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Tether Reel Mechanism for the MR SAT Project

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The Missouri-Rolla Satellite (MR SAT) system is being designed and constructed by students at the University of Missouri – Rolla in order to give Aerospace Engineering students along with other majors practical experience in spaceflight concepts. The satellite system will consist of two tethered satellites that will eventually be completely disconnected and use a propulsion method to enter the chase phase of our mission. New design concepts are being used on this satellite including the possible use of a honeycomb-aluminum friction stir-welded structure and micro-pulse plasma thrusters for maneuvering. The research done this summer focused on the tether reel mechanism (TRM) including its initial deployment, unreeling/slowing down, and its final separation. The ideas for each mode of operation were put in trade studies to compare the feasibility and reliability of each concept. Two hovercrafts were also designed and built to test the TRM concepts in an environment that most closely resembled microgravity on Earth.

Introduction:

The NASA Goddard Space Center has been doing significant research in the benefits of using a Distributed Space System (DSS). This concept would send several smaller satellites into space to perform the function of one larger satellite. One area of research is in the tethered versus non tethered configuration of these satellite systems. With this in mind the MR SAT project team designed a mission that will allow both tether configurations to be tested. For the first phase MR SAT and its smaller counterpart MRS SAT (Missouri Rolla Second Satellite) will be formed into one satellite. Then in phase two they will separate along a ten meter tether. After remaining in this configuration for a few weeks the will finally disconnect completely in phase three of the mission. One of the greatest challenges to this mission concept is developing a mechanism that will separate the satellites, reel MRS SAT out to ten meters, decelerate her to a gentle stop at ten meters, and finally disconnect her completely from MR SAT. This is the challenge that was researched and will be discussed in this paper.

Satellite Separation:

A solenoid-magnet device was designed to separate the two satellites and disconnect the tether. The tether disconnect function will be discussed later. In its initial configuration MR SAT will have the Missouri Rolla Second Satellite (MRS SAT), another smaller satellite, tucked into the top of it. For the first phase of the mission MR SAT will need to release MRS SAT and allow her to reel out along a tether. One concept for this separation is the solenoid-magnet. A circular magnet will be attached to MR SAT and magnetically connected to a piece of iron on MRS SAT. The solenoid will be in the center of this magnet and when an electric pulse is sent through the solenoid will allow for the release of the magnet. This release will be due to the reverse of the poles in the magnet thus causing it to repel the iron as oppose to adhering to it. This design can be seen in Figure 1 below.

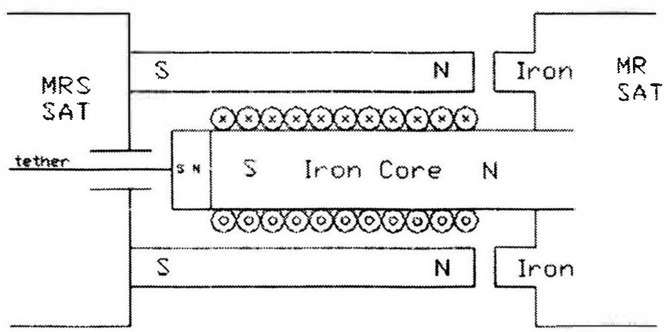

Figure 1

Another concept discussed by previous researchers was the use of springs for separation of MRS SAT. This concept posed several problems. The spring would have to be located at the exact center of MRS SAT in order to prevent her from spinning as she deployed. If multiple springs were used then they would all have to release simultaneously or it too could lead to spin. For these reasons this concept has nearly been discarded.

Trade Study Chart

Tether Separation

		Score						Weight	Alternate Designs					
									[illegible]			[illegible]		
Criteria	Units	0	1	2	3	4	5	1 to 4	Value	RS*	WS**	Value	RS*	WS**
Complexity		Very High	High	Mod high	Significant	Mod Accept	Accept	2	Mod High	2	4	Mod High	2	4
[illegible]	%	100	100-75	75-50	50-25	25-0	0	4	100-75	1	4	75-50	[illegible]	8
Development Time Required	Minutes	> 12	12 to 10	10 to 7	7 to 4	4 to 2	< 2	1	> 12	0	0	10 to 7	2	2
Cost	$	> 5000	5000-4000	4000-2000	2000-1000	1000-500	< 500	2	< 500	5	10	1000-500	[illegible]	8
Mass	kg	> 2	2-1.5	1.5-1.0	1.0-0.5	0.5-0.1	< 0.1	3	< 0.1	5	15	1.5-1.0	2	6
								Weighted Score Totals			33			28

Figure 2

Tether deceleration:

One concept for the deceleration of MRS SAT as she is reeled away from MR SAT is to use a tapered tether design. The tether would be designed for one basic diameter and then during approximately the last meter of the tether it would gradually widen. The entire tether would deploy through a circular opening that would allow the initial width of the tether to move freely, but as the tether widened it would cause more and more friction to form on the tether eventually stopping it completely when the width of the tether exceeds the width of the whole it is traveling through. Companies that create tapered tethers were researched and after email discussions with these companies it was determined that this design would not be feasible due to the extreme cost of designing this type of tether.

