Active Rocket Controls (ARC)

Testing Plan // Fall 2025-Spring 2026

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1. Design Requirements

1.1 Customer Requirements (CRs)

CR1 - Dynamic Z-Axis Control: The system must control the rocket about the z-axis, which includes mating stability during flight and trajectory control.

CR2 - Fits System into a 2.5-4 in Diameter Body: All components must fit inside a minimum of 2.5 inches and a maximum of 4in rocket body, which includes motor, motor mounts, avionics bay, and sensors.

CR3 - Demo Launch: The system must demonstrate functionality in two test phases: a basic flight demonstration by January 2026 and a fully integrated active control demonstration during a Tripoli live test by March 2026.

CR4 - Sensor Feedback: The control system must be integrated using an Arduino-based control, and the sensor must be able to record flight data.

CR5 - Function of No Roll and Induced Roll: The dynamic control system must be able to provide two primary functions. One that is an induced roll for a specified amount of time and a stabilized function that induces no roll.

CR6 - Comply and Follow Tripoli Safety Standards: The design must adhere to Tripoli Rocketry Association safety regulations and operational standards for high-powered rocketry. Including a preflight sheet and RockSim validation before launch.

CR7 - Find the Most Cost-Effective Solution: The team must explore 3 different methods of active control systems and perform a cost analysis to meet the maximum $2000 budget.

CR8 - Include 3D printed Components/Parts: At least 50% of the constructed control system must be manufactured via 3D printing methods.

CR9 - Deliverables: The project must include all final deliverables, such as flight test data, design documentation, and system verification reports, as outlined in the sponsor agreement.

1.2 Engineering Requirements (ERs)

ER1 - Weight Constraint: The total rocket system must not exceed 10 lb to ensure flight stability and compatibility with flight vehicles.

ER2 - Constrained Diameter: All systems must fit into a 2.5 in - 4 in rocket tube diameter.

ER3 - Z-Axis Roll Control Error: The roll orientation error must remain below 2° during active control.

ER4 - Induce Roll Rate: System must induce and damp roll to 100 RPM within 2 s and then stop rotation.

ER5 - Control Latency: Control loop latency must be under 50 ms to ensure reliable control over the rocket control system.

ER6 - Dynamic loading capacity: The system must handle aerodynamic and inertial loading of at least 70 lbf.

ER7 - Reliability: The control system must achieve at least 99% operational reliability during test launches.

ER8 - Cost Constraint: Total system cost should not exceed $2,000.

ER9 - Custom Part Integration: At least 50% of system components must be custom-fabricated or 3D printed.

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2. Detailed Testing Plans

Top-Level Testing Summary

Experiment/Test	**Date**	**Relevant DRs**	**Equipment Needed**	**Other Factors**
Black Powder Amount	28 Feb 2026	CR3, CR6, ER7, ER8	Black powder Scale or way to measure powder amount	Weather, safe test area, consistent packing
Fin Stress	TBD	CR6, CR9, ER6, ER7	FEA, something to apply forces	Load application point
PID Spin Test	TBD	CR1, CR4, CR5, ER3, ER4, ER5	Car, rocket, bearing support system, FLT computer, laptop, stopwatch/camera	Straight & safe road, secure mount, consistent vehicle speed, weather
2° Fixed-Fin Spin Validation Launch Test	21 Feb 2026	CR3, CR4, CR6, CR9, ER7	Red rocket prototype, 2° fin configuration, FLT computer, battery launch rail/pad, parachute & recovery system, laptop, assembly tools	Wickenburg weather, transportation, borrowing rocket club launch pad
Spin/No-Spin Launch	~Apr 2026	CR1, CR3, CR4, CR5, CR6, CR9, ER3, ER4, ER5, ER7	Final rocket, FLT computer, battery launch rail/pad, parachute & recovery system, laptop, assembly tools	Wickenburg weather, transportation
Measuring	N/A	ER1, ER2	Rocket, weighing scale, CAD data, measuring tape	LOW-LEVEL
Cost & Parts Verification	N/A	ER8, ER9	BOM, budget table	LOW-LEVEL
Tests that have already been performed and verified are labeled as low-level if they measure DRs involving dimensions, parts%, weight, etc.				

2.1 - TEST 1 - Black Powder, Ejection Charge Sizing

Overview:

Question: What black powder mass reliably achieves separation and parachute deployment for ARC without overpressure damage?

