal force vector is encountered in lifting. That is, when the column is off vertical for whatever reason, we must have a correcting force vector, which will generally be much smaller than the vertical component. If we correct quickly when perturbations occur (terrain, wind, or whatever), the correcting force remains quite small. In our preferred design, this horizontal force vector is provided by a 3 or 4 section sliding beam, secured to the base of the column and also to the top disk of the column.

All other designs we have seen for a practical military mast end up weighing a great deal more. Furthermore, simple physics shows that this military mast increases its advantage over alternatives as the required payload increases. As the following equation shows, it is a simple matter to increase the lifting force of this device with very little increase in weight:

$$F(v) = p * \text{Area} = p * \pi * d^2/4$$

Doubling the diameter quadruples the lifting forces with relatively small increase in the weight of fibers or end disks, while alignment beams may not need to be increased in size or weight. The same increase in a hydraulic or mechanical system increases weight and runs the risk of becoming very top-heavy.

If the base is maintained level (not to the vehicle but to the earth), then the sliding beam will ensure that the top disk is also level. Our preferred design utilizes a pair of these sliding beams, acting in unison to maintain “levelness” by exerting the required horizontal forces. Since the forces are comparatively small, we intend to utilize overlapping I-beams which can be easily pultruded from fiber-reinforced thermoset resin, such as epoxy. Thus, the military mast has two different, lightweight and tough systems which provide for both lifting forces and horizontal alignment forces by separating the two.

An important operational characteristic of this military mast is the extreme flexibility of the gas power system. Field changes of pressure control valves, filling valves, and dump valves can change the load bearing, speed up and speed down, literally in minutes.

This innovation promises such light weight that unprecedented heights may be reached, with faster speed and on numerous vehicle platforms. Models of different maximum height merely require different cylinder lengths.

As a core example, a mast system weighing between 100-200 kilograms, capable of lifting a 500-1000 kilo payload to 8-12 meters height in a few seconds is targeted at much lighter vehicles, down to modified pickup trucks or step vans. This performance opens markets beyond military patrol and assault, including SWAT, border patrol, firefighting, and other missions. (See artist rendering below)

In a (not very) later phase, we envision mounting the mast on a 4WD pickup truck with a robotic driving system and an animatronics driver (think Chuck-E-Cheese). With sensors and a weapon system aloft, it becomes a remotely operated escort vehicle controllable from any infantry patrol unit, a supply convoy, or a drone. The system’s low costs and light weight provides operational flexibility resulting in lower causalities.

For combat survivability in missions such as urban patrol or assault, the coated fabric cylinder design allows expansion to multiple walls with interstitial sealant system to survive penetration by projectiles. However, hardening of the mast system from hostile fire is a work in progress. The mast works with a single layer of Kevlar®, but might be deflated and brought down slowly by hits from small arms. As an option, a dual-layer design with appropriate reactive, polymeric sealant between the two layers would seal any holes from small caliber hits: this technology is well-known in military aviation applications.

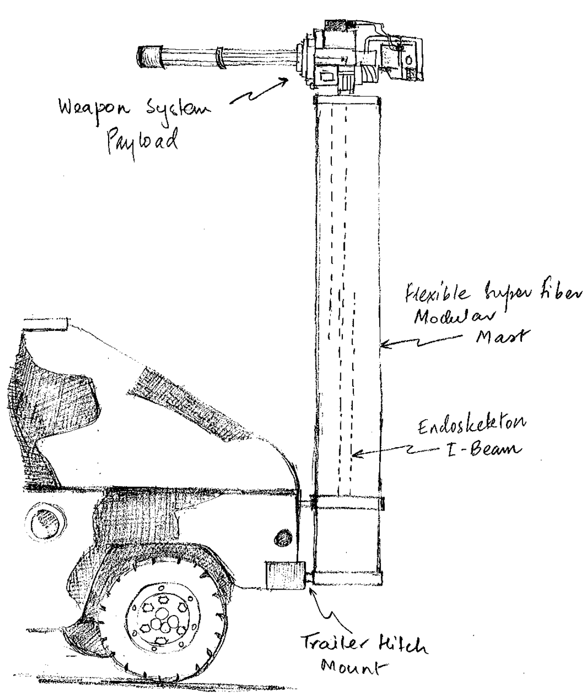
Recently, BAE Systems has announced a new technology they call Bulletproof Custard, which coats Kevlar® with a custard-like reactive material and might even be able to harden so quickly that the projectiles would not penetrate. Their application target was personnel armor, but using such a system with the military mast is an intriguing, unexplored possibility.

Serendipitously, the construction improves several operational characteristics of the system.

1) Modularity of the design allows simple field maintenance and repair by replacing/interchanging components or even sewing on a “patch”.

2) Coated super-fabrics resist corrosion, sand, heat, cold, and salt better than most metals or thermoset polymers.

3) Light weight supports low manufacturing cost, simplifies field logistics, and prevents personnel hernias.



An Artist Rendering of the STUMP

Below is a picture of the proof of concept of a 12" diameter mast erected with just 10 psi air pressure. It is rated for withstanding 200 psi with a safety factor of 2. It is a 40 ft pole that is capable of lifting 10,000 lbs at 100 psi. As can be seen, even at 10 psi it is very rigid and strong.

CONCLUSION

In the new world of warfighting, implementing this innovation will allow relatively low cost equipping of allies with patrol and assault vehicles based on civilian vehicles. Whether on the African veldt, crossing Siberian tundra, or in downtown Karachi, the ability to locally source a suitable vehicle and quickly convert to an armed or sensor-equipped vehicle will cut global response times drastically.

Once proven, the STUMP could become standard equipment for all field forces, available to be readily deployed to gain that extra much needed height. In many cases this could be the only advantage an otherwise fully equipped soldier may need.

Yarn Property Comparison		Updated 11-4-08				
		Axial 1	Bias	Axial 2		
Yarn		Vectran	Vectran	Vectran	Kevlar 1420D	
Denier		1500	1500	1500	1420	
yield / yd/lb		2976	2976	2976	3144	
Tenacity (g/D)		23	23	23	22	
Allowable tenacity		23	23	23	22	
Density (g/cc)		1.44	1.44	1.44	1.44	
lb/in^3		0.052	0.052	0.052	0.052128	
Area		0.000179	0.000179	0.000179	0.000169	
Modulus (g/d)		555	555	555	940	10222579
Modulus		10222579	10222579	10222579	17327154	
Breaking Load (Lbs)		76.06	76.06	76.06	68.87	
Allowable Load		76.06	76.06	76.06	68.87	
Yarn Cost ($/lb)						

Load Calculations																		
		Values Updated on Form2 Sheet					Form 2 Outputs					Bias Calculations						
Braid	Name	Bias Ends	Dia	Nc	Angle	Pressure	PPI hoop	PPI axial	OZ/SQYD	Coverage	UCW	Hoop Load (lb/in)	Force per end (lb)	Allowable Breaking Load	F.S. (must exceed 2)	Status
1500D Vectran		3.0	6	208	66.00	740	12.392	5.517	20.10		0.181	2220	32.68	68.87	2.11	PASS

Axial ends 1	520	Axial ends 2	0						Nx	1110
Total Axial 1 EA	1527098	Total Axial 2 EA	0	Sum Axial EA	1527098				Nh	2220
Total Axial 1 EI	6888977	Total Axial 2 EI								
Fblowoff	20923.01	lbs								
Faxial total	18157.98	lbs	Strain	0.0119						
Working Load 1	34.919									
Working Load 2										
FS axial 1	2.0									
FS axial 2										

Comparison Table Between Kevlar® and Vectran