Other concepts are being developed currently at the University of Missouri-Rolla by another team of students. These concepts along with the tapered tether concept are being compared (Figure 3) to see which will work best for the MR SAT mission.

Trade Study Chart

Tether Deployment Control

		Score						Weight	Alternate Designs: Active Control Trim			Trim with "Friction"			Tapered Tether			Spring		
Criteria	Units	[illegible]	1	2	3	4	5	1 to 4	Value	RS*	WS**	Value	RS*	WS**	Value	RS*	WS**	Value	RS*	WS**
[illegible]		Very High	High	Mod High	Significant	Mod Accept	Accept	2	Mod High	2	4	Mod Accept	4	8	Mod High	2	4	Mod Accept	4	8
Risk of Rebound	%	>100	100-75	75-50	50-25	25-0	0	4	75-50	2	8	50-25	3	12	25-0	4	16	75-50	2	8
[illegible]	minutes	>12	12-10	10-7	7-4	4-2	<2	1	12-10	1	1	7-4	3	3	7-4	3	3	4-2	4	4
Cost	$	>5000	5000-4000	4000-2000	2000-1000	1000-500	<500	2	4000-2000	2	4	1000-500	4	8	2000-1000	3	6	<500	5	10
[illegible]	kg	>2	2.0-1.5	1.5-1.0	1.0-0.5	0.5-0.1	<0.1	3	2-1.5	1	3	0.5-0.1	4	12	0.5-0.1	4	12	0.5-0.1	4	12
					Weighted Total Score				[illegible]			43			[illegible]			42		

Figure 3

Tether disconnect:

The same solenoid-magnet configuration used to separate the satellites was used to disconnect the tether. A bar magnet was inserted in the center of the solenoid. It was attached to the tether connecting MRS SAT to MR SAT and to another piece of iron on MR SAT. The initial pulse of electricity through the solenoid will not affect the polarity of this magnet because it is on the inside of the solenoid instead of around the outside like the circular magnet. A secondary pulse will be sent through the solenoid in the reverse direction causing the polarity of the bar magnet to reverse and thus release the tether from MR SAT. This design is also shown in Figure 1 above.

Another concept for tether disconnect was the use of the same epoxy mentioned above. It was also discarded as an option for the reasons listed above. The trade study in Figure 2 was used for this portion of the mission as well.

Hovercraft:

It was decided that hovercraft would best simulate microgravity here on Earth and therefore would be the best method in testing both the TRM and other MR SAT applications. The hovercrafts were designed from a concept used at the University of Virginia, by Dr. Robert Tai [(1)]. This idea was modified to be of more use to the MR SAT project. The original hovercrafts were designed to be circular, but since the MR SAT project has two satellites next to each other this design would not work. Therefore, two half circle hovercrafts were designed using the same method as the circular hovercrafts in order to allow the hovercraft to rest with a full side touching. They were constructed using quarter inch plywood cut in the semi-circle design. This plywood was then wrapped in thick plastic and sealed with duct tape. The center of the hovercraft was bolted in order to create a semi-circular pocket of air inside the plastic around the bolt. The air was provided by a cordless leaf blower that was connected to the hovercraft by a flexible plastic tube. Construction of these hovercrafts was done at a shop on the University of Missouri-Rolla campus. After significant testing, it was discovered that the hovercraft did not glide smoothly enough across a normal floor to truly simulate microgravity, so they had to be further modified. Most of the heavy-duty plastic wrapped around the plywood frame was removed and the wholes in the plastic on the bottom of the hovercraft were enlarged. Though they perform more proficiently now, they are still being modified in the hopes of further improving their performance. The original configuration of the semi-circle hovercrafts can be seen in Figure 5 below.

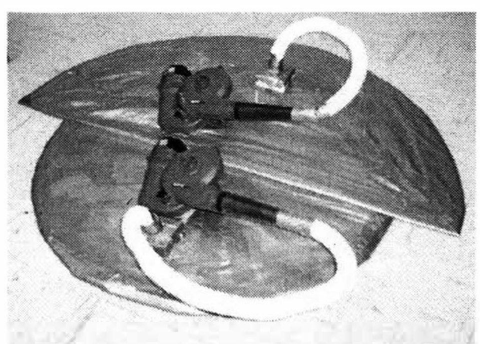

Figure 5

Conclusion:

Though the final decision has not been made on the TRM design, the research done over the summer was a good foundation for the future testing and research being done in this area. A prototype of the solenoid-magnet design is being built and will be tested with the new modified hovercrafts. The tapered tether idea has been discarded due the expense of creating this tether, but other prototypes and ideas are also being tested currently. The final TRM is scheduled to be completed by the end of May 2005.

Acknowledgements:

The continued efforts of this design are being conducted by Everett Klapperich and Brian Peters at the University of Missouri-Rolla. They have taken my research from the summer and further developed a more complete model of the TRM design. The work done this summer was helped greatly by the efforts of Mike Ellebrecht who consulted on the Electrical Engineering aspect of the solenoid/magnet concept. The entire project was overseen by my advisor, Dr. Henry Pernicka, whose advice and assistance was invaluable to the research process.

References:

(1) http://www.vast.org/vip/HOVERCFT/instrctn/