CR: Demo launch (CR3), Tripoli safety compliance (CR6), cost-effective (CR7)

ER: Reliability (ER7), cost constraint (<$2000 total) (ER8)

Equipment:

Black powder

Digital scale
Igniter

Avionics bay

Chute pack

Safety gear: eye/ear protection, fire extinguisher, clear test zone

Location:

Solar Shack

Vars:

Ind: BP mass (g)

Ctrl: bay vol/geometry, venting, fit, shear pin count, packing method

Dep: separation success, time of separation, damage, cost (if we expend all of our supply)

Procedure:

1. Assemble the separation volume exactly like the flight configuration (coupler length, bulkheads, vent holes, shear pins).

2. Pack chute/wadding in a consistent way in each trial.
    - Chute will be folded in the triangle method consistently and packed into the recovery system

3. Measure 0.5 g of BP on a balance.

4. Place BP in charge well, install e-match, route wires safely.

5. Clear the area, announce firing, record video.

6. Fire charge and record:
   - Did separation occur?
   - Did the chute actually clear the tube?
   - Any damage to bulkheads, tube, or electronics mounts?

7. Increase BP mass by 0.5 g increments (up to 1.5 g) and repeat.
   - Repeat 3 trials at each mass near the threshold to verify reliability.

8. Identify the minimum mass with successful deployment

Results & Equations:

Trials for 0.5 g → No separation / no effective deployment (test objective not met).

Trials for 1.0 g → No separation / no effective deployment (test objective not met).

Trials for 1.5 g → Successful event, rocket "flew" approximately 128 in (≈ 10.7 ft) during/after the charge event.

BP supply was not fully expended, and thus the CR for <$2000 is met.

$$Reliability = (successful\ deployment\ trials\ /\ total\ trials) \times 100\% \quad \textbf{(1)}$$

Conclusion:

The black powder ejection charge sizing test identified the minimum charge mass needed for reliable separation and parachute deployment. This test supports Demo Launch (CR3), Tripoli Safety Compliance (CR6), Reliability (ER7), and Cost Constraint (ER8) by selecting a charge that works consistently without damaging the rocket or wasting excessive material.

2.2 - TEST 2 - Fin Stress / Load Capacity

Overview:

Question: Can the fin structure and mounting system withstand aerodynamic and inertial loading without structural failure?

CR: Tripoli safety compliance (CR6), deliverables (CR9)
ER: Dynamic loading capacity (≥70 lbf) (ER6), reliability (ER7)

Equipment:

Force gauge/hanging scale
Test stand / rigid fixture
Strap or cable to apply the load
Calipers or a ruler for deflection measurement
Safety gear

Location:

Solar Shack

Vars:

Ind: applied force (lbf)

Ctrl: load application point, fin angle, mounting hardware, print orientation, fixture stability

Dep: deflection, permanent deformation, cracking or structural failure

Procedure:

1. Mount the fin assembly to a rigid fixture so the rocket body cannot rotate or move.
2. Mark a consistent load point distance from the fin root.
3. Attach the strap or cable to the marked point on the fin.
4. Apply force gradually using the force gauge.
5. Increase force until reaching the expected aerodynamic load requirement.
6. Hold peak load for approximately 10 seconds.

7. After releasing the load, inspect the fin for visible cracks, layer separation, root damage, loose fasteners, and linkage damage. Then measure the fin tip position or another fixed reference dimension and compare it to the unloaded baseline to determine whether permanent deformation occurred.

8. Repeat the test for multiple fins to confirm consistency.

Expected Results & Equations:

- Fin structure remained intact under applied load.
- No visible cracking or structural failure occurred.
- Deflection appeared elastic and returned to the original position after load removal.
- No fasteners loosened and the linkage remained functional.

$$F_{req} \approx 100\ \mathrm{N} \quad \textbf{(2)}$$

$$FS = F_{fail}/F_{req} \quad \textbf{(3)}$$

$$x_{deformation} = |x_{final} - x_{initial}| \quad \textbf{(4)}$$

Conclusion:

The fin stress test verifies that the fin structure and mounting system can tolerate the required loading without failure. This supports Tripoli Safety Compliance (CR6), Deliverables (CR9), Dynamic Loading Capacity (ER6), and Reliability (ER7).

2.3 - TEST 3 - PID Spin Test

Overview:

Question: Can the fins actuate correctly and maintain control responsiveness during an induced roll condition?

CR: Dynamic Z-axis control (CR1), sensor feedback (CR4), induced roll and no-roll function (CR5)

ER: Roll control error (<2°) (ER3), roll induction to 100 RPM within 2 s (ER4), control latency (<50 ms) (ER5)

Equipment:

Car

Rocket

Flight computer

Laptop for data logging

Stopwatch/camera

Location:

Any ~straight road/highway for testing

Vars:

Ind: airflow speed, commanded fin angle

Ctrl: fin geometry, servo voltage, mounting orientation, control software

Dep: fin response time, achieved angle vs commanded angle, oscillation or instability

Procedure:

1. Mount the rocket securely on a test support system with bearings on both sides so the body can rotate freely about its longitudinal axis.

