Hold Down Release Mechanism
Team Stellar Hold

Finalized Testing Plan

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1) Design Requirements Summary

The Customer Requirements the HDRM is being designed to meet consist of CR1- No Space Debris, CR2- No Pyrotechnics, CR3- Resettable, CR4- Hold Load, CR5- Can't Protrude more than 1 cm from the external face of the Cube Satellite, CR6-Low Outgassing, CR7-Solar Panel Deployment (20x30 cm), CR8-Simultaneous Solar Panel Deployment, and CR9- Release on Command. The engineering requirements consist of ER1- No Space Debris, ER2- Low Outgassing Materials, ER3- No Combustion, ER4- Minimize Volume, ER5- Minimize Protruding Material, ER6- Maximize Deployment Force, ER7- No Deformation, ER8- Maximize Retention Reliability, ER9- Receive an Input Command, ER10- Minimize Weight, ER11- Minimize Reset Time, ER12- Actuation/Resettable. The design will produce no space debris because there will be no parts that come free, and the actuation will be done through heating the SMA spring instead of by utilizing combustion/explosives. The device will be resettable by cooling the SMA spring back down to continue testing, and the device was designed to be able to hold the very light load on the external shaft from the wires connected to the solar panels. There will be washers and nuts added to the design to ensure there will only be approximately 1 cm of the external shaft showing before actuation, and the materials chosen were due to their low outgassing properties. All solar panels are attached to the retracting shaft so that deployment will occur to all four sides at once and will all happen as the actuation is called for. The device was designed to be close to 1”x1”x1” to minimize volume and weight, and the shaft retraction is a quick movement to ensure the force is strong enough to deploy all four panels simultaneously. The device is made from material that can withstand the heat applied for actuation and the heat applied to the SMA spring is tested to ensure no deformation will happen to any point of the device. The input command has been received successfully through the circuit to heat up the SMA spring and the SMA spring cool down time will be tested in order to find the minimum temperature it can be heated to minimize reset time.

Table 1: Design Requirements

#	CR	ER
1	No Space Debris	No breakaway parts
2	Low Outgassing	Low outgassing materials
3	No Combustion	No combustion
4	20x30 cm Deploy Solar Panels	Minimize volume
5	Minimize Protruding Material	Minimize protruding material
6	Maximize Deployment Load/ Simultaneously	Maximize deployment force
7	Easily Resettable	No deformation
8	Retain Stowed Configuration prior to deployment	Maximize retention reliability
9	Receive Input Command	Receive input command
10	Minimize Weight	Minimize weight
11	Minimize Reset Time	Minimize actuation time
12		Maximize SMA spring life

2) Top Level Testing Summary

Below the testing plan for the engineering and customer requirements can be seen. There is a list of nine planned tests which will be used to accumulate data on one or more requirements. Each of these tests will be performed multiple times to find reliability and product wear. The first test will be done to ensure that the actuation is reliable in the HDRM and in simultaneous solar panel deployment. The actuation voltage test will be specific to the SMA spring position change. The spring force test will be done to ensure there are no unintentional/failed actuations due to the opposing spring force being too large/small. Since the retracting shaft will be holding the weight of HDRM and the solar panel locking mechanisms, the load test and weight verifications will be done to ensure it can still actuate under the weight. Measurement verifications will be done to see how close the manufactured HDRM came to the size requirements given. Outgassing verifications will be tested through calculations to decide how much gas each material gives out from how much is used in the device. CubeSat deployment testing will be specific to the solar panels moving into place reliably and simultaneously. There will be a visual test to ensure no debris is accumulated during actuation.

Table 2: Test Summary Table

Experiment #	Experiment/ Test	Relevant DRs
1	Actuation Test	ER9/CR9, ER3/CR3, CR7
2	Actuation Voltage Test	ER11/CR11
3	Spring Force	ER9
4	Shear Load Test	ER7, ER6/CR6/ER12
5	Measurement Verifications	ER5/CR5, ER4
6	Weight Verifications	ER10/CR10
7	Outgassing Verifications	ER2/CR2
8	CubeSat Deployment	CR4, ER6/CR6/CR12, CR8
9	Debris Verification	ER1/ CR1

3) Detailed Testing Plans

Nomenclature

- F_N = Nitinol Force output
- y = spring distance (mm)
- k_s = spring constant (N/mm)