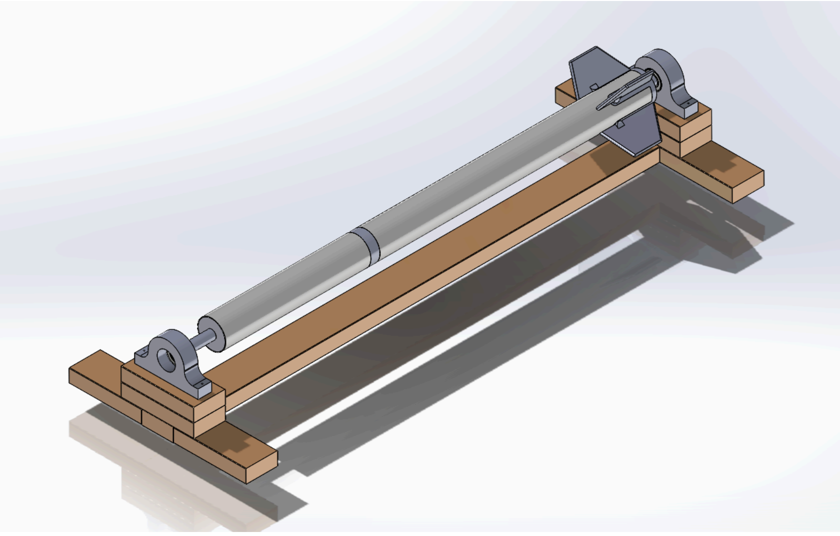

Figure 1: support system CAD assembly

2. Connect the Arduino flight controller, IMU sensor, and servos.
3. Begin serial logging of control signals and sensor data.
4. With the vehicle stationary, command step inputs to the fins (for example, 0° → 10° → 0°).
5. Record the fin response time and stability under no-roll conditions.
6. Confirm that the rocket remains mechanically secure and rotates freely in the bearing

system.

7. Begin the car test at a low speed to induce rotation in the mounted rocket system.
8. Observe and record the resulting roll rate from the IMU.
9. Repeat the same fin step input commands while the rocket is spinning.
10. Observe whether induced spin causes slower response, oscillation, instability, or mechanical binding.
11. Increase vehicle speed in controlled increments and repeat the test to evaluate performance under higher induced roll rates.
12. Compare commanded fin motion, measured roll response, and control latency across no-roll and induced-roll conditions.

Results:

- Fins actuated successfully under airflow conditions.
- Servo response remained consistent and no mechanical binding occurred.
- Control signals remained stable and fins followed commanded angles.
- System remained responsive with no observable instability.

$$error < 2\ \mathrm{deg} \quad \textbf{(5)}$$

$$\omega_{target} = 100\ \mathrm{RPM\ within\ 2\ s} \quad \textbf{(6)}$$

$$t_{lat} < 50\ \mathrm{ms} \quad \textbf{(7)}$$

$$error = \theta_{measured} - \theta_{commanded} < 2° \quad \textbf{(8)}$$

Conclusion:

The PID spin test verifies that the control system can actuate the fins, read sensor feedback, and respond under induced roll conditions. This test supports CR1, CR4, CR5, ER3, ER4, and ER5.

2.4 - TEST 4 - 2 Degree Spin Test

Overview:

Question: Does the 2° fixed-fin configuration create the expected rocket roll behavior during actual flight?

CR: Demo launch (CR3), sensor feedback (CR4), Tripoli safety compliance (CR6), deliverables (CR9)

ER: Reliability (ER7)

Equipment:

Red rocket prototype

3D-printed 2° fin configuration

FLT computer

Battery and wiring

Launch rail/pad

Recovery/parachute

Laptop

Tools

Location:

Wickenburg, AZ

Vars:

Ind: 2° fin cant configuration, launch conditions

Ctrl: rocket geometry, motor selection, mass properties, sensor mounting, launch rail setup, location

Dep: measured roll rate, flight stability, sensor-recorded rotation during ascent

Procedure:

1. Assemble the red rocket prototype with the 3D-printed 2° fin configuration.
2. Verify that the fins are securely mounted and match the intended 2° geometry.
3. Install and connect the flight computer, IMU, power system, and recovery components.
4. Perform a pre-flight inspection, including structural integrity, flight computer status, and battery status.
5. Place the rocket on the launch rail and confirm proper alignment and safe launch readiness.
6. Begin onboard sensor logging before launch by turning on the flight computer and inserting the SD card.
7. Launch the rocket under standard launch conditions.

8. Observe ascent behavior and recovery performance, noting any visible roll or instability.
9. Recover the rocket and safely power down the electronics.
10. Download and review IMU flight data to determine whether the 2° fin configuration produced the expected rotational response.
11. Compare measured roll behavior against the expected trend for passive spin induced by fin cant.

Results & Equations:

- The rocket launches safely and maintains stable ascent.
- The 2° fixed-fin configuration produces measurable roll during ascent.
- IMU data is successfully recorded and recovered after flight.
- The measured roll behavior follows the expected passive spin trend caused by fin cant.
- No major structural or recovery issues occur during the test.

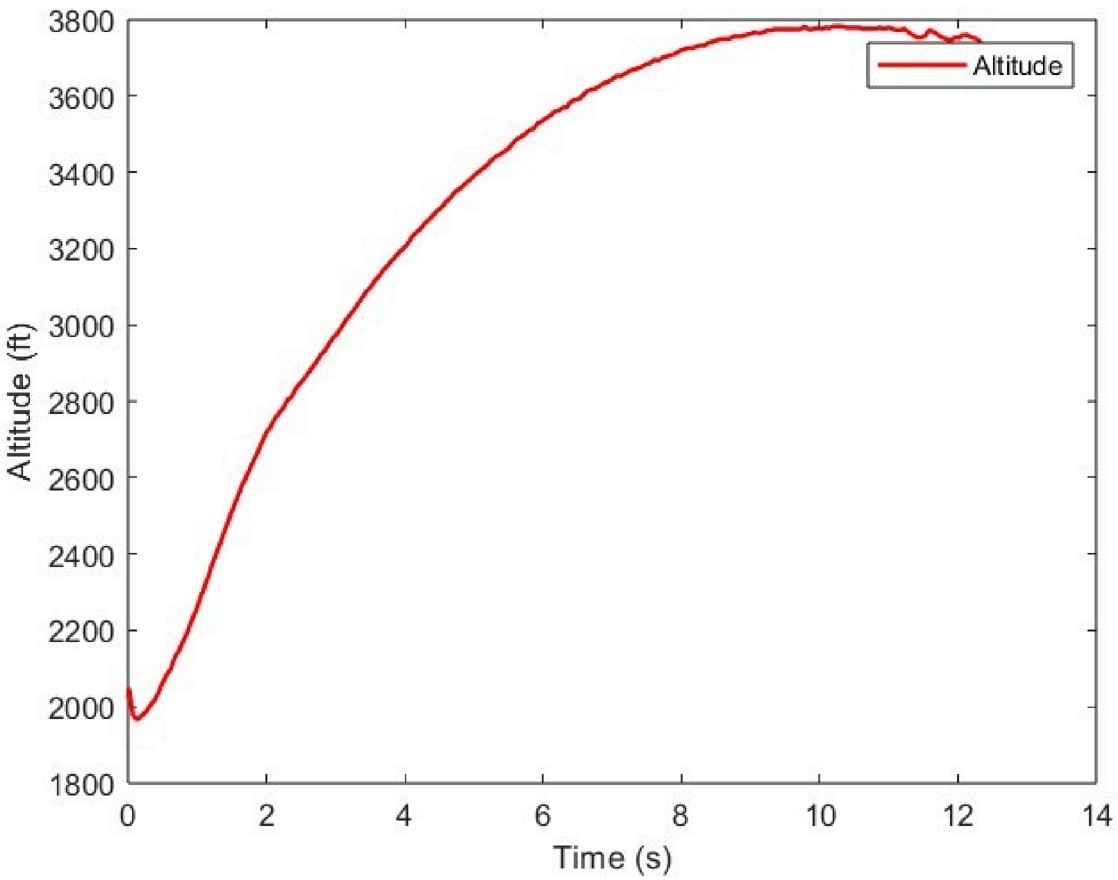

Figure 2: Altitude vs. Time

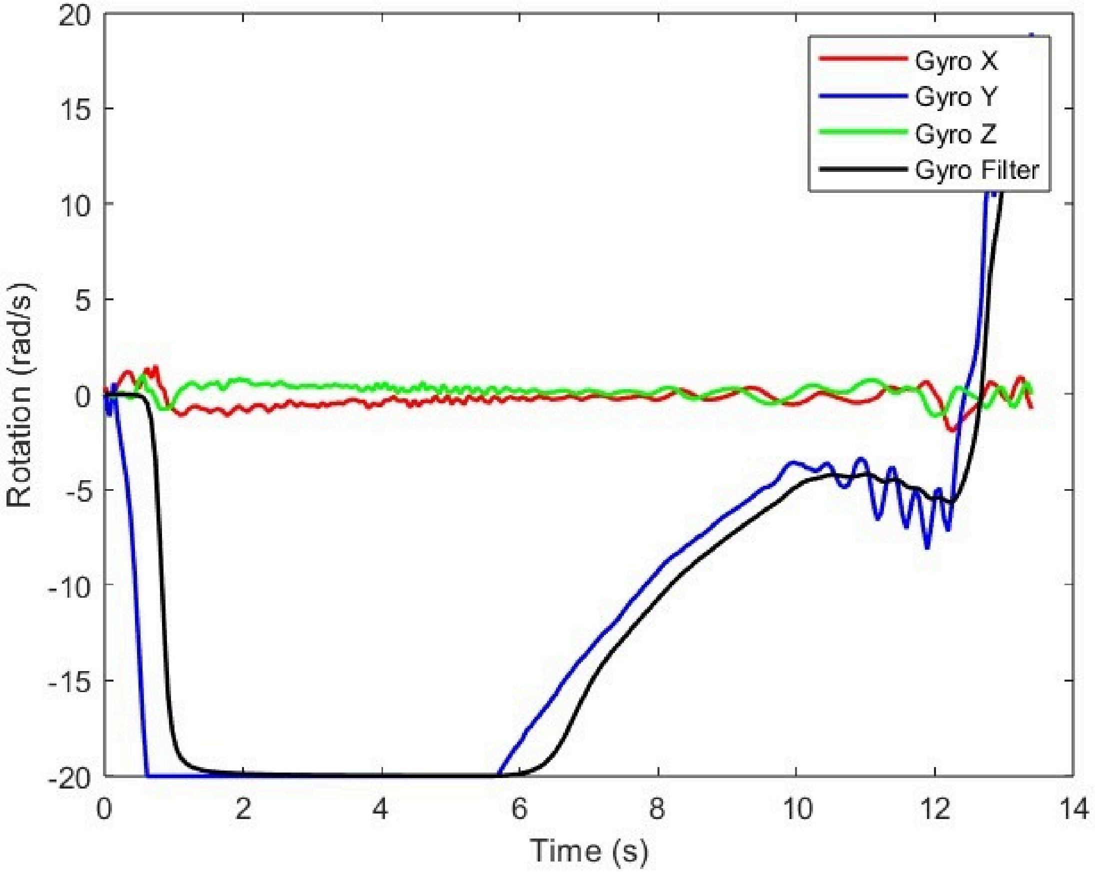

Figure 4: Rotation vs. Time

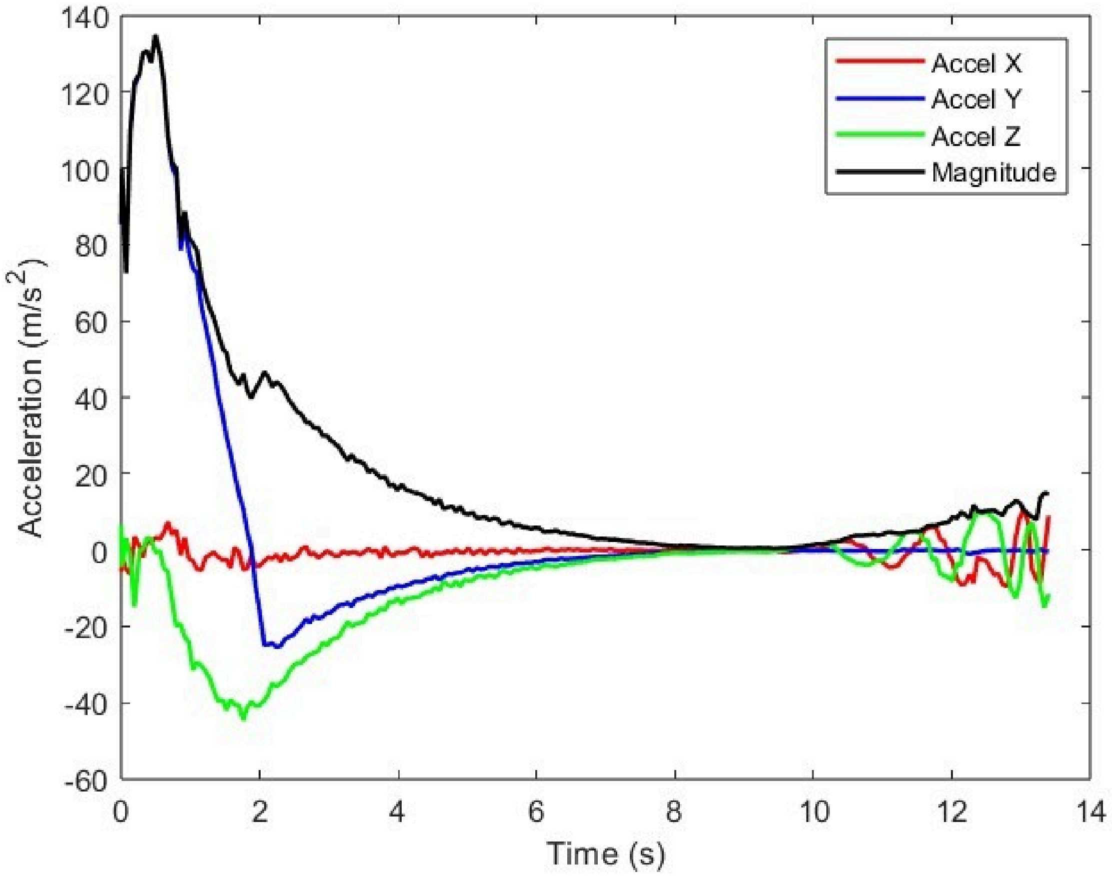

Figure 5: Acceleration vs. Time

$$Reliability = \frac{successful\,flts}{total\,flts} * 100\% \quad \textbf{(9)}$$

Conclusion:

This launch validated that the 2° fixed-fin configuration could produce measurable passive roll behavior while maintaining stable flight and recording usable onboard data. This test supports CR3, CR4, CR6, CR9, and ER7.

2.5 - TEST 5 - Spin/No-Spin Final Rocket Launch