- d = diameter of wire (mm)
- D = diameter of spring (mm)
- N = number of coils (#)
- G_M = Shear Modulus of Martensite (Pa)
- δ_L = Compressed spring length (mm)
- m = mass (g)
- T_2 = temperature required for Austenite state (^OC)
- T_1 = temperature required for Martensite state (^OC)
- I = current in amperes (A)
- R = resistance in ohms (Ω)
- t = time to actuate (s)
- c = specific heat ($\frac{J}{kg*^OC}$)

3.1) Experiment 1: Actuation

For experiment 1, ER9/CR9, ER3/CR3, and CR7 will be tested through actuation tests. This experiment is designed to test how well the device can actuate by sending a current through the nitinol spring a set number of times. The equipment needed will be a power supply with adjustable voltage output and a phone/ timer. Both the voltage and time to actuate will be isolated to properly assess the performance of the nitinol actuator. No variables need to be calculated, however, the results of experiment 2 will output the optimal voltage and time variables. The results of the experiment demonstrate how the performance of the actuation is affected after 100 actuations. To define performance, the team is specifically focusing on how actuation time is impacted and if the force output of the nitinol spring is affected. Equation 1 will be used to compare the force outputs of the nitinol spring.

$$F_N = \frac{G_{max} * d^4}{8 * D^3 * N} * \delta_L \tag{1}$$

3.2) Experiment 2: Actuation Voltage

Experiment 2 will focus on verifying ER11 and CR11, which deals with actuation time. A power supply with adjustable voltage output and a timer will be needed for this experiment. The procedure for this experiment will start with actuating the nitinol spring at 5 different voltages that range from 5v to 10v to determine which is the most optimal voltage setting. Once the voltage begins to have little effect on the time, the lower voltage will be selected. This will ensure that the device has the quickest actuation time possible. Equation 2 will be used to calculate the predicted time value for the corresponding current. This value will be used to compare to the experimental one for verification.

$$I = \sqrt{\frac{m * c * (T_2 - T_1)}{R * t}} \tag{2}$$

3.3) Experiment 3: Spring Force

For the spring force test the following design requirement will be tested: ER9. This will verify whether the nitinol spring can overcome the opposing normal spring to actuate the device. The procedure will involve using a load sensor to check the springs force output, along with the nitinol spring. If the nitinol spring force is not greater then the team will need to find a spring that it can overcome. The expected nitinol spring force will be calculated using equation 1. This answer will be compared to the results of the test to verify the solution.

3.4) Experiment 4: Shear Load Test

The load test will be used to verify that the device meets ER7, ER/CR6, which revolve around meeting load requirements. The device must be able to hold a load perpendicular to the device of at least 25 N. The procedure will start with adding a load to the pin starting at 5 N and increasing in increments of 5 until 25 N is reached. If the pin can handle a load of 25 N without deforming, then it has met the requirements.

3.5) Experiment 5: Measurement Verifications

For this experiment the team will ensure the device meets all of the measurement constraints (ER/CR5 and ER4). This test will not require any calculations since the dimensions are already set. The experiment will require a caliper to measure how much of the device is protruding from the CubeSat and how much space it is taking up inside. The device must not protrude more than 1 cm and take less than 1 inch by 1 inch of space inside of the CubeSat. If it meets these dimensions, then the team can conclude that the design requirements are met.

3.6) Experiment 6: Weight Verifications

For this experiment the team will ensure the device meets all of the weight constraints (ER/CR10). This test will not require any calculations since the weight constraints are set. The experiment will require a scale to measure how heavy the device is. The client has not specified a specific weight requirement and the team’s prototype will be scaled up, taking these details into consideration a mass of 30 g is to be expected. This mass is based off the clients previous HDRM design.

3.7) Experiment 7: Outgassing Verifications

This experiment verifies that the design meets ER/CR2, low outgassing. These requirements will be verified by using the industry standard test for measuring outgassing, ASTM E595. No equipment or calculations will be used for this test; however, the team will use NASA’s outgassing data to verify each material meets the standards.