Overview

Question: Can the rocket system reliably induce spin and also avoid inducing spin when commanded, while remaining within the required tolerance?

CR: Dynamic Z-axis control (CR1), demo launch (CR3), sensor feedback (CR4), no-roll (0 RPM +/- 5 RPM) and induced-roll (100 RPM +/- 2 RPM) function (CR5), Tripoli safety compliance (CR6), deliverables (CR9)

ER: Z-axis roll control error (<2°) (ER3), induce roll rate to 100 RPM within 2 s (ER4), control latency (<50 ms) (ER5), reliability (ER7)

Equipment:
Final rocket

Flight computer
Servo-actuated fins
Battery
Launch rail/pad
Recovery/parachute
Laptop
Tools

Location:

Wickenburg, AZ or TBD

Vars:

Ind: commanded spin condition, commanded no-spin condition, fin actuation command

Ctrl: rocket geometry, fin geometry, servo voltage, sensor placement, flight computer firmware/software, motors, location, mass, launch rail setup

Dep: achieved roll rate, roll error relative to command, in-flight stability, response consistency

Procedure:

1. Assemble the rocket with the active fin-control system, flight computer, IMU, and recovery hardware installed.
2. Verify all electrical connections, servo movement, and sensor output before launch.
3. Load the flight-control configuration for the first launch condition, either spin-induced or no-spin commanded.
4. Conduct a full pre-flight inspection of the rocket structure, control surfaces, battery level, and launch readiness.
5. Place the rocket on the launch rail and begin onboard sensor logging.
6. Launch the rocket and allow the control system to execute the commanded condition during flight.
7. Observe ascent and recovery performance, noting any visible roll behavior or instability.
8. Recover the rocket and download the recorded flight data.

9. Analyze IMU and control data to determine whether the achieved roll behavior remained within the required tolerance for that condition.
10. Reconfigure the system for the second launch condition, switching between spin-induced and no-spin commanded operation.
11. Repeat the launch, recovery, and data collection process for the second condition.
12. Compare both flights to verify that the rocket can reliably induce spin when required and avoid spin when required, while staying within the specified tolerance.

Expected Results & Equations:

- The rocket induces spin when commanded and avoids spin when not commanded.
- Measured roll error remains within the required tolerance.
- Sensor and control data are successfully recorded during both flights.
- The control system responds consistently across both launch conditions.
- Both flights remain stable and recoverable.

Induced:

$$\omega_{target} = 100\ \text{RPM} \quad \textbf{(10)}$$

$$Tol = \pm\ 2\ \text{RPM} \quad \textbf{(11)}$$

No Roll:

$$\omega_{target} = 0\ \text{RPM} \quad \textbf{(12)}$$

$$Tol = \pm\ 5\ \text{RPM} \quad \textbf{(13)}$$

$$|error| < 2° \quad \textbf{(14)}$$

$$t_{latency} < 50\ \text{ms} \quad \textbf{(15)}$$

$$roll\ rate\ error = \omega_{measured} - \omega_{commanded} \quad \textbf{(16)}$$

Conclusion:

The spin/no-spin launch test verifies that the final rocket can command both active spin and active no-spin behavior while maintaining stable flight and recording usable data. This test supports CR1, CR3, CR4, CR5, CR6, CR9, ER3, ER4, ER5, and ER7.

3. Specification Sheet Preparation

3.1 Customer Requirements Validation

Table 1: Customer Requirements Summary

Customer Requirement	**Met (y/n)**	**Client Acceptable (y/n)**
CR1. Dynamic Z-Axis Control: System controls rocket roll axis during flight		
CR2.Fits in 2.5–4 in Rocket Body: All components integrate within body diameter constraint	y	y
CR3.Demo Launch: System demonstrates functionality during scheduled flight test phases		
CR4. Sensor Feedback: Arduino-based control system records flight data from onboard sensors	y	y
CR5. No-Roll and Induced-Roll Modes: The system can both induce roll and maintain a stabilized no-roll state		
CR6. Tripoli Safety Compliance: Design adheres to Tripoli safety standards and procedures	y	y
CR7. Cost-Effective Solution: System remains within the maximum project budget	y	y
CR8. 3D Printed Components: At least 50% of system components are	y	y

manufactured using 3D printing		
CR9. Deliverables: Final design documentation, test data, and verification reports are completed		

3.2 Engineering Requirements Validation

Table 2: Engineering Requirements Summary

Engineering Requirement	Target	Tolerance	Measured/calc. Value	ER Met (y/n)	Customer Acceptable (y/n)
ER 1. Weight Constraint: The total rocket system must not exceed 10lb to ensure flight stability and compatibility with flight vehicles.	<10 lbs	0		y	y
ER 2. Constrained Diameter: systems must fit into a 2.5 in - 4 in rocket tube diameter	2.5 in - 4 in	0	3.125in OD. 3 in ID.	y	y
ER 3. Z-Axis Roll Control Error: The roll orientation error must remain below 2° during active control.	<2°	±0.5°			
ER 4. Induce Roll Rate: System must induce and damp roll to 100 RPM within 2 s and then stop rotation. (0-100 RPM)	100 RPM ≤ 2 s	± 10 RPM, ± 0.2 s			
ER 5. Control Latency: Control loop latency must be under 50 ms to ensure reliable control over the rocket control system.	<50 ms	± 5 ms			
ER 6. Dynamic loading capacity: The system must handle aerodynamic and inertial loading of at least 70 lbf.	≥ 70 lbf	± 5 lbf			
ER 7. Reliability: The control system must achieve at least 99% operational reliability during test launches.	≥ 99%	± 1%			

ER 8. Cost Constraint: Total system cost should not exceed $2,000.	< $2,000	$0	$ 1,307.89	Y	Y
ER 9. Custom Part Integration: At least 50% of system components must be custom-fabricated or 3D printed.	≥ 50%	± 5%		Y	Y