3.8) Experiment 8: CubeSat Deployment

For experiment 8, CR4, ER/CR6, and CR8 will be verified to ensure that the design can deploy the solar panels simultaneously and be stowed in its position. This test will not require any equipment or calculations as this will be a visual verification. The procedure will require the team to position the HDRM in the appropriate location of the demo CubeSat and attach the mock solar panels to the pin. Next the team will actuate the device and if all of the solar panels release then the team can conclude that the device meets these requirements.

3.9) Experiment 9: Debris Verification

Experiment 9 will verify whether the design meets ER/CR 1, no space debris. This will be a simple test that requires no calculations or equipment. The procedure will consist of a physical inspection of the device during three stages, pre-actuation, actuation, and post-actuation. During this inspection, the team will check to see if any physical pieces are falling out. The expected result is that there will be no debris from this device and the team can conclude whether it meets this requirement or not.

4) Specification Sheet Preparation

Table 3: Customer Requirement Specification Sheet

Customer Requirements	CR Met? Y/N	Client Acceptable? Y/N
No Space Debris	Y	
Low Outgassing	N	Y
No Combustion	Y	
Can deploy 20x30cm panels	Y	
Minimize protruding material	Y	
max deployment load / simultaneously		
Easily resettable	Y	
Retain stowed config prior to deployment	Y	
Receive input command		
Minimize Weight		
minimize reset time	Y	

Table 4: Engineering Requirement Specification Sheet

Engineering Requirement	Target	Units	Tolerance	Measured/ Calculated Value	ER Met? Y/N	Client Acceptable? Y/N
No breakaway parts	0	-	0	0	Y	Y
Low outgassing materials	0.1	-	0		N	Y
No combustion	0	-	0	0	Y	Y
Minimize volume	1	cu. In	+0.5	3.4 in^3	N	Y
Minimize protruding material	1	cm	0.1	0.1 mm	Y	Y
Maximize deployment force	25	N	- 5		N	Y
No deformation	0	%	+2			
Maximize retention reliability	100	%	1.5			
Receive input command	-	-	-	-	Y	Y
Minimize weight	200	g	+50 -200	75	Y	Y
Minimize reset time	30	sec	+30		Y	Y
Maximize SMA Spring life (1N)	50	Cycles	5	20	N	Y

5) QFD

System QFD

Project:	GA-EMS HDRM
Date:	04/14/2022
	Team Stellar Hold NAU SP22 ME476C

Legend	
A	
B	
C	

Technical Requirement	No Breakaway parts	Low outgassing materials	no combustion	minimize volume	minimize external hardware	maximize deployment force	no deformation	maximize retention reliability	must receive input	minimize weight
No Breakaway parts										
Low outgassing materials										
no combustion	1	1								
minimize volume										
minimize external hardware										
maximize deployment force					-1					
no deformation	1		1							
maximize retention reliability	1		1		-1		1			
must receive input										
minimize weight		-1		1		-1				
minimize reset time	1		1		-1		1	1		

key
1 = positive correlation
-1 = negative

Customer Needs	Customer Weights	No Breakaway parts	Low outgassing materials	no combustion	minimize volume	minimize external hardware	maximize deployment force	no deformation	maximize retention reliability	must receive input	minimize weight	minimize reset time	Customer Opinion Survey: 1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
No Space Debris	5	1		1		1			1			1					
low outgassing	3		1					1	1								
No pyrotechnics	5	1	1	1				1	1		1	1					
must deploy solar panels 20x30cm	3				1												
cannot protrude more than 1cm from bottom	4				1	1			-1		1	-1					
Must deploy panels on all sides simultaneously	3					-1	1		1								
Must be able to easily reset	5	1		1	-1			1				1					
Must be able to retained stowed config prior to launch	5					1	1		1								
must release on command	3									1							
must have rotational abilities	2								1								

	No Breakaway parts	Low outgassing materials	no combustion	minimize volume	minimize external hardware	maximize deployment force	no deformation	maximize retention reliability	must receive input	minimize weight	minimize reset time
Technical Requirement Units	#	%	n/a	CU IN	cm	N	%	%	n/a	g	s
Technical Requirement Targets	0.00	0.10		1.00	1cm	25	2	98.5		200	<60s
Absolute Technical Importance	15.0	8.0	15.0	2.0	11.0	8.0	13.0	19.0	3.0	9.0	11.0
Relative Technical Importance	3	2	3	1	2	2	3	5	1	2	2

Figure 1: QFD