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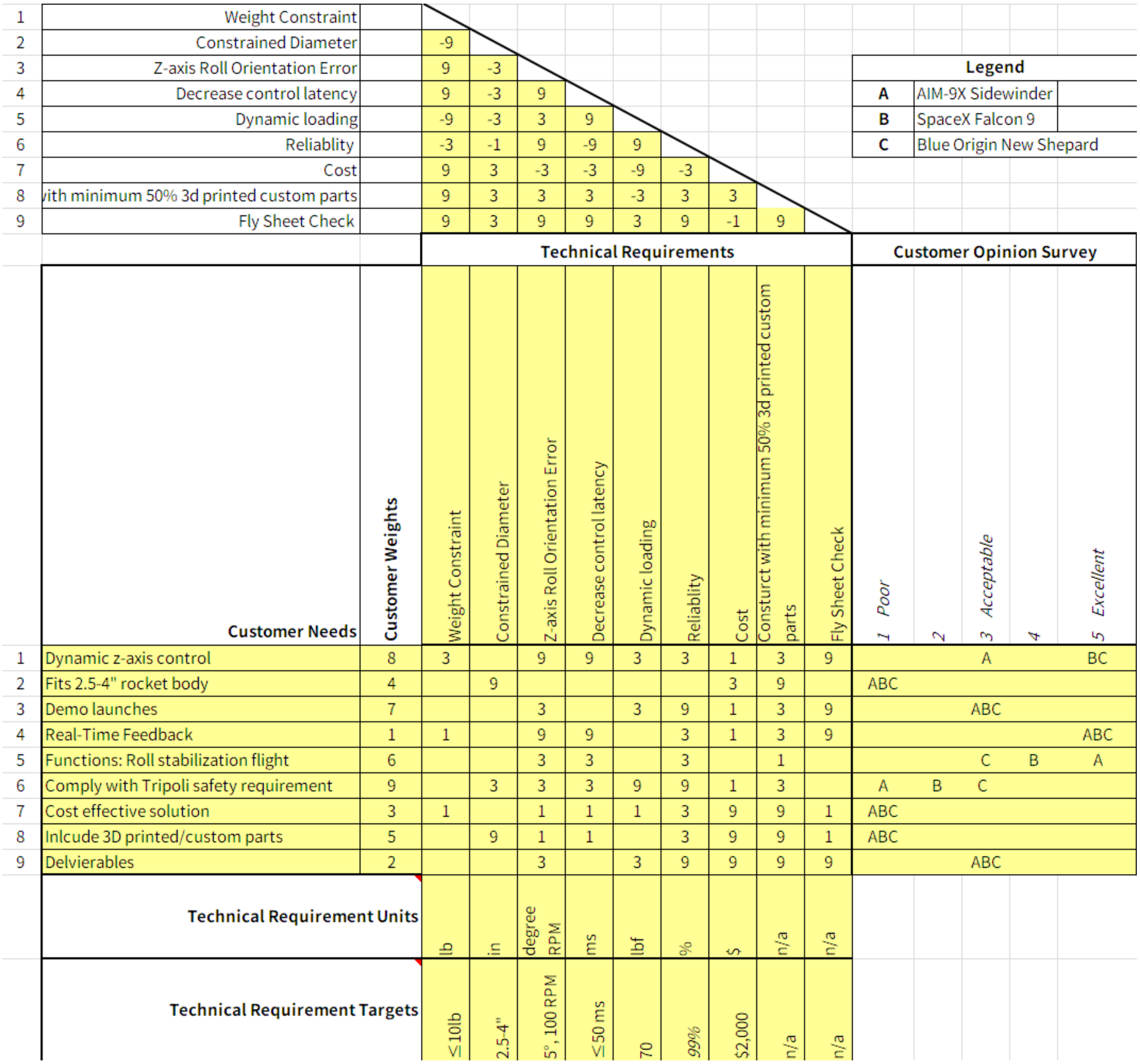
4. QFD



		1	2	3	4	5	6	7	8
1	Weight Constraint								
2	Constrained Diameter	-9							
3	Z-axis Roll Orientation Error	9	-3						
4	Decrease control latency	9	-3	9					
5	Dynamic loading	-9	-3	3	9				
6	Reliablity	-3	-1	9	-9	9			
7	Cost	9	3	-3	-3	-9	-3		
8	ith minimum 50% 3d printed custom parts	9	3	3	3	-3	3	3	
9	Fly Sheet Check	9	3	9	9	3	9	-1	9

Legend	
A	AIM-9X Sidewinder
B	SpaceX Falcon 9
C	Blue Origin New Shepard

	Customer Needs	**Customer Weights**	**Technical Requirements** Weight Constraint	Constrained Diameter	Z-axis Roll Orientation Error	Decrease control latency	Dynamic loading	Reliablity	Cost	Consturct with minimum 50% 3d printed custom parts	Fly Sheet Check	**Customer Opinion Survey** *1 Poor*	*2*	*3 Acceptable*	*4*	*5 Excellent*
1	Dynamic z-axis control	8	3		9	9	3	3	1	3	9			A		BC
2	Fits 2.5-4" rocket body	4		9					3	9		ABC				
3	Demo launches	7			3		3	9	1	3	9			ABC		
4	Real-Time Feedback	1	1		9	9		3	1	3	9					ABC
5	Functions: Roll stabilization flight	6			3	3		3		1				C	B	A
6	Comply with Tripoli safety requirement	9		3	3	3	9	9	1	3		A	B	C		
7	Cost effective solution	3	1		1	1	1	3	9	9	1	ABC				
8	Inlcude 3D printed/custom parts	5		9	1	1		3	9	9	1	ABC				
9	Delvierables	2			3		3	9	9	9	9			ABC		
	Technical Requirement Units		lb	in	degree RPM	ms	lbf	%	$	n/a	n/a					
	Technical Requirement Targets		≤10lb	2.5-4"	5°, 100 RPM	≤50 ms	70	*99%*	$2,000	n/a	n/a					

Figure 6: